THE ASSOCIATION BETWEEN MUSICAL TRAINING, BILINGUALISM, AND EXECUTIVE FUNCTION

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Abstract

Previous research has shown far transfer effects of skill training, such as bilingualism and musical training, on executive function. Despite a growing interest in the subject, some areas of higher cognition have been left under- or un-examined. This dissertation presents two papers that investigated whether exposure to bilingualism or musical training was associated with improvements in four specific domains of executive function, including working memory, inhibitory control, task switching, and dual task performance. Results for working memory and inhibition are presented in Paper 1 and those for task switching and dual task performance are reported in Paper 2. Both papers are based on the same sample of participants, which included 153 university students, who were matched on age and socio-economic status. In Paper 1, results demonstrated a musician advantage on working memory and interference suppression tasks, but not on response inhibition. In comparison, bilinguals did not demonstrate advantages on working memory or inhibitory control abilities compared to monolinguals. Moreover, a combined effect of bilingualism and musical training was not found. Similarly, in Paper 2, results demonstrated cognitive advantages in task switching and dual task performance among musicians compared with non-musicians. However, bilinguals did not demonstrate advantages on either construct relative to monolinguals, and additive effects of bilingualism and musical training were not detected. Taken together, the findings further our understanding of the different domains of cognition that are impacted by musical training, including areas, such as dual task performance, that have not been examined thus far. Moreover, the findings support previous research demonstrating associations between musical training and improvements in executive function, while recognizing that associations between bilingualism and executive function may require further investigation.

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Chapter 1: General Introduction

Far transfer refers to the process whereby learning in one domain influences performance in another, more distant, domain (Barnett & Ceci, 2002). For example, when physical exercise produces cognitive benefits. Given the growing interest in far transfer effects on cognition, research is needed to determine which aspects of "higher-level" cognition acquire benefits as a result of different types of skills training or experience. The present research examines the relationship between executive function components and two specific types of experience, namely bilingualism and musical training. Recent studies have compared the benefits of musical training and language experience and how they differentially affect cognition (Bialystok & DePape, 2009; Bidelman, Hutka, & Moreno, 2013; Cooper & Wang, 2012). This research can help identify which type of experience is associated with greater cognitive improvements and, possibly indicate whether a music or language program might be more cognitively beneficial for children or at-risk populations. Furthermore, this work can help researchers identify which types of experience or combined experiences need to be controlled or accounted for in research studies. For example, literature indicating cognitive benefits of bilingualism has led many researchers to collect language background information in cognition studies to account for the possible added influence of bilingualism on cognitive performance (Barac & Bialystok, 2012). One of the objectives of this research is to determine whether having both bilingualism and musical training experience leads to interactive effects on cognitive performance. For example, research indicates that music and language are structurally similar. That is, both have proper syntax and semantics and a fixed number of ways to combine elements, such as pitch and rhythm (Patel, 2003). Moreover, music and language processing involve overlapping cortical networks (Patel & Iverson, 2007), suggesting that the brain processes musical and linguistic stimuli using the same brain regions. Despite the similarity between these domains, few studies have examined the interactive effects of music and language experience (Cooper & Wang, 2012).

More specifically, this research investigates the relationship between musical or bilingualism experience and specific areas of executive function, some of which have been neglected in the literature. For example, past investigations have examined the association between bilingualism, musical training, and some areas of executive function, such as inhibition and working memory (Bialystok & DePape, 2009; Lee, Lu, & Ko, 2007), while components such as task switching and dual task performance have received inadequate attention. Moreover, the literature has not provided sufficient detail regarding the role of specific types of inhibitory control and working memory in skills training/experience, and there has been a failure to account for important variables, such as age and socio-economic status (SES). One of the objectives of our research is to address these limitations. While our research is not intended to test and distinguish alternate theoretical frameworks, we believe our investigation has the potential to inform theory. As such, we consider a discussion of executive function, its key constructs, and their theoretical background to be necessary in laying the foundation for the upcoming studies. We will begin with an introduction of executive function and related theories, as well as a description of and theoretical background for specific executive function components, including working memory, inhibition, task switching, and dual task performance.

Executive Function

Executive function is an umbrella term referring to a family of mental processes involved in effortful and goal-directed behavior (Anderson, 2002; Diamond, 2013). However, there has been a lack of consensus regarding the precise definition of executive function, its subcomponents, and the best methods to measure this group of abilities (Jurado & Rosselli, 2007). What is evident is the importance of executive function in human adaptive behavior. In fact, executive function has been found to affect many fundamental aspects of life, including mental and physical health, school and job success, as well as an individuals' social and cognitive development (Diamond, 2013).

An ongoing debate in the executive function literature has been whether there is one central or underlying mechanism that can explain all executive function subcomponents (theory of unity) or whether executive function is made up of distinct processes (theory of non-unity). There is evidence for unity (Duncan, Emslie, Williams, Johnson, & Freer, 1996), as well as that of non-unity (Godefroy, Cabaret, Petit-Chenal, Pruvo, & Rousseaux, 1999) in executive function. For example, Duncan et al. (1996) suggest that Spearman's g is an underlying central mechanism that unifies other components of executive function, such as working memory and problem solving. Moreover, they propose that in the event of frontal lobe damage, cognitive impairments largely overlap with the functions reflected in general intelligence. Other supporters of the unity theory have proposed working memory ability (Kimberg, D'Esposito, & Farah, 1997), behavioural inhibition (Barkley, 1997) or a combination of both working memory and inhibition (Pennington, Bennetto, McAleer, & Roberts, 1996) to be the central mechanism underlying executive functioning. In contrast, Godefroy et al. (1999) have argued against the existence of a central unifying mechanism underlying executive functioning based on their research with patients with frontal lobe lesions, and suggest that executive functions rely on multiple, separable control processes.

Furthermore, an influential factor analytic study by Miyake et al. (2000) provides support for both unity and diversity, by demonstrating that executive function is made up of at least three separate but related components, including working memory, inhibition, and task switching. In addition, similar components have been identified in studies containing developmental populations (Lehto, Juujarvi, Kooistra, & Pulkkinen, 2003).

Several influential models have been proposed that attempt to explain both cognitive and neurobiological origins of executive function. For the purpose of this paper, we will focus primarily on cognitive theories of executive function. For instance, Baddeley & Hitch (1974) proposed a working memory model, which included three components, namely the phonological loop, the visuo-spatial sketchpad, and the central executive. In this multi-component model of short-term memory, the central executive is responsible for controlling and regulating cognitive processes and is limited in processing capacity. It carries out its role with the assistance of its' two subsystems: the visuo-spatial sketchpad, which creates and maintains visuo-spatial representations, and its verbal/acoustic equivalent, the phonological loop, which holds verbal information for immediate recall. In earlier versions of this theory, the central executive was viewed as capable of both processing and storage. However, Baddeley (2000) later added a fourth component to the model called the episodic buffer, which acts as a supplemental storage system to the central executive.

Another leading model is that of Norman & Shallice (1986), which also includes a central attention system located in the prefrontal cortex. According to this model, two systems are involved in cognitive regulation: the Supervisory Attention System (SAS) is required in situations where automatic processing is inadequate and when non-routine decision-making is necessary (e.g., when encountering novel stimuli); and, in contrast, the contention scheduling system operates in routine situations where automatic processing is necessary. A common criticism of both Baddeley and Norman & Shallice's model is that they propose a single overarching body (i.e., the central executive) that controls other cognitive processes and is located in the front lobes (Parkin, 1998; Stuss & Alexander, 2007). Many current theories of executive function do not assume a central executive (Fuster, 2001; Kimberg et al., 1997; Stuss & Alexander, 2007), and research now suggests that executive functioning involves multiple and interactive brain regions, which include but are not limited to regions of prefrontal cortex and anterior cingulate cortex (Alvarez & Emory, 2006; Aron, 2008; O'Reilly, 2010). Similarly, while Stuss & Alexander (2000) acknowledge the supervisory role of executive functions as a control system, they do not support a central executive. Instead, they consider executive functioning to be integrated and inter-related.

Anderson (2002) has proposed the Executive Control System model, a conceptual framework that is based on factor analytic and developmental research. In this system, executive function is identified as an overall control system that encompasses four domains including, attentional control, cognitive flexibility, goal setting, and information processing. These domains process information from multiple regions in the brain in an interactive and bidirectional manner, and are thought to be highly integrated (Anderson, 2002).

Difficulties in defining executive function and identifying its component domains contribute to a number of challenges in the accurate assessment of these functions. First, the assessment of executive function is task-based and often relies on tests that have been developed to identify dysfunction in individuals with frontal lobe damage. This approach can introduce issues with criterion validity, since the validity of the tests primarily depends on whether the tests are sensitive to frontal lobe damage (Jurado & Rosselli, 2007; Miyake et al., 2000).

Second, executive function tasks commonly suffer from task impurity (Burgess, 1997). Although tasks are intended to evaluate only one executive construct, performance typically involves other cognitive processes, including ones that may not involve executive processes. For example, tasks that measure information processing speed often require participants to demonstrate speed by clicking a mouse or tapping a keyboard, tasks which involve motor abilities that are non-executive in nature.

Lastly, another limitation with assessment is that of poor ecological validity in tests of executive function. That is, a discrepancy often exists between performance on measures of executive function and behavior in real-life. For example, patients may perform well in a clinic, but display major behavioural problems at home or in their personal life. This is may be partly due to the nature of the testing environment, which is often well-structured, quiet, and may encourage motivation and optimal performance in patients. Patients may be less able to minimize distraction, self-regulate or adequately solve problems in a real-life setting (Anderson, 2002; Mesulam et al., 1986).

In summary, there is a lack of consistency among theorists regarding the definition, role, and breakdown of executive function. Some theorists support a unity theory of executive function (Duncan et al., 1996; Kimberg et al., 1997), whereas others believe that this system contains many separate, yet related components (Miyake et al., 2000). Moreover, some investigators support a hierarchical view where the prefrontal cortex plays a central executive or supervisory role to other subsystems (Baddeley & Hitch, 1974; Norman & Shallice, 1986), while other theorists believe executive function is an integrated system that involves multiple and inter-related brain regions (Anderson, 2002; Stuss & Alexander, 2000). Our paper supports the latter view and is in line with theorists such as Miyake et al. (2000) who propose that components of executive function are both separate, yet interrelated. Finally, the challenges in defining executive function often extend to the measurement of these functions. These include difficulties with criterion validity, task impurity, and ecological validity, factors that we must consider in our assessment and understanding of executive function particularly as it relates to far transfer effects of experience or skill training.

The present paper will discuss four components of executive functioning, including working memory, inhibitory control, task switching and dual task performance, four domains that we believe are affected by bilingualism and musical training.

Working Memory

One definition of working memory is the ability to maintain and manipulate information in mind (Diamond, 2013). As with executive function, researchers differ in their definition and terminology of working memory and it’s characteristics. However, it is widely accepted that working memory plays an important role in cognitive function. For example, working memory is critical for important cognitive processes such as language comprehension, arithmetic, reasoning, and problem solving (Baddeley, 1986).

Working memory has been categorized into different sub-types, including phonological (simple) and executive (complex) working memory (Engle, Tuholski, Laughlin, & Conway, 1999). The former involves simply holding information in mind without the need to manipulate or work with the information, while the latter involves both storage and processing of information in memory.

There is disagreement in the literature regarding the extent to which working memory influences and is influenced by other constructs, as well as the degree of overlap between working memory and other constructs (Diamond, 2013). For instance, some believe that inhibitory control is separate from working memory, while others believe it is a product of exercising working memory, not a separate construct (Egner & Hirsch, 2005; Munakata et al., 2011).

Various cognitive models of working memory have been proposed, some of which we will outline here. A leading model in the study of working memory has been Baddeley's multicomponent model of working memory, which we have alluded to earlier. In this model, working memory is dependent on a core attentional control system– the central executive. According to Baddeley, the central executive has several functions, which include inhibitory control and cognitive flexibility, i.e., shifting between tasks, multitasking, and the ability to selectively attend to and inhibit stimuli (Baddeley & Hitch, 1994; Diamond, 2013).

In Cowan's (1988) embedded processes model, working memory is viewed as limited in capacity and dependent on short-term memory, which is considered to be the activated portion of long-term memory. The model proposes that capacity for short-term storage is approximately four chunks, rather than seven items as suggested by previous theorists (Miller, 1956). Though the model appears disparate from Baddeley's model, there are many similarities between the two. For example, both theories identify similar components, such as a central executive and long-term store (e.g., episodic buffer). However, they differ in their usage of terminology and emphasis on certain components. While Baddeley is focused on the relationship between the central executive and it's slave systems, Cowan's model stresses the link between the central executive and long-term memory (Baddeley, 2012). Cowan's model is similar to ideas proposed by Anderson (1983) who also emphasizes the importance of activation of working memory representations, and that task relevant representations only enter working memory when they have a higher versus lower level of activation. The idea of levels of activation is not too distant from graded working memory theory, which proposes that knowledge is graded in nature and underlying representations vary in strength with the degree of support from multiple interacting components (Munakata & Yerys, 2001). While most working memory theories discuss *how many* representations can be maintained and manipulated in mind, the graded working memory account discusses *how strongly* the these representations are maintained in working memory.

Proponents of the individual-difference based theories (Engle, Kane, & Tuholski, 1999; Just & Carpenter, 1992) support the view that working memory is domain-general, limited in capacity, and innately different across individuals. They commonly show that individuals with very high and those with very low working memory spans differ in performance on working memory and interference based tasks (Engle & Kane, 2004). Moreover, some proponents of this view strongly emphasize the importance of inhibitory control in supporting successful working memory ability, which they suggest helps to prevent the disturbance of memory representations.

In summary, various models of working memory have been proposed, and there is overlap in the components identified. However, these models differ in their lingo and emphasis on particular model components. Some emphasize the importance of activation and focal attention, while others emphasize individual differences and the supporting role of constructs, such as inhibitory control.

Inhibition

Despite decades of research on cognitive inhibition, there is little agreement among researchers regarding its definition, terminology, taxonomy, and theoretical understanding. This lack of coherence is exemplified by some of the types of inhibition that have been identified in the literature, including but not limited to automatic inhibition (Nigg, 2000; Schneider & Shiffrin, 1977; Verbruggen & Logan, 2008), behavioral inhibition (Nigg, 2000), cognitive inhibition (Harnishfeger, 1995; Nigg, 2000), effortful/controlled inhibition (Nigg, 2000; Verbruggen & Logan, 2008), interference control (Bunge et al., 2002; Nigg, 2000), and response inhibition (Bunge et al., 2002; Verbruggen & Logan, 2008).

Despite a lack of consensus in conceptualizing inhibition, most researchers would agree that inhibition plays a key role in executive or goal directed behavior (Aron, 2007; Miller & Cohen, 2001; Verbruggen & Logan, 2008). As such, gaining a better understanding of inhibition has important implications for successful functioning in individuals. In fact, inhibition plays a critical role in many areas of human function, such as a person's social relationships, work productivity, mental health, and activities of daily living (Diamond, 2013). For instance, it would be very difficult to successfully drive from point A to B without the ability to ignore distracting information or stimuli, such as the appearance of the person driving in an adjacent lane, or the passing scenery. Given its applicability to many areas of functioning, it is no wonder then that researchers have had trouble pinpointing the exact nature and role of this construct.

Several theorists have proposed that inhibitory processes may involve a family of functions rather than being unitary in nature (Harnishfeger, 1995; Nigg, 2000), and there is empirical data that supports this notion (Friedman & Miyake, 2004). Using factor analysis, Friedman & Miyake (2004) investigated the relationship between three types of inhibition, namely, Prepotent Response Inhibition (one's ability to suppress a dominant/prepotent response), Resistance to Distractor Interference (one's ability to resist irrelevant and interfering stimuli from environment), and Resistance to Proactive Interference (the ability to resist memory intrusions that were previously, but not currently, relevant to the task). Their study demonstrated fairly high correlations between Prepotent Response Inhibition and Resistance to Distractor Interference, while Resistance to Proactive Interference did not correlate with the other two types of inhibition. These results demonstrate that inhibition is not unitary in nature and involves multiple factors or aspects of function, some of which are more closely related than others.

While Friedman & Miyake suggest that inhibiting a prepotent response and interference control fall along one factor of inhibition, they do not imply that these two functions are indistinguishable. In fact, several researchers have noted the distinction between response inhibition and interference control (Bunge et al., 2002; Diamond, 2013; Luk et al., 2010; Nigg, 2000). In addition, these two components of inhibition are typically measured using different tasks. For example, response inhibition is commonly assessed using the *go/no-go* or *stop signal* paradigms, which measure one's ability to inhibit an ongoing or dominant response established through previous repeated trials (Logan & Cowan, 1984). In contrast, interference control is typically assessed using the *flanker Erikson* or *stroop* tasks, which measure one's ability to resist distracting or competing stimuli, such as flanking stimuli that surround a target arrow in the flanker task or reading words when one must name the color of the printed word in the stroop (Eriksen & Eriksen, 1974; Stroop, 1935).

Aside from interference control and response inhibition, other conceptual distinctions within inhibitory processes have been made. For example, Nigg (2000) classified inhibition into four types of effortful cognitive or motor processes, including (a) cognitive inhibition, which refers to suppression of irrelevant information from working memory, (b) interference control, which refers to suppression of interference resulting from resource or stimulus competition, (c) behavioral/motor inhibition, which refers to suppression of prepotent responses, and (d) oculomotor inhibition, which refers to suppression of reflexive saccades. Nigg's taxonomy was influenced by the work of Harnishfeger (1995) who suggests that inhibition varies along several dimensions, including being intentional or unintentional, behavioral or cognitive, and drew distinctions between resistance to interference and inhibition (Friedman & Miyake, 2004).

In summary, inhibition has been used to describe a wide range of phenomenon, and definitions for this construct have not been consistent. However, most researchers agree that inhibition is integral to executive processes and adaptive human functioning, it is not unitary, and inhibitory processes often involve multiple factors rather than a singular function. Recent investigations demonstrate that inhibition can be further broken down to response inhibition and interference control, two functions that are highly inter-related yet separate. Additional dimensions of inhibition have also been proposed, such as behavioral versus cognitive inhibition, intentional versus unintentional inhibition, as well as oculomotor inhibition.

Task Switching

Task switching is the ability to switch between tasks or mental sets (Jersild, 1927) and may reflect cognitive flexibility (Meiran, 2010). Studies have consistently found that switching or alternating between tasks results in higher reaction times (or switch costs) compared to repeatedly performing the same task (Allport, Styles, & Hsieh, 1994; Rogers & Monsell, 1995). Two types of switch cost can be measured in a task-switching paradigm. Local switch cost (also referred to as specific or switching cost) can be defined as the reaction time difference between a switch trial and a non-switch trial within a mixed-task block (i.e., a block that contains both switch and non-switch trials), while global switch cost (also referred to as general or mixing costs) can be defined as the difference in reaction time between non-switch trials within a single-task block (i.e., a block that contains a single, repeated task) and a mixed-task block (Braver, Reynolds, & Donaldson, 2003; Mayr, Diedrichsen, Ivry, & Keele, 2006; Philipp, Kalinich, Koch, & Schubotz, 2008). These two types of switch cost are associated with separate cognitive processes (Philipp et al., 2008; Prior & MacWhinney, 2010; Rubin & Meiran, 2005). Local switch costs are considered to reflect the cognitive effort required to shift from one mental set to another (Verhaeghen & Basak, 2005), while global switch costs are considered to reflect the ability to maintain and activate two or more competing task sets in memory (Braver et al., 2003; Dibbets & Jolles, 2006). However, there is also evidence to suggest that increasing working memory load does not appear to impact global switch cost in certain task switching paradigms (Rubin & Meiran, 2005).

Several theories have been proposed to account for the cognitive processes that contribute to switch costs, including ones that emphasize the role of task set preparation and reconfiguration (Rogers & Monsell, 1995), activation and maintenance (Altmann & Gray, 2008), task set inertia (Allport et al., 1994), inhibition (Mayr & Keele, 2000), task-set priming (Schneider & Logan, 2005), and hybrid accounts (Meiran, 2000; Yeung & Monsell, 2003). One longstanding debate in task switching theory has been whether activation of a current task set, interference from a previous task set, or both contribute to switch costs. For example, in an influential study, Rogers and Monsell (1995) varied the duration of the response-stimulus intervals (RSIs) between task blocks, which affected the time participants had to prepare for an upcoming task. Longer RSIs resulted in lower switch costs and this effect was especially prominent on task switch trials versus task repetition trials, suggesting that preparation takes place for an upcoming task. Moreover, though switch costs could be reduced with adequate preparation time, they could not be eliminated (referred to as *residual switch costs*). The emphasis on endogenous or internally driven task control in this theory is considered to be indicative of executive control. This is in contrast to stimulus-triggered exogenous control, which occurs in response to task cue presentation regardless of a participant's prior intention.

Another debate is the role of goal-related *top-down* processes in task switching (Altmann & Gray, 2008; Meiran, 2000). For example, according to Altmann and Gray (2008), when performing a task, a certain task code or representation is formed that must be maintained in episodic memory over several trials as a person switches from one task set to another. However, some task codes have higher activation levels than others, are better represented in memory, and can then be more easily retrieved later on. Moreover, if a system is distracted by a previous, more active task code, this activation noise can interfere with a current representation causing slowing (switch costs) or even error.

Conversely, some theories support the role of automatic, *bottom-up* processes in task switching, which involve inhibitory or interference control. For example, Allport et al. (1994) suggested that switching between one task set to another involves inhibition of a previous task set. That is, previous task sets continue to compete with current sets to produce a form of proactive interference called *task-set inertia*, which results in switch costs. Moreover, when a task set is strongly activated, it becomes more difficult to inhibit later on and causes greater interference in response selection. According to this theory, highly activated task sets can persist over time and interfere with newer task set configurations.

Mayr and Keele (2000) also support the role of inhibition in task switching, suggesting that successful switching requires that the previously performed task be suppressed in order to allow a person to engage in a new task. Moreover, it is harder to suppress a more recently performed task than one that hasn't been performed in a while. For example, it is more difficult to suppress task A in the first sequence (A-B-A) than in the second sequence (A-C-B-A). They called this effect *backward inhibition.*

Hybrid accounts, in contrast, contend that there are multiple processes at work in task switching (Meiran, 2000; Yeung & Monsell, 2003). Moreover, many theorists acknowledge the role of both activation and inhibition in task switching (Allport & Wylie, 2000; Goschke, 2000; Meiran, 2000; Monsell, 2003; Sohn & Anderson, 2001; Yeung & Monsell, 2003). The present research has potential to improve understanding of the degree to which training can influence performance, and is not intended to directly inform or resolve theoretical debates.

Dual Task Performance

Dual task performance is another component of executive function, and refers to the ability to perform two or more tasks concurrently (Pashler, 1994). Performing two or more tasks simultaneously can be challenging because one task can interfere with the performance of the other (e.g., talking on a cell phone and driving). Like task switching, the literature identifying the exact cognitive mechanisms involved in dual task performance is complex, and conflicting views surrounding the contribution of activation and/or interference to performance costs also extend to dual task performance.

A dominant dual-task model is the central bottleneck or single-channel theory, which suggests that during dual task performance, two operations are not processed in parallel, but sequentially as if passing through a bottleneck (Pashler, 1994). Moreover, as the struggle ensues for one of these tasks to pass through the filter, the other task is necessarily inhibited. As a result, responses to one or more tasks are delayed, with slowing often occurring on the second task and becoming greater as the time between stimulus onsets is reduced. This process describes the psychological refractory period (PRP) effect (Ruthruff, Pashler, & Klaassen, 2001).

Another proposed account is that of capacity sharing. This model is based on the idea that when two tasks need to be processed simultaneously, mental processing capacity must be shared because there are limited resources (or effort) available (Kahneman, 1973; Navon & Miller, 2002). In contrast to bottleneck theories that emphasize sequential processing, capacity sharing models suggest that processing of two tasks occur in parallel (i.e., parallel processing). However, the two tasks are processed more slowly since there are limited resources available.

Furthermore, some parallel processing models suggest that after sufficient practice, two tasks can be processed simultaneously (i.e., have virtually perfect time sharing) without any significant delays in performance (Schumacher et al., 2001). However, this effect can only be attained under very specific conditions, and is otherwise difficult to replicate (Lien, Ruthruff, & Johnston, 2006).

Crosstalk models suggest that dual task interference is dependent on the type of tasks that are concurrently performed. For example, two similar tasks can produce more interference and are more difficult to perform than two non-similar tasks. This may be because the mental representations for two similar tasks can cause greater confusion than for two different tasks (Navon & Miller, 1987). This model appears to incorporate both bottleneck and dual processing theories given that crosstalk is said to occur (leading to sequential processing) only when two similar tasks are performed, which implies that simultaneous or parallel processing occurs when tasks are sufficiently different from one another (Pashler & Johnston, 1998).

Whereas both the bottleneck and crosstalk models appear to emphasize the role of inhibitory or interference processes, capacity sharing may reflect effortful control or activation of resources. Hybrid accounts have proposed that dual task processing involves contributions of both activation and inhibitory processes (Tombu & Jolicoeur, 2003).

Taken together, there are multiple frameworks for cognitive processes underlying dual task performance. Though there are many versions of bottleneck theories, the core assumption is that multiple presenting tasks need to be processed sequentially at a certain point, and that purely parallel processing is rare. As with task switching, we aim to contribute data that will inform the degree to which training can improve dual task performance rather than resolve any theoretical debates.

Chapter 2: Musical Training, Bilingualism, and Executive Function: An Investigation of Working Memory and Inhibitory Control (Paper 1)

Aspects of this research were presented at the 23rd Annual Convention for the Association for Psychological Science (Washington, May 2011).

Preface

The current study investigated whether long term exposure to musical training and bilingualism is associated with enhancements in working memory and inhibitory control. Participants (n = 153) were matched on age and socio-economic status, and assigned to one of four groups (monolingual musician, bilingual musician, bilingual non-musician, or monolingual non-musician). Results revealed that musical training was associated with enhanced executive and phonological working memory, as well as improved interference suppression. Results did not support a bilingual advantage in working memory or inhibitory control, and no additive effects of musical training and bilingualism were demonstrated. The findings support previous research demonstrating associations between musical training and improvements in executive function.

Keywords: working memory, inhibition, transfer of training, musical training, bilingualism, executive function

Musical Training, Bilingualism, and Executive Function: An Investigation of Working Memory and Inhibitory Control

A growing number of studies have reported transfer effects of skill training or experience to seemingly distant areas of cognition, known as far transfer. Training domains that have demonstrated far transfer include physical exercise (Colcombe & Kramer, 2003), video game playing (Boot et al., 2008; Feng et al., 2007; Green & Bavelier, 2003), bilingualism (Bialystok, Craik, Klein, & Viswanathan, 2004), and musical training (Moreno et al., 2011). Despite that many studies report correlations between musical training and improvements in cognition, these investigations often indirectly measure aspects of cognition while their main focus is other behavioral or neural measures. Moreover, many studies in the field contain methodological limitations, such as small sample sizes that result in underpowered analyses, failure to account for socioeconomic status (SES) factors that are likely to differ between musicians and controls and thus confound interpretation, or use of paradigms that allow limited interpretations. The bilingualism literature is plagued with inconsistent findings and conflicting theories, in part due to similar limitations and confounds (See Table 6).

In light of recent evidence (Bialystok et al., 2004; Boot et al., 2008; Colcombe & Kramer, 2003; Moreno et al., 2011) demonstrating training induced changes in cognition, the present study investigated the degree to which musical training and bilingualism are associated with enhancements in a range of cognitive domains. The specific areas reported here are working memory and inhibition, with task switching and dual task improvements from the same study reported separately in Paper 2 (Moradzadeh, Blumenthal, & Wiseheart, submitted). We used theoretically motivated paradigms while controlling for critical variables such as SES, and we explored the possibility of additive effects of musical training and bilingualism on different forms of working memory and inhibition.

Musical Training, Working Memory, and Inhibition

Musical training. Musical training involves processing complex motor, sensory, auditory, visual, and cognitive information, such as translating symbols to sound and keeping the rhythm and tempo of a musical piece in memory, while simultaneously controlling fine motor movements. Higher-level cognition is required to carry out tasks such as switching between notes and rhythms, maintaining and manipulating musical information in working memory (e.g., notes, mechanics, and rhythms), and attempting to inhibit or ignore competing stimuli in the environment (e.g., music generated by other musicians in a band or orchestra).

It is not surprising then that expert musicians, who typically spend at least 10 years practicing an instrument from a young age (Ericsson, Krampe, & Tesch-Romer, 1993) might develop greater executive function benefits than non-musicians. Being exposed to a context where higher-level cognitive function is constantly in demand may contribute to advanced executive function skills in this sample. In fact, accumulating evidence suggests that musical training is associated with improvements in various cognitive skills, including verbal memory (Chan, Ho, & Cheung, 1998; Franklin et al., 2008; Jakobson, Cuddy, & Kilgour, 2003), verbal and general intelligence (Moreno et al., 2011; Schellenberg, 2004; Schellenberg, 2006), speech processing (Moreno & Besson, 2006), visuospatial abilities (Costa-Giomi, 1999), and working memory (Lee et al., 2007).

Musical training and working memory. Research examining far transfer effects of musical training on executive function has been accumulating in recent years, and some of this literature supports the link between musical training and working memory performance. For example, Lee et al. (2007) compared children and adults who previously had received musical training to those without musical training on a set of working memory span tasks (both simple and complex). Within each age group, participants were matched on IQ and SES. The data showed that children who had received musical training performed better on both simple and complex working memory tasks measuring phonological storage, central executive, and visual spatial components. By comparison, musically trained adults outperformed controls only on simple span tasks measuring phonological storage. This study demonstrated far transfer effects of musical training on simple and complex working memory.

Franklin et al. (2008) demonstrated benefits of verbal executive working memory in musicians compared to non-musicians on the Reading Span and Operation Span tasks (Turner & Engle, 1989). They found significant differences between musicians and non-musicians on both tasks, with musicians outperforming controls. A notable feature of the study was better than average demographic matching.

Fujioka, Ross, Kakigi, Pantev, & Trainor (2006) investigated cognitive performance in 4 to 6 year-old children who had received either one year of music lessons (using the Suzuki training method) or no lessons. The two groups were compared on tests of auditory responses and working memory. Children who received one year of music lessons not only were better able to discriminate between musical sound and noise, but also performed significantly better on the digit span task, which measures simple and phonological working memory, at post-test compared to their pre-test performance, while such improvements were not demonstrated in control participants.

George and Coch (2011) investigated the relationship between previous musical training and working memory benefits using event-related potentials (ERPs) as well as behavioral measures of working memory. Their study provided both behavioral and electrophysiological evidence supporting musician benefits in working memory. Specifically, musicians outperformed non-musicians on all subtests of a standardized measure of working memory (Test of Memory and Learning—Second Edition), which assessed phonological, visuospatial, and executive aspects of working memory. Moreover, musicians demonstrated faster and stronger (larger P300 amplitude) neural responses to visual and auditory stimuli compared with non-musicians. However, the authors did not measure SES or IQ. Thus, we cannot rule out third variable effects.

Finally, in a recent study, Bidelman et al. (2013) compared cognition and pitch perception among musicians, tone-language speakers, and controls. The findings demonstrated better working memory capacity among musicians relative to Cantonese (tone-language) speaking and English speaking non-musicians (controls), while both musician and Cantonese speaking groups performed better on pitch perception tasks than controls. Notably, this study extends previous working memory findings to a non-verbal measure, Corsi blocks, which is a form of far transfer effect.

Despite this set of studies demonstrating a link between musical training and working memory, the literature remains ambiguous. For example, Hanna-Pladdy and MacKay (2011) found no significant differences in working memory performance in older adults who were musically trained versus those without musical training. They employed the Digit Span task and the Letter-Number Sequencing subtests of the Wechsler Adult Intelligence Scale (WAIS; Wechsler, 1997) to assess attention and auditory working memory, and the Spatial Span subtest of the WMS-III (Wechsler, 1997) to measure visual attention. Though their study provides evidence in favor of the effects of musical training on some forms of executive processes (e.g., cognitive flexibility), they did not find any differences between musicians and non-musicians on working memory capacity. Similarly, Strait, Kraus, Parbery-Clark, and Ashley (2010) found no group differences between adult musicians and non-musicians on tests of auditory working memory (e.g., similar to the Digit Span task). However, it is possible that this failure to show working memory benefits were specific to the simplicity of the task used or a small sample size (n= 33) in this study. To start to resolve uncertainty in the literature, the present study included a range of tasks that measure different components of working memory, used appropriate sample sizes, and controlled for SES.

Musical training and inhibition. Investigations into the relationship between musical training and executive function have for the most part neglected to examine the impact of musical training on inhibitory control. Here, we outline a few studies that have examined this association. Hurwitz, Wolff, Bortnick, and Kokas (1975) tested two groups of first-grade children who were matched on age, IQ, and social class on a range of cognitive measures, including the Stroop interference task, which is an RT task requiring participants to respond to one attribute of stimuli, such as color, while ignoring a more dominant and conflicting attribute, such as reading conflicting color words (Stroop, 1935). Children who received Kodaly music lessons (a music curriculum that places emphasis on teaching folk songs using techniques such as singing, clapping, reading musical notes, and rhythmic notation) performed faster than those who had not received music lessons on the Stroop interference task.

In a more recent study, Bialystok and DePape (2009) investigated the relationship between musical training, bilingualism, and executive function in university students. They compared instrumentalists and vocalists with monolinguals and bilinguals on a set of executive function tasks and found that musicians and bilinguals outperformed monolinguals on a form of inhibitory control measured by the Simon arrows task. This RT task requires participants to respond to the direction of arrow stimuli, and sometimes arrow location and direction conflict (e.g., left facing arrow on the right side of the screen). Musicians and bilinguals also outperformed monolinguals on an auditory version of the Stroop task. Unfortunately, SES was neither collected nor controlled, so that third factor explanation potentially could account for the findings.

In a randomized controlled study of children assigned to receive music or visual arts training, Moreno et al. (2011) examined performance differences on aspects of executive function, including response inhibition. Findings did not demonstrate any pre-intervention differences in performance on the go/no-go task between children who received music and visual arts training. However, after training the music group alone showed improvements in go/no go performance. Thus, musical training appears to produce response inhibition benefits.

This group of inhibitory control studies suggests potential for a range of types of inhibition to benefit from musical training. A goal of the current study was to further examine the association between musical training and inhibition using a range of paradigms that measure different aspects of inhibitory control, including response inhibition and interference control.

Bilingualism, Working Memory, & Inhibition

Bilingualism. Bilingualism has been studied in relation to executive function since the 1960s (Ben Zeev, 1977; Bialystok, 1988, 2001, 2009; Peal & Lambert, 1962). By speaking two languages, bilinguals become skilled at controlling their attention in order to inhibit one language when speaking the other, to maintain and manipulate multiple components of language in memory (e.g., vocabulary and grammar specific to one language), and to switch from one language to the other (e.g., when there is a change in speaker).

Studies have demonstrated that bilinguals outperform their monolingual counterparts in metalinguistic abilities (Bialystok, 1988), awareness of the mental states of others (called Theory of Mind; Goetz, 2003), and cognitive control (Bialystok et al., 2004; Gold, Kim, Johnson, Kryscio, & Smith, 2013). This bilingual advantage has been observed in a range of populations, age groups, and cross-culturally (Bialystok et al., 2004; Engel de Abreu, 2011).

Some authors have noted inconsistencies in research findings on the bilingual advantage as it relates to higher cognition (Hilchey & Klein, 2011; Paap & Greenberg, 2013). However, further investigation is needed to understand the exact mechanisms and conditions that support or fail to support a bilingual advantage. Some potential causes for the inconsistent results include comparison of data across age groups, using tasks that do not purely measure one type of cognitive construct, and failing to control for SES (Bialystok & Shapero, 2005). Moreover, it is possible that some of the inconsistencies are associated with trying to pin down a single cognitive construct that is involved in bilingualism, whereas the act of speaking and understanding two or more languages often requires multiple cognitive requirements including task switching, inhibitory control, and working memory (Bialystok, Craik, & Luk, 2012).

Bilingualism and working memory. The need to actively manage two simultaneous language systems has commonly been attributed to enhanced inhibitory functioning. However, more recent evidence suggests that bilingualism involves more than just inhibitory control. Evidence suggests that even when bilinguals are speaking one language, both languages are active (Costa, Roelstraete, & Hartsuiker, 2006). This parallel activation of two or more languages has the potential to cause lexical conflict, which might be resolved through cognitive control mechanisms. Manipulation of information in working memory across different contexts (e.g., speaking two separate languages with different interlocutors) is a primary mechanism used to resolve this type of conflict (Engel de Abreu, 2011; Morales, Calvo & Bialystok, 2013). Moreover, those who exercise this skill on a daily basis should show advantages in working memory ability (Morales et al., 2013). There is evidence that both supports a bilingual advantage in working memory (Bialystok et al., 2004; Luo, Craik, Moreno, & Bialystok, 2013; Morales et al., 2013; Yang, Yang, Ceci, & Wang, 2003) and challenges this effect (Bialystok & Feng, 2009; Bonifacci, Giombini, Bellocchi, & Contento, 2011; Engel de Abreu, 2011). Thus, evidence demonstrating a bilingual advantage in working memory is inconsistent (Adesope, Lavin, Thompson, & Ungerleider, 2010).

This trend may be due partly to methodological limitations and inconsistencies present in the aforementioned literature. For example, in a longitudinal study, Engel de Abreu (2011) examined differences between monolingual and bilingual children from Luxembourg on tasks of simple and complex working memory. Their findings demonstrated no differences between age and SES matched monolinguals and bilinguals in working memory performance. A limitation of their study was use of a relatively small sample (n= 44), leaving open the possibility that a lack of power led to a failure to reach significance where an effect truly exists. Moreover, given that bilingual children had been exposed to their second language for only 9 months, it is possible that this degree of experience was not sufficient to produce changes in cognition.

Another study that failed to demonstrate evidence of a bilingual advantage in working memory is that of Bonifacci et al. (2011), who compared performance of bilinguals and monolinguals on measures of working memory in a sample of children and youth. Their findings indicated no advantages of working memory for bilinguals in either age group.

In contrast, Morales et al. (2013) demonstrated more efficient working memory processing in bilingual children compared to monolingual children across two studies. In their first study, they examined children's performance on a Simon-like task, which required manipulation of working memory, and involved different levels of working memory load and conflict. This effect was then replicated in a second study, using a visuospatial working memory task that did not require verbal processing. However, some of the tasks used in their study (e.g., the Frog Matrices task) were not pure measures of working memory because conflict trials required individuals to inhibit or suppress distracting stimuli (i.e., inhibitory control), a construct that is related to but distinct from working memory. A study by Yang et al. (2003) provides further support for the link between bilingualism and working memory. In their study, they demonstrated a bilingual advantage in young adults on a Stroop-like task that required participants to indicate the ink colors for strings of printed color words. The last to-be-recalled word in the string was underlined and participants needed to either indicate the color or read the word. Participants' performance was adversely affected on their response for the last word when they had to indicate the ink color rather than read the word. The authors imply that greater controlled attention in bilinguals can contribute to better working memory capacity and recognition in this group. An alternate interpretation is that the effect is a result of inhibitory control differences, as the task demands included a hybrid of various cognitive requirements, including inhibitory control and task switching. As well, the authors failed to mention efforts made to control for age and SES.

Evidence from studies of bilingualism and cognitive control suggest that in addition to inhibitory control there are additional executive processes involved during bilingual language control, including working memory. For example, researchers typically find that bilinguals perform better on the flanker and Simon tasks on both congruent and incongruent trials, indicating that even when there is no conflict to inhibit, bilinguals continue to outperform monolinguals. This trend may reflect bilinguals' superior working memory abilities, which allow bilinguals to maintain and manipulate information in mind, whether or not there is a need to inhibit information.

One of the goals of the present study is to examine the association between working memory and bilingualism, while addressing limitations in the literature, including controlling for SES and using purer measures of working memory. Another goal is to compare working memory and inhibitory control performance, taking into account the potential contributions from both constructs to cognitive control in bilinguals.

Bilingualism and inhibition. Bilingualism often is associated with enhanced cognitive control (Bialystok, Martin, & Viswanathan, 2005; Green, 1998). Research shows that when bilinguals use one language, the other language is also active and may compete for selection (Jared & Kroll, 2001). Thus, bilinguals must regularly manage two languages at the same time and exercise control over both languages in order to produce the correct language output.

This notion of dual activation of languages in bilinguals has been proposed in Green's Inhibitory Control Model (1998). The model suggests that the activation of semantic/syntactic representations in both languages is determined by our schemas or experiences, and in order to access the intended word in language one (L1), the semantic representations or *lemmas* of language two (L2) must be inhibited by the supervisory attentional system (SAS). Therefore, in order for the SAS to successfully retrieve the correct semantic unit for speech, it uses inhibitory control to resolve the conflict that occurs when two semantic representations are simultaneously activated. Moreover, the proportion of inhibitory control used by the SAS increases as the presence of irrelevant information increases. Similarly, Meuter and Allport (1999) argue that language-switching costs provide support for the concept of dual activation of both languages in bilinguals and the need to inhibit one language in order to successfully switch to the other language.

Despite wide theoretical support for the role of inhibition in explaining the attentional control component in bilingualism, empirical support demonstrating bilingual advantages in inhibition has been inconsistent. In a review, Hilchey and Klein (2011) argued that the findings in the bilingual literature typically demonstrate a very small magnitude of interference effects, indicating little support for a bilingual advantage in conflict resolution or non-linguistic interference effects.

One explanation for why there is so much inconsistency in the literature may be that research has not yet uncovered all the parameters under which the bilingual advantage occurs in relation to inhibitory control. Perhaps, for this reason, the occurrence of the bilingual advantage due solely to inhibitory control processes can only be observed under very specific conditions, meaning that it is not found globally across all tasks or conditions.

Some bilingualism researchers have begun moving away from the inhibitory control model to explain bilingual language control and toward a global executive function model (Costa, Hernandez, Costa-Faidella, & Sebastian-Galles, 2009). According to this model, bilinguals can be expected to demonstrate overall or global RT benefits on executive function tasks, especially when the task is sufficiently challenging or difficult (Costa et al., 2009; Martin-Rhee & Bialystok, 2008). For example, in one study, bilinguals had RT benefits during high-monitoring conditions when half of the trials were congruent and the remaining incongruent, but they did not show similar benefits during low-monitoring conditions (Costa et al., 2009). Therefore, the bilingual advantage on cognitive control tasks may not be due solely to better inhibitory control processes but additionally to faster domain-general executive function processing as demonstrated by global RT benefits under conditions of high task difficulty (Costa, Hernandez, & Sebastian-Galles, 2008; Costa et al., 2009; Hilchey & Klein, 2011).

However, further empirical evidence is required to support this theory. For example, in a recent study, Poarch and van Hell (2012) predicted that trilingual children would demonstrate enhanced global RT and conflict resolution benefits compared to their bilingual and second-language learner counterparts, and that similarly, bilinguals would outperform their second-language learner and monolingual counterparts. Though a bilingual and trilingual advantage was found on conflict resolution, no global RT advantages were demonstrated among trilingual or bilingual children compared to other language groups. Similarly, a study by Salvatierra and Rosselli (2011) demonstrated bilingual advantages on a simple version of the Simon task that required inhibitory control and selective attention, but not on the complex version that involved higher working memory demands, thereby challenging the theoretical explanation of effortful executive processes as being responsible for the bilingual advantage.

In summary, there is a large body of literature investigating the role of inhibitory control in bilinguals compared to monolinguals. However, the effects have not been entirely consistent. Newer models suggest the role of more global executive function processes in the bilingual advantage in cognitive control, though further support is needed. It is too early to make definitive claims that either model works best. Moreover, it is possible that both models play a role; that is, the bilingual advantage may involve not only enhanced inhibitory control, but also these skills may be moderated by global executive function processing advantages (Costa et al., 2009). One of the aims of the current research is to provide greater insight into the association between bilingualism and different components of inhibitory control. Our study is especially relevant in light of recent work indicating differences in behavioral performance as well as brain function on tests of response inhibition versus interference control in bilinguals and monolinguals (Luk, Anderson, Craik, Grady, & Bialystok, 2010). Luk et al. (2010) used the Flanker task, which included a go/no-go condition, to measure both types of inhibitory control. Their results demonstrated that for incongruent trials, monolinguals activated the left temporal pole and left superior parietal regions, while bilinguals activated an extensive network including bilateral frontal, temporal, and subcortical regions. However, for go/no go trials, bilinguals and monolinguals activated similar regions. This finding provides support for differential behavioral and neural functioning for interference control and response inhibition components of inhibition.

Musical Training, Bilingualism, and Executive Function

Bialystok and DePape (2009) is one of few studies that have examined the association between musical training, bilingualism and executive function. Though this study provided a comparison between monolingual musicians, bilinguals, and monolinguals in cognitive performance, a question that might occur is how bilingual musicians would compare to the remaining groups. If monolingual musicians and bilinguals outperform monolingual non-musicians in executive function, then there is a possibility that having both musical skills and the ability to speak two languages fluently could contribute to an even greater cognitive benefit than either alone (Cooper & Wang, 2012). One of the aims of the current study was to further investigate this question to determine whether musical training and bilingualism together might produce additive effects.

Music and language processing appear to involve overlapping cortical networks (Patel, 2003; Patel & Iverson, 2007). However, music and language processing also are known to activate non-overlapping neural regions (Rogalsky, Rong, Saberi, & Hickok, 2011). To the extent that different regions or networks process music and language (Rogalsky et al., 2011), and to the extent that these regions are used during executive function task performance and thus music and/or language experience have strengthened associations between neurons that are relevant to executive function task performance (Posner & Patoine, 2009), we predict that music and language experience should confer differing, additive benefits during executive function task performance. We were interested in exploring this possibility as it extends to working memory and inhibitory control.

Current Study

There were several predictions for the current study. First, we expected musicians to outperform non-musicians on working memory ability and inhibitory control. In terms of working memory, we expected musicians to have better accuracy than non-musicians on both executive and phonological working memory tasks, since musical training involves manipulation and maintenance of multiple symbols and codes. In terms of inhibitory control, we expected musicians to have faster response times on tasks that require suppression of interfering stimuli, as well as on tasks that require stopping an automatic response, since musical training involves ignoring irrelevant symbols and sounds as well as suddenly pausing and restarting performance when required, particularly in group musical performance.

Second, we expected bilinguals to outperform monolinguals on working memory ability and inhibitory control. Literature demonstrating bilingual advantages in working memory has been inconsistent. However, it is possible that this inconsistency is more pronounced in studies with children who have not had enough exposure to the second language, and due to methodological limitations. However, if these limitations are addressed, we might expect bilinguals to show better performance than monolinguals on executive working memory, especially given evidence suggesting the significant role of cognitive control (which includes working memory) in bilingualism. In terms of inhibitory control, evidence suggesting that bilinguals commonly suppress one language in order to produce the second language supports the hypothesis that bilinguals would have faster response times than monolinguals on tasks involving interference suppression. In contrast, previous research suggests weak links between bilingualism and response inhibition (Luk et al., 2010), a type of inhibition that is not commonly associated with executive control. Thus, we did not expect bilinguals to outperform monolinguals on this type of inhibition.

Finally, we were interested in examining whether there would be additive effects of musical training and bilingualism on working memory and inhibition. Some research suggests that music and language access overlapping neural regions (Patel, 2003; Patel & Iverson, 2007), while other studies point to non-overlapping regions (Rogalsky et al., 2011). We explored the possibility that being both musically trained and bilingual may confer additive benefits compared to having only one type of experience.

Method

Participants

Participants (*n* = 153) were recruited through advertisements posted at York University and the University of Toronto, and through professional contacts. They were paid $30 for their time, and all provided written informed consent prior to participation. The sample included 98 females and 55 males who were between the ages of 18 and 31 years old (*M* = 22.0*, SD* = 2.9). Participants were carefully screened over the phone, and those who met the required inclusion criteria were assigned to one of four experimental groups, which included monolingual musicians (*n* = 45), monolingual non-musicians (*n* = 36), bilingual musicians (*n* = 36), and bilingual non-musicians (*n* = 36). Sample size was determined based on an a priori power analysis and was designed to have 80% power to detect both predicted main effects and the predicted interaction, based on effect sizes of studies reported in prior literature in the target populations of interest. Main effects exceed our target power. To meet the study's inclusion criteria, subjects were required to be within the ages of 18 to 35, have no prior history of neurological or psychological disorders, and meet certain language and music criteria as outlined below.

Bilinguals were fluent in English plus at least one other language (Arabic, Armenian, Bulgarian, Cantonese, Farsi, French, German, Ghanian, Greek, Gujarati, Hebrew, Hindi, Italian, Indonesian, Japanese, Kachi, Korean, Mandarin, Portugese, Punjabi, Romanian, Russian, Serbian, Sinhalese, Spanish, Tibetan, Turkmen, Twi, Urdu, Vietnamese, Yoruba, Zulu). Among bilinguals who were asked to describe themselves on level of bilingualism on a 5-point scale (i.e., 1= speak only one language, 2= weak bilingual, 3= unbalanced bilingual, 4= practical bilingual, and 5= fluent bilingual), 93% described themselves as either practical bilinguals (i.e., can carry out conversation fluently but do not use second language daily) or fluent bilinguals (i.e., able to converse fluently and actively use two languages everyday) and 7% considered themselves to be unbalanced bilinguals (i.e., able to carry out basic conversation with minor grammatical errors, without the other speaker repeating the sentence, but are not fully fluent). Individuals were considered to be monolingual if they were fluent only in the English language, with little or no training in a second language.

Musicians included individuals who had at least eight years of experience playing and performing music, and who regularly practiced music. Musicians had, on average, 12 years of formal musical training, using the Royal Conservatory of Music curriculum or similar, and length of training ranged from 7 to 22 years. Moreover, 90% had musical theory training, 83% had ear training, and on average musicians rated themselves 3.25 or having “good” sight-reading ability on a 5-point scale where 1 = “beginner”, and 5 = “expert.” The majority of musicians in the sample (96%) began their training before the age of 12. Musicians consisted of instrumentalists (88%) who played at least 1 of 17 instruments (bass, cello, clarinet, drums, flute, guitar, keyboard, organ, piano, saxophone, shamisen, steel drum, trombone, trumpet, ukulele, viola, violin) and vocalists (12%). Non-musicians included individuals with little (< 2 years) or no exposure to musical training, and who did not currently practice or perform music.

Tasks

Background questionnaires. Participants completed a detailed self-report questionnaire about their music, language, and demographic background prior to completing the experimental tasks. The music background questionnaire included questions regarding the age at which participants began taking musical lessons, the duration of their training, the frequency and duration at which they practiced music on a weekly basis, and the level of sight-reading, ear training, and musical theory achieved. The language background questionnaire included questions regarding what languages the participant could speak and understand, the frequency of language use, and the context and proportion of use of the languages spoken (i.e., percentage of time spent talking, listening, reading, and the language used at home/work/school). Finally, demographic questions inquired about the level of education completed by the participant and the participant's parents, their family income, the participant's daily use of computer or video games, involvement in sports and other physical activities, and general health.

Intelligence and vocabulary. Vocabulary and non-verbal intelligence were assessed using the Kaufman Brief Intelligence Test 2 (K-BIT-2; Kaufman & Kaufman, 2004). The Matrices subtest of the K-BIT-2 is a standardized measure of non-verbal fluid intelligence. In this task, a series of abstract images were presented, and participants were required to complete visual analogies by indicating the relationship between images. The Verbal Knowledge subtest of the K-BIT-2 was used to examine receptive vocabulary. In this task, participants were presented with a word or phrase, and they were required to choose a picture that corresponded to that word or phrase. This task required no reading or spelling on the part of the participant. Both the Matrices and Verbal Knowledge subtests were administered and scored according to the K-BIT-2 manual, and standardized Matrices scores were obtained for participants. We did not administer the Riddles subtest, so Verbal Knowledge scores are raw, not standardized.

Working memory paradigms. The digit span (Wechsler, 1997), reading span (Unsworth, Heitz, Schrock, & Engle, 2005), and operation span (Unsworth et al., 2005) tasks were used to measure working memory. The digit span task is a subtest of the Wechsler Adult Intelligence Scale (WAIS) and consists of digit span forward and digit span backward. Whereas the former task is thought to measure phonological working memory, the latter is considered a measure of executive or complex working memory (George & Coch, 2011). In digit span forward, participants were presented verbally with a sequence of digits at a rate of one digit per second by an examiner, and they were required to recall the numbers back in the same order. In the digit span backward, participants were verbally presented with a series of numbers, and they were required to immediately repeat them back in the reverse order. In both forward and backward spans, if the participant correctly recalled the sequence, the number of digits presented increased by one in the following sequence. This procedure was repeated until participants recalled a set of two digit sequences inaccurately. The total number of digit sequences correctly recalled by participants was measured, and the task took approximately five min to complete.

In the automated reading span task (Unsworth et al., 2005), participants were required to determine whether the sentences they read made sense while trying to remember a string of unrelated letters. For example, participants were first presented with a sentence, such as “the young pencil closed his eyes”, and they were required to indicate whether the sentence made sense by answering true or false. Next, letters were individually presented on the screen and participants were required to remember the letters and the sequence in which they appeared. The presentation of sentence and letters alternated until a recall screen was presented, where participants were required to recall the letter sequences. If a participant forgot a letter, they had the option to mark the position of missing letters by pressing the “blank” button provided on the screen. There were 10-15 words in each sentence. The number of letters to be recalled varied from set to set, ranging between three to seven letters, and 81 sentence problems were presented. Practice sessions were provided, including 15 sentence problems as well as letter recall, and participants were given feedback. The total number of letters correctly recalled in the correct position was measured and the task took approximately 20-25 min to complete.

In the automated operation span task (Unsworth et al., 2005) participants were required to remember a string of letters while solving simple math questions. For example, participants were required to compute a simple math question (e.g., 2*1+3) in mind as quickly as possible. On the following screen, a number was presented. If the number on the screen was the correct answer to the math question, participants clicked the box identified as “true”, and if it was the wrong answer, participants clicked on the box identified as “false.” Then a letter appeared on the screen (lasting 800 ms), and participants were required to remember the letter. At the end of each set of math questions and letters, a recall screen appeared where participants were presented with a matrix of letters where they were required to recall the letters they were presented with and in their correct order. If a participant could not recall a letter within the sequence, there was an option to mark the position of missing letters by pressing the “blank” button provided on the screen. The number of letters to be recalled and math problems to be solved varied from set to set, ranging between three to seven letters or math problems for a total of 75 math problems and 75 letters. Practice sessions for the math and letter portions of the task were also provided beforehand consisting of 15 simple math questions, and feedback was provided on the practice trials. The scoring procedure and total time to complete the task was the same as that of the automated reading span task.

Inhibition paradigms. The Stroop (Stroop, 1935) and Flanker (Eriksen & Eriksen, 1974) tasks were used to measure interference control. The Stroop task is used to examine how well individuals can suppress interfering information or stimuli in order to select the appropriate response. This version of the Stroop task (Cepeda, Blackwell, & Munakata, 2013) involved three sets of stimuli: (1) non-color words (i.e., words that do not refer to colors) printed in red, orange, yellow, green, blue, or purple (e.g., the word advice printed in blue ink). These were considered to be congruent since non-color words were not expected to interfere with naming the ink color; (2) color words (i.e., words that refer to colors) printed in ink that differed from the color that the word described (e.g., the word purple printed in red ink). These were considered incongruent, since there would be greater interference when trying to identify the ink color and not read the word; and (3) asterisks printed in color (e.g., ***** printed in green ink). This baseline set of trials was expected to produce the fastest RTs because there was no interference or conflict, such as word reading, when naming the ink color of the stimuli. Stimuli were presented to participants on sheets of paper and they were required to read the ink colors out loud. The examiner recorded how long (in seconds) it took participants to complete each page using a stopwatch.

Each set of stimuli contained 60 items. Initially, participants were presented with practice trials requiring them to name the ink colors of 12 incongruent word stimuli (color words printed in different color ink; no participants reported colorblindness). The final interference score was computed by subtracting the time it took to read the non-color words from the time it took to read the color words. The task took approximately five min to complete.

In a modified version of the Flanker task (Bunge, Dudukovic, Thomason, Vaidya, & Gabriela, 2002; Luk et al., 2010), participants were asked to respond to the direction of a red target chevron either on its own or among flanker stimuli. If the target arrow pointed to the left, participants had to press the far left mouse button with their left index finger on a mouse located to the left of a keyboard. If the target arrow pointed to the right, participants had to press the far right mouse button using their right index finger on another mouse located to the right of the keyboard. There were three parts to the task. The first part consisted of the null condition, where participants were presented with a red chevron and were required to indicate its' direction using a mouse button (e.g., < or >). The second part consisted of neutral conditions, where participants were presented with a red chevron that was flanked by black diamonds (e.g., <> <> < <> <>), and participants were required to indicate the direction of the chevron despite the presence of black diamonds. The null and neutral conditions were non-experimental in nature since there were either no flankers present or the presence of flankers did not interfere with the participant's response. Both conditions contained six practice trials, which included feedback on trials, and 24 experimental trials. In the third part of the task, both congruent and incongruent conditions were mixed together in one block, and consisted of 12 practice trials and 48 experimental trials. In the congruent condition, a red chevron was flanked by four black chevrons pointing in the same direction as the target (e.g., < < < < <), and in the incongruent condition, a red chevron was flanked by four black chevrons pointing in the opposite direction of the target (e.g., < < > < <). In this task, participants' mean reaction time was measured. The fixation duration was 250 ms, and the stimulus duration was 2000 ms.

Once the stimulus disappeared from the screen, the trial automatically progressed regardless of whether a response was made. The task took approximately 10 min to complete. The task was programmed in E-Prime software.

The Stop Signal task (Logan & Cowan, 1984) was used to measure response inhibition. First, in a reaction time block consisting of 16 trials, participants were required to press the letter “f” on the keyboard when they saw a blue circle on the screen or the letter “j” when they saw a red circle, as quickly and accurately as possible. No cues were provided, and the mean reaction time was used as a baseline to compare performance on the stop signal trials. Next, participants performed a practice stop signal block consisting of 16 trials, where they were presented with go and no go trials. On the no go trials participants were required to inhibit their response (i.e., not press f or j in response to the circle on the screen) when they heard a stop signal (i.e., the verbal prompt “stop”). This block allowed participants to become better acquainted with the stop signal portion of the task and allowed for calibration of the stop signal delay.

In the experimental part of the task, consisting of three blocks of 48 trials, participants heard a stop signal (i.e., the verbal prompt “stop”) on 25% of trials, which required them to inhibit their response to the go task. On another 25% of trials, a go signal (i.e., the verbal prompt “go”) was presented, and on 50% of trials no prompt was provided (identified as no signal). During all stop signal blocks, the stop signal delay was iteratively adjusted up or down by 50 ms intervals, depending on whether the participant successfully stopped their response, with the goal of producing 50% successfully stopped trials in response to the stop signal. When the participant’s RT to the primary task was more than 2.3 standard deviations longer than the mean initial choice RT, a verbal prompt (“faster!”), reminded participants to respond as quickly as possible.

Stop signal reaction time (SSRT) was used as a measure of individual response inhibition. SSRT is an estimate of the time it takes for a stop process to finish once it is initiated by a stop signal. As in

Ridderinkhof, Band, and Logan (1999), the finishing time of the stop process was estimated by taking the ith percentile of the go trial distribution, where i corresponded to the percentage of successfully stopped trials in the stop signal condition. The average stop signal delay was subtracted from the estimated finishing time of the stop process in order to determine the stop signal reaction time. A smaller SSRT indicated faster inhibition when responding to the primary task. The task took approximately 10 min to complete.

Procedure

The working memory and inhibition paradigms were a part of a larger battery consisting of 11 tasks that measured various executive constructs. The task battery took approximately two hours to complete, and the tasks were presented to participants in a fixed order, beginning with informed consent, followed by the background questionnaires, the cognitive paradigms, and lastly, debriefing of participants. The flanker task was added to the battery partway through initial data collection. Thus, data were collected for 92 participants on this task. Participants were contacted one year after the initial testing session to return for a follow-up session where additional cognitive tasks were administered, including operation span. Of the 153 participants in the original study, 54 participants could be reached and agreed to partake in the follow-up session. Of this subset, all participants had partaken in the first testing session, and demographic variables for this group were consistent with the initial 153 participants. The computer-based tasks were presented on a Microsoft Windows XP computer with Core i5 CPU and displayed on a 15-inch (1280 by 1024 pixels) monitor.

Data Analyses

Data cleaning was performed for the Flanker task, where trial RT scores that were above 100 ms and below 1500 ms were removed prior to analysis, a method consistent with that of Luk et al. (2010). No outliers were removed for digit span, reading span, operation span, stroop, or stop signal tasks. Data for all experimental tasks showed a normal univariate distribution given that most skewness and kurtosis values fell between the range of -1.0 to +1.0. Mean scores for all the tasks can be found in Table 1. Moreover, there were no ceiling or floor effects for any of the measures.

Table 1.

Mean Scores (SD) for Working memory and Inhibitory Control Measures

	Measures	Mean	*SD*
Working Memory	Digit Span Forward (# correct items)	11	2
	Digit Span Backward (# correct items)	8	2
	Reading Span (total score)	51	13
	Operation Span (total score)	41	20
Inhibitory Control	Stroop (s)	14	7
	Flanker- Incongruent (ms)	541	70
	Flanker- Congruent (ms)	481	64
	Stop signal SSRT (ms)	282	62

Results

Demographic Variables

There were no significant differences between groups on age, $F(3, 148) = 1.63$, $p = .185$, or SES (as measured by mother's education level), $F(3, 149) = 2.24$, $p = .086$ (Table 2). As an additional check of SES matching, non-verbal IQ did not differ between groups, $F(3, 148) = .255$, $p = .857$. Vocabulary score was significantly higher in musicians compared to non-musicians, $t(70) = 2.88$, $p < .005$, $d = .68$, and higher among monolinguals compared to bilinguals, $t(70) = 3.47$, $p < .001$, $d = .82$. Within the musician group, there were no significant differences in mean years of musical experience, $t(80) = .33$, $p = .740$, or mean age at which musicians began training, $t(79) = .26$, $p = .797$, between monolingual and bilingual musicians. However, at the point when the study was run, monolingual musicians spent significantly more hours per week practicing music than bilingual musicians, $t(76) = 2.52$, $p = .014$, $d = 0.57$.

Table 2.

Participant Characteristics. Mean (SD).

	Musician		Non-Musician	
Variable	Monolingual	Bilingual	Monolingual	Bilingual
Age (years)	21.5 (3.1)	22.5 (3.2)	22.6 (2.6)	21.5 (2.3)
SES (mother's education)	3.4 (1.1)	3.4 (1.4)	2.7 (1.3)	3.4 (1.3)
K-BIT-2 Vocabulary (raw)**	51.0 (3.4)	49.2 (3.6)	49.7 (4.4)	45.0 (4.4)
K-BIT-2 Matrices (standardized)	102.8 (22.3)	104.6 (14.7)	103.7 (15.2)	101.2 (12.5)
Musical Training (years)	12.0 (4.7)	12.4 (5.6)	-	-
Age Started Musical Training (years)	7.7 (2.9)	7.9 (3.5)	-	-
Weekly Musical Practice (hrs)*	9.8 (7.0)	5.7 (7.3)	-	-

Note: SES = socioeconomic status. Mother's education ranged from 0 to 5 (0 = high school not completed, 1 = high school diploma, 2 = some college, 3 = college diploma, 4 = Bachelor's degree, 5 = graduate or professional degree). **p* < .05, ***p* < .01.

Working Memory

In line with previous literature demonstrating a phonological and executive working memory advantage in musicians (Lee et al., 2007), musician benefits were predicted on the digit span forward and backward tasks. A 2 x 2 (musician status [musician, non-musician] x language status [bilingual, monolingual]) between-subjects ANOVA showed a main effect of musician status, $F(3, 148) = 6.17$, $p = .014$, $\eta_p^2 = .04$, where musicians ($M = 11.5$ items, $SE = 0.2$) outperformed non-musicians ($M = 10.7$ items, $SE = 0.2$) on the digit span forward (Table 3). Results also demonstrated a main effect of language status on this task, $F(3, 148) = 11.10$, $p = .001$, $\eta_p^2 = .07$. However, the effect was in the opposite direction than what was predicted; that is, monolinguals ($M = 11.6$ items, $SE = 0.2$) outperformed bilinguals ($M = 10.5$ items, $SE = 0.2$). Moreover, no interaction between musician and language status was demonstrated. In the digit span backward task, results demonstrated a main effect of musician status, $F(3, 148) = 6.07$, $p = .015$, $\eta_p^2 = .04$, where musicians ($M = 8.4$ items, $SE = 0.3$) outperformed non-musicians ($M = 7.4$ items, $SE = 0.3$). There was neither a main effect of language status, nor a musician by language status interaction.

Results of the reading span task were in line with predictions. A 2 x 2 (musician status [musician, non-musician] x language status [bilingual, monolingual]) between-subjects ANOVA showed a main effect of musician status, $F(3, 145) = 8.46$, $p = .004$, $\eta_p^2 = .055$, with musicians ($M = 53.2$ items, $SE = 1.4$) outperforming non-musicians ($M = 47.2$ items, $SE = 1.5$) on the reading span total score. We did not predict a bilingual advantage, because of the verbal nature of the task. In line with typical bilingualism deficits on verbal tasks, our results showed a main effect of language status, $F(3, 145) = 5.17$, $p = .024$, $\eta_p^2 = .034$, with monolinguals ($M = 52.6$ items, $SE = 1.4$) outperforming bilinguals ($M =$

47.8 items, *SE* = 1.5). In addition, a marginal interaction between musician and language status was demonstrated, *F*(3, 145) = 3.75, *p* = .055, η_p^2 = .025. A follow up *t*-test demonstrated higher accuracy in monolingual musicians (*M* = 57.6, *SD* = 9.6) compared to monolingual non-musicians (*M* = 47.5, *SD* = 11.7) on this task, *t*(79) = 4.28, *p* < .001. However, no performance differences were detected between bilingual musicians and non-musicians (*p* > .573).

Next, differences in performance on the operation span among music and language groups were investigated. A 2 x 2 (musician status [musician, non-musician] x language status [bilingual, monolingual]) between-subjects ANOVA demonstrated a main effect of musician status, *F*(3, 50) = 4.62, *p* = .018, η_p^2 = .108, with musicians (*M* = 60.3 items, *SE* = 2.4) outperforming non-musicians (*M* = 51.4 items, *SE* = 2.7) on mean accuracy. No main effect of language was demonstrated. The analysis showed an interaction between musician and language status, *F* (3, 50) = 5.44, *p* = .024, η_p^2 = .098. A follow up *t*-test demonstrated higher accuracy in monolingual musicians (*M* = 63.9, *SD* = 11.9) compared to monolingual non-musicians (*M* = 46.5, *SD* = 14.7) on this task, *t*(30) = 3.70, *p* = .001. However, no significant difference was found on this task between bilingual musicians relative to bilingual non-musicians (*p* > .940).

Table 3.

Mean Correct Items (SD) for Working Memory Measures by Participant Group.

		Digit Span Forward	Digit Span Backward	Reading Span (total score)	Operation Span (total score)
Musician	Monolingual	12 (1)**	9 (2)*	58 (10)**	64 (12)**
	Bilingual	11 (2)*	8 (2)*	49 (17)**	57 (11)
Non-	Monolingual	11 (2)**	8 (3)	47 (12)*	46 (15)

musician	Bilingual	10 (2)	7 (2)	47 (12)	56 (15)

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

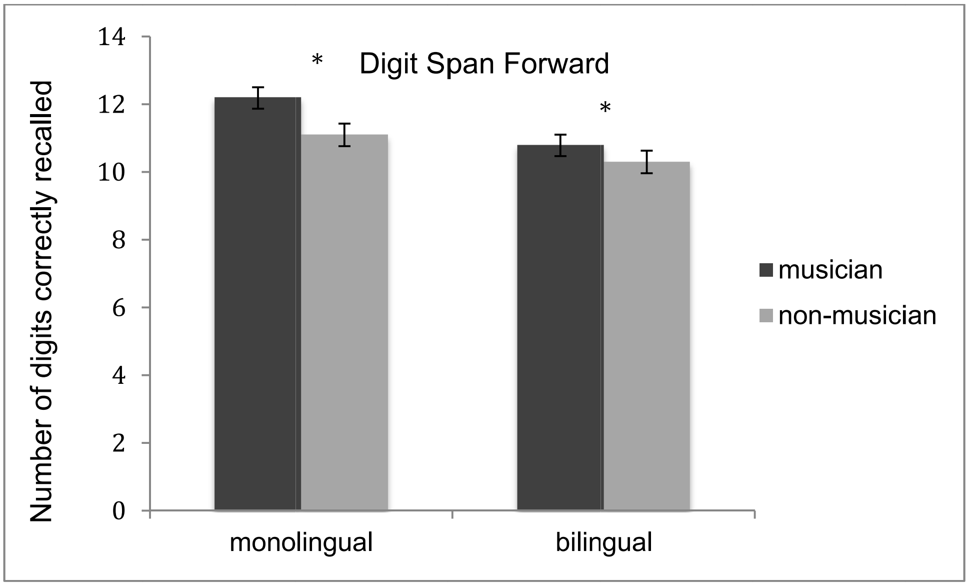

Figure 1a. Main effects of musician (*p* = .014) and language (*p* = .001) status in Digit Span Forward. Errors bars represent *SEM*. *$p < .05$.

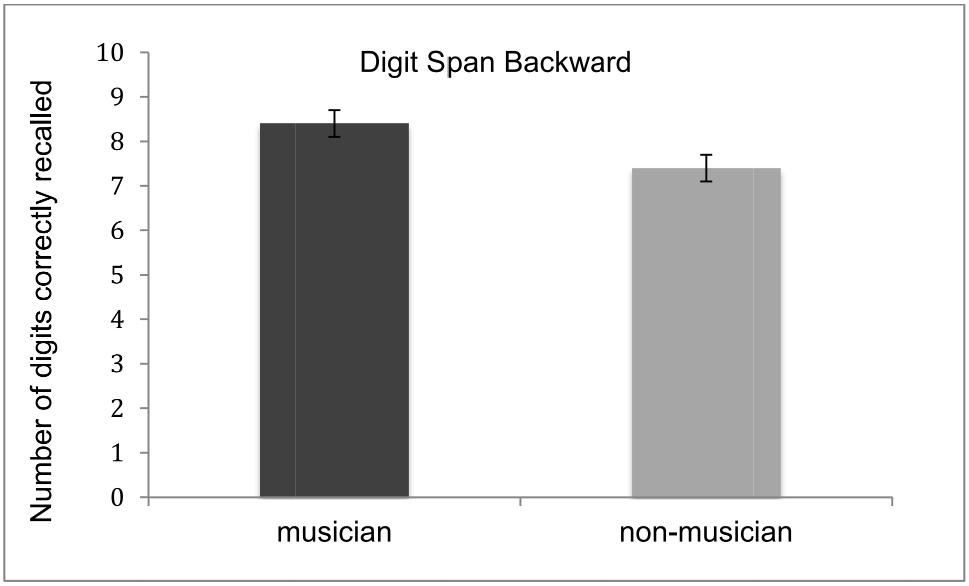

Figure 1b. Main effect (*p* = .015) of musician status in Digit Span Backward. Errors bars represent *SEM*.

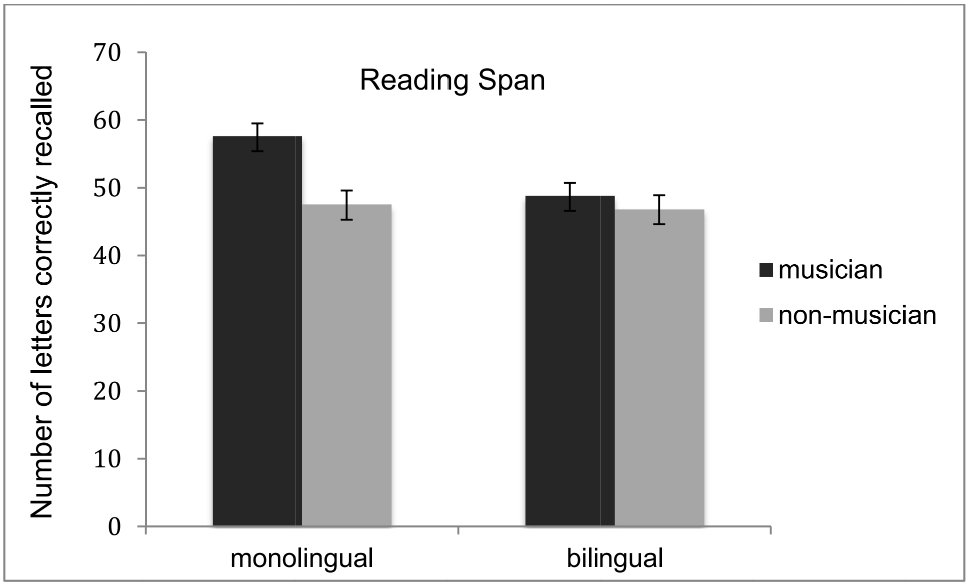

Figure 2. Main effect of musician (*p* = .004) and language (*p* = .024) status and marginal musician x language status interaction (*p* = .055) in the Reading Span task. Errors bars represent *SEM*.

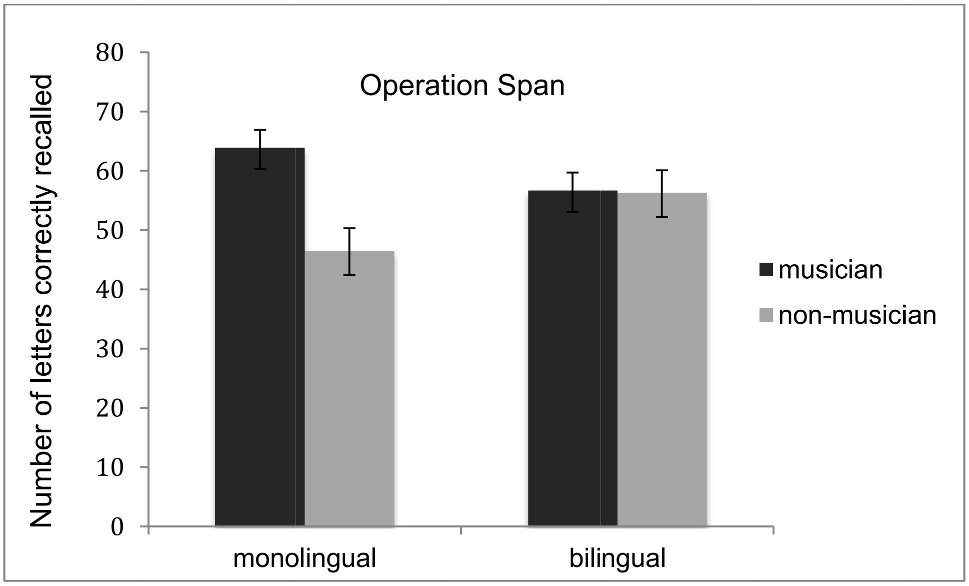

Figure 3. Main effect of musician (*p* = .018) and musician x language status interaction (*p* = .024) in the Operation Span task. Errors bars represent *SEM*.

Inhibition

In line with previous research, we predicted both musician and bilingual benefits on measures of interference suppression, including Stroop and Flanker tasks, as well as an interaction between musician and language status, with bilingual musicians outperforming the remaining groups (Table 4). For Stroop, a 2 x 2 (musician status [musician, non-musician] x language status [bilingual, monolingual]) between-subjects ANOVA demonstrated a marginal main effect of musician status, F (3, 147) = 3.56, $p = .061$, $\eta_p^2 = .024$, with musicians (M = 13.3 s, SE = 0.8) performing faster than non-musicians (M = 15.4 s, SE = 0.8). Neither a main effect of language, nor a language by musician status interaction was demonstrated.

We predicted both musician and bilingual benefits on the Flanker task, particularly on congruent and incongruent conditions, which require greater interference suppression and facilitation in comparison to neutral or null trials. Further, this trend has been previously demonstrated in musicians and bilinguals (Bialystok & DePape, 2009; Luk et al., 2010). Results of a 2 x 2 x 2 (musician status [musician, non-musician] x language status [bilingual, monolingual] x congruency [incongruent, congruent]) repeated measures ANOVA demonstrated a main effect of congruency, $F(1, 92) = 199.08$, $p < .001$, $\eta_p^2 = .684$, with faster performance on congruent (M = 490 ms, SE = 6.8) than incongruent (M = 543 ms, SE = 6.9) trials. Tests of between-subjects effects demonstrated a main effect of music, $F(1, 92) = 8.18$, $p = .005$, $\eta_p^2 = .082$, with faster performance among musicians (M = 497 ms, SE = 8.5) than non-musicians (M = 535 ms, SE = 10.1). No other effects reached significance. Moreover, independent samples t-tests examining performance of musicians and non-musicians on the Flanker task revealed significant differences in RT on all conditions, including null [$t(94) = -3.04$, $p = .003$], neutral [$t(94) = -2.25$, $p = .027$], congruent [$t(94) = -2.57$, $p = .012$], and incongruent [$t(94) = -3.10$, $p = .003$], trials, suggesting a possible processing speed advantage among musicians compared to non-musicians.

Finally, musicians were predicted to outperform non-musicians on the stop signal task, since this group was expected to be highly skilled at inhibiting prepotent responses as a result of training that requires stopping and restarting musical performance in an orchestral setting. However, findings did not support these predictions. A 2 x 2 (musician status [musician, non-musician] x language status [bilingual, monolingual]) between-subjects ANOVA demonstrated no significant differences between musicians and non-musicians in their performance on no signal trial SSRTs in the stop signal task ($p > .22$). We considered the possibility that some musicians may not have been as proficient in an orchestral or group musical environment where response inhibition is necessary. Thus, in order to analyze differences on response inhibition in the relevant musician group, the performance of musicians who had specifically indicated that they were a part of an orchestra or band was compared to those without musical training on the stop-signal task. Results of this follow-up analysis also did not indicate any musician benefits on SSRT ($p > .76$). Based on previous literature, bilinguals were not predicted to outperform monolinguals on the stop signal task, a measure of response inhibition. The results mirror these predictions as no bilingual advantage was found for this task ($p > .90$).[1]

Controlling for Weekly Hours of Music Practice

Given that a significant difference was found between monolingual and bilingual musicians on current weekly hours of music practice, it was important to account for this variable in the analysis. However, this variable could not be included as a covariate in the analysis since this would mean that non-musicians would have zero hours of current practice, which would result in covariate data for only half of the sample. Consequently, participants were split into three groups, consisting of non-musicians, low practicing musicians, and high practicing musicians, and to classify musicians as high or low

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[1] Data analyses for all tasks were performed using more stringent classification criteria for bilingualism and musician status (Appendix A). The secondary analyses produced results consistent with those reported in the primary text.

practicing, the median number of hours of weekly music practice was used to split the musician sample into two equal sized groups.

Working memory. The results of the working memory analysis demonstrated that even after controlling for weekly hours of music practice, the pattern of findings was consistent with that of the original analyses. For example, results of a 2 x 3 (language status [bilingual, monolingual] x musician status [high-practicing musician, low-practicing musician, non-musician]) between-subjects ANOVA for the digit span forward task demonstrated a main effect of language, $F(5, 146) = 11.27$, $p = .001$, $\eta_p^2 = .072$, with monolinguals outperforming bilinguals, and a marginal main effect of musician status, $F(5, 146) = 2.73$, $p = .069$, $\eta_p^2 = .036$, with musicians outperforming non-musicians. There was no significant interaction between musician and language status. Post-hoc comparisons using the Tukey HSD test indicated a significant difference between high practicing musicians and non-musicians ($p = .02$) on mean accuracy scores. However, mean score differences between high and low practicing musicians were non-significant ($p = .658$), as was the difference between low practicing musicians and non-musicians ($p = .195$). Results of the digit span backward demonstrated a marginal main effect of musician status, $F(5, 146) = 2.64$, $p = .075$, $\eta_p^2 = .035$, with musicians outperforming non-musicians. Post hoc Tukey HSD comparisons of musician status demonstrated a significant mean difference between high practicing musicians and non-musicians ($p = .041$), while differences between high and low practicing musicians ($p = .807$), and that of low practicing musicians and non-musicians ($p = .192$) were non-significant. Finally, consistent with the original analysis, there was neither an interaction between musician and language status, nor a main effect of language status.

For the reading span task, a 2 x 3 (language status [bilingual, monolingual] x musician status [high-practicing musician, low-practicing musician, non-musician]) between-subjects ANOVA was performed. Results demonstrated a main effect of musician status, $F(5, 143) = 4.36$, $p = .015$, $\eta_p^2 = .057$, with musicians outperforming non-musicians, and a main effect of language status, $F(5, 143) = 5.22$, p

= .024, $\eta_p^2 = .035$, with monolinguals outperforming bilinguals. A significant interaction between music and language status was not demonstrated. Post-hoc comparisons using the Tukey HSD test indicated a significant difference between high practicing musicians and non-musicians ($p = .001$). However, the performance of high practicing musicians was not significantly different from that of low practicing musicians ($p = .112$), nor was the difference in performance between low practicing musicians and non-musicians ($p = .324$).

For the operation span, a 2 x 3 (language status [bilingual, monolingual] x musician status [high-practicing musician, low-practicing musician, non-musician]) between-subjects ANOVA was conducted. Results demonstrated a main effect of musician status, $F(3, 48) = 3.62$, $p = .034$, $\eta_p^2 = .131$, with musicians outperforming non-musicians. An interaction between music and language status was no longer demonstrated once level of practice was factored in. Post-hoc comparisons using the Tukey HSD test indicated that there was a significant difference between high practicing musicians and non-musicians ($p = .006$) on mean accuracy scores. However, mean score differences between high and low practicing musicians were non-significant ($p = .321$), as was the difference between low practicing musicians and non-musicians ($p = .304$).

Inhibition. The results of the inhibition analysis demonstrated that after controlling for hours of weekly music practice, the pattern of findings are generally the same as the original analyses. For the flanker, examination of performance on the task across the three levels of musician status produced results that were consistent with original findings. A 2 x 2 x 3 (congruency [congruent, incongruent] x language status [bilingual, monolingual] x musician status [high-practicing musician, low-practicing musician, non-musician]) repeated-measures ANOVA was run. Results indicated a main effect of congruency, $F(2, 90) = 150.81$, $p < .001$, $\eta_p^2 = .626$, with faster performance on congruent ($M = 487.9$, $SE = 7.6$) versus incongruent ($M = 539.8$, $SE = 7.7$) trials. No musician or language benefits were found in this analysis. However, tests of between-subjects effects demonstrated a marginal main effect of music, *F*(2, 90) = 2.62, $p = .079$, $\eta_p^2 = .055$, with faster performance among high-practicing musicians (*M* = 498.5, *SE* = 14.3) than low-practicing musicians (*M* = 508.1, *SE* = 13.5) or non-musicians (*M* = 535.0, *SE* = 10.1).

For the stroop task, a 2 x 3 (language status [bilingual, monolingual] x musician status [high-practicing musician, low-practicing musician, non-musician]) between-subjects ANOVA did not demonstrate any significant main effects or interactions. That is, when musician status was divided into high practicing, low practicing, and non-musician groups, a trend in favor of musician benefits was no longer demonstrated on the stroop task. In addition, there was no significant main effect of language, nor an interaction between musician and language status.

Similarly, for the stop signal, examination of musician status at three levels produced results that were consistent with initial findings. That is, results of a 2 x 3 (language status [bilingual, monolingual] x musician status [high-practicing musician, low-practicing musician, non-musician]) between-subjects ANOVA for the stop signal task did not demonstrate any significant main effects for musician or language status, and no music by language status interaction was found (*p*s > 28). Sample size limitations did not allow us to further break down this group into musicians who were part of an orchestra or band, as we had in the original analyses.

In summary, after controlling for weekly hours of music practice, the findings for working memory and inhibition measures are consistent with the original analyses. Specifically, digit span forward still produced a main effect of language with monolinguals outperforming bilinguals, and though main effect of musician status (where musicians outperformed non-musicians) was now marginal, the pattern of findings was similar to initial results. Similarly, the digit span backward produced a marginal main effect of musician status (i.e., musicians outperformed non-musicians), whereas original findings demonstrated main effects of this group. Reading span results showed a main effect of musician status and language status, consistent with original findings. However there was no longer a marginal interaction between musician and language status. Finally, operation span results showed a main effect of musician status consistent with original findings. However, a music by language interaction was no longer present. Similar to the working memory findings, results of the flanker task continued to demonstrate a main effect of musician status, and results for stop signal still did not show any main effects or interaction effects of music or language. Finally, whereas the original finding demonstrated a marginal main effect of musician status for the stroop task, the current results did not show such benefits. Overall, the findings suggest that after taking into account the role of weekly hours of music practice, musicians continue to display a performance advantage on working memory, as well as, interference control measures. Furthermore, these benefits appear to be more robust among high practicing musicians versus low practicing or non-musicians.

Table 4.

Mean Scores (SD) for Inhibitory Control Measures by Participant Group.

		Stroop (s)	Stop Signal-SSRT (ms)	Flanker-Incongruent (ms)	Flanker-Congruent (ms)
Musician	Monolingual	12 (6)	281 (61)	518 (66)**	469 (62)*
	Bilingual	14 (8)	271 (70)	526 (58)**	476 (57)*
Non-musician	Monolingual	15 (6)	284 (55)	561 (82)	503 (83)
	Bilingual	15 (7)	292 (62)	566 (51)	510 (56)

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

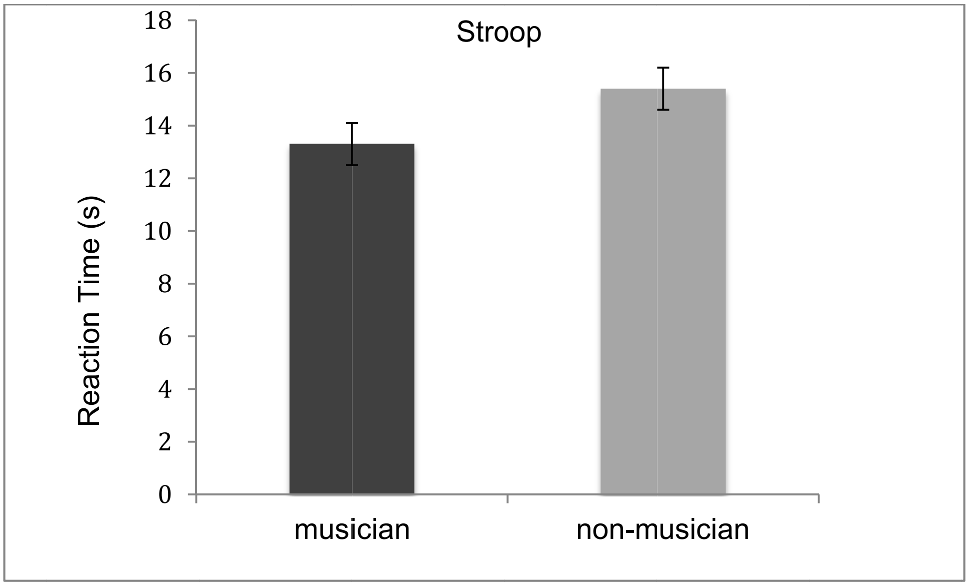

Figure 4. Marginal main effect (*p* = .061) of musician status in Stroop task.

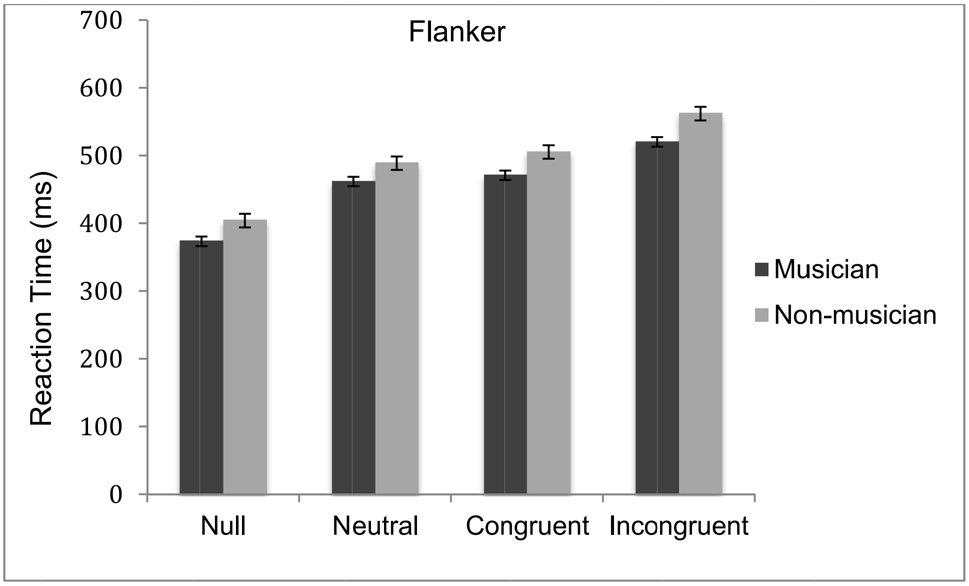

Figure 5. Comparison of musicians groups across different conditions of the Flanker task. Musicians outperformed non-musicians on null, neutral, congruent, and incongruent conditions (*p*s < .027).

Discussion

The present study investigated the association between musical training, bilingualism, and two specific areas of executive function, namely, working memory and inhibitory control. Results indicated that musical training is associated with advantages in working memory (both simple and complex), while this type of experience is associated with benefits in one type of inhibitory control, namely interference suppression. Musician advantages were not found in response inhibition. Furthermore, the findings failed to show any bilingualism benefits across working memory and inhibition tasks, nor a combined benefit of being both bilingual and musically trained.

Working Memory

Findings for the working memory tasks (e.g., digit, reading, and operation span tasks) demonstrated main effects of musician status, which showed performance benefits in musicians versus non-musicians. This trend is consistent with previous research demonstrating working memory benefits in musicians compared with controls, in both child and adult populations (George & Coch, 2011; Lee et al., 2007). A common limitation in the literature has been the use of a single task or paradigm to measure working memory, which not only limits the generalizability of the findings, but also taps into only one form of this construct, such as phonological, visuospatial, or executive working memory. The present study examined performance of musician groups on a range of working memory paradigms, while tapping into different aspects of working memory, including phonological and executive domains.

Surprisingly, results demonstrated a main effect of language status for the digit span forward task, which was contrary to study predictions; that is, monolinguals outperformed bilinguals on these measures of working memory. Similarly, a significant music by language status interaction was found for the operation span task, where monolingual musicians outperformed monolingual non-musicians, while bilingual musicians and non-musicians did not differ. While the digit span and operation span tasks do not rely heavily on verbal fluency or lexical access, two areas where bilinguals typically show deficits (Bialystok, 2001; 2009), they do require processing of verbal information. Thus, the verbal requirements in these tasks may have led to performance deficits in bilinguals compared to their monolingual counterparts.

In contrast to the results of the digit and operation span tasks, trends demonstrating a monolingual advantage for the reading span were not surprising. The reading span task requires greater language proficiency skills in order to read sentences and determine their accuracy, a task that has been found to be more demanding for bilinguals than monolinguals.

Alternative explanations for the absence of a bilingualism-working memory connection in this study should be considered. For example, the link between bilingualism and working memory may be weaker than proposed in previous work, and more research is needed to specify the mechanisms and conditions under which the link occurs. As previously noted, literature demonstrating a link between bilingualism and working memory has been conflicting (Adesope et al., 2010). Paap & Greenberg (2013) propose that a common limitation of the bilingualism literature is the lack convergent validity found among tasks measuring the same constructs, which might lead one to question if domain-general benefits of executive processing in bilinguals occur.

Additive benefits of musical training and bilingualism in working memory were predicted in the present study. However, our data neither support nor refute this hypothesis. Given that we did not find a bilingual advantage, the absence of a combined effect may have been influenced by a lack of a bilingual effect in the first place. That is, it is possible that an additive effect may exist, but in this investigation there was not a bilingual effect to ‘add’ to the music effect. It is possible that the tasks used in the current study were not sensitive to differences between bilinguals and monolinguals, and thus, the potential combined effect of bilingualism and musician status could not be adequately examined.

In summary, the present study demonstrated working memory performance benefits in musicians versus non-musicians on three separate paradigms, which measured phonological and executive working memory. Results support an important connection between musical training and better working memory in adults, a finding that is consistent with prior literature.

In contrast, the present findings failed to support a connection between bilingualism and working memory. This was surprising given efforts to control for SES and use adequate sample size. The absence of a bilingual effect may have been due to the nature of the tasks that were used in this study, suggesting the importance of employing measures that are entirely non-verbal in nature. Alternatively, given the equivocal nature of the literature, determining the cause for the absence of a bilingualism-working memory link may require further investigation, such as determining under which conditions and in which tasks the link appears, and reasons for these possible trends.

Inhibitory Control

As expected, the current study demonstrated musician benefits on interference suppression measures, including Stroop and Flanker tasks, suggesting the important link between musical training and the development of cognitive skills in suppressing distracting or irrelevant stimuli. Interference control is not only critical in musical performance and training, it also extends beyond the training domain to other aspects of the individual's life (e.g., driving, having a conversation in a crowded or noisy environment, etc.) where selective attention is necessary to successfully perform the task at hand.

Interestingly, in the Flanker task, musician RT benefits were found across all types of trials, including null, neutral, congruent, and incongruent conditions. This trend suggests musician benefits, not only in trials where interference suppression is required, but also in baseline trials where there are no distracting stimuli. Hence, it is possible that musicians were simply faster in processing information than non-musicians, a finding that has been demonstrated in previous work (Bugos & Mostafa, 2011).

Contrary to results of the interference suppression tasks, musicians did not outperform non-musicians on response inhibition (i.e., stop signal). This finding diverged from our predictions that musicians would be faster at inhibiting a prepotent response, a skill that likely develops during musical group performance and practice. Even when data from a selective sample of group performers were analyzed, this prediction did not hold. It is possible that our failure to detect group differences was due to the nature of the paradigm used. For example, unlike the stop signal, the go/no go paradigm (employed in Moreno et al., 2011) did not include any verbal prompts signaling the need to inhibit a response. It is possible that the verbal cue in the stop signal paradigm may have distracted participants from the inhibitory portion of the task, whereas a visual cue may have been more appropriate.

Alternatively, it is possible that an association between musical training and response inhibition does not exist. A recent study by Amer, Kalender, Hasher, Trehub, & Wong (2013) for example, assessed middle-aged to older adult musicians and non-musicians on the go/no-go task, a measure of response inhibition, and they failed to report any differences in performance on this task. Further research is required to determine whether a connection between musical training and response inhibition exists, and which paradigms would be most appropriate to examine this connection.

Results examining the association between bilingualism and interference suppression were inconsistent with study predictions. No performance differences were demonstrated between monolinguals and bilinguals on the stroop or flanker tasks. The absence of a bilingual advantage in interference suppression is surprising given extensive literature demonstrating this effect. Further, the current results cannot support either the inhibitory control or global EF model, as no performance (including RT) advantages were demonstrated in bilinguals. One explanation for the pattern of results could be that the tasks employed in this study were not sufficiently challenging to trigger group differences. Past research indicates that the bilingual effect is more commonly observed in complex cognitive control tasks, such as the Simon task (Bialystok et al., 2004). Both the stroop and flanker tasks may be considered as having low task difficulty.

The failure to demonstrate a bilingual advantage may also be due to an absence of a bilingual effect in the first place. As previously noted, this effect is generated under very specific conditions, which demonstrates the elusiveness of the bilingual advantage (Hilchey & Klein, 2011; Paap & Greenberg, 2013).

Overall Summary

The current findings suggest that long-term musical training is associated with advantages in working memory ability and interference suppression. Contrary to expectations, bilingualism was not associated with benefits in these domains relative to being monolingual. Future studies should devote attention to higher-level cognitive benefits of musical training, including complex forms of executive function benefit.

Appendix A

Further analyses using more stringent classification criteria for bilingualism and musician status were conducted in order to establish that our sample selection criteria for the present study was comparable to that of other literature examining bilinguals and musicians (Bidelman et al., 2013). Our revised classification criteria included bilinguals who considered themselves completely fluent in both languages and used both languages on a daily basis, while musicians consisted of instrumentalists who played their instrument regularly, who had at least 10 years of training beginning at or before the age of 13, and had at least five years of formal lessons. These criteria are also consistent with Bidelman et al. (2013). A total of 53 participants did not meet these criteria and were removed from the analysis, leaving data for 100 participants to be analyzed.

Working Memory

Digit span. Consistent with the previous findings for the digit span backward task, the results of a 2 x 2 (musician status [musician, non-musician] x language status [bilingual, monolingual]) between-subjects ANOVA showed a main effect of musician status, $F(3, 96) = 7.68$, $p = .007$, $\eta_p^2 = .074$, with musicians ($M_{mus}= 8.97$) outperforming non-musicians ($M_{n\text{-}mus} = 7.44$) on the digit span backward. Similar to before, there was neither a main effect of language status, nor an interaction between musician and language status (ps > .58). However, the results of the follow-up analysis were not consistent with that of the original analysis for digit span forward. A musician benefit and a monolingual advantage, which had been demonstrated earlier were no longer present. Here, results may have been affected by low power when the sample was reduced. However, data patterns and effect sizes were consistent with the original analysis.

Reading span. A 2 x 2 (musician status [musician, non-musician] x language status [bilingual, monolingual]) between-subjects ANOVA demonstrated a significant interaction between musician and language status, $F(3, 95) = 4.28$, $p = .041$, $\eta_p^2 = .043$. A follow up *t*- test demonstrated higher accuracy in monolingual musicians (*M* = 57.4, *SD* = 9.8) compared to monolingual non-musicians (*M* = 47.5, *SD* = 11.7) on this task, *t*(68) = 3.81 , *p* < .001. However, a significant difference in accuracy between bilingual musicians and bilingual non-musicians was not detected (*p* > .78). No main effects of music or language status were demonstrated.

Operation span. The results of a 2 x 2 (musician status [musician, non-musician] x language status [bilingual, monolingual]) between-subjects ANOVA demonstrated a main effect of musician status, *F*(3, 31) = 5.97, *p* = .02, η_p^2 = .161, with musicians (M_{mus}= 61.9, *SE* = 3.7) outperforming non-musicians ($M_{n\text{-}mus}$ = 49.5, *SE* = 3.4) on the operation span. Neither a main effect of language status, nor a music by language status interaction was found.

Inhibition

Stroop. A 2 x 2 (musician status [musician, non-musician] x language status [bilingual, monolingual]) between-subjects ANOVA demonstrated a marginal main effect of music, *F*(3, 95) = 3.34, *p* = .07, η_p^2 = .034, with musicians (M_{mus}= 12.3, *SE* = 1.1) outperforming non-musicians ($M_{n\text{-}mus}$ = 14.9, *SE* = 0.9) in terms of reaction time (in seconds) on the stroop task. A main effect of language or a music by language status interaction was not demonstrated in this analysis (*ps* > .29).

Flanker. Results of a 2 x 2 x 2 (musician status [musician, non-musician] x language status [bilingual, monolingual] x congruency [incongruent, congruent]) repeated measures ANOVA demonstrated a main effect of congruency, *F* (3, 60) = 147.13, *p* < .001, η_p^2 = .710, with faster performance on congruent (*M* = 485, *SE* = 8.5) than incongruent (*M* = 540, *SE* = 8.3) trials. No musician or language benefits were found in this analysis. However, tests of between-subjects effects demonstrated a main effect of music, *F* (3, 60) = 15.88, *p* < .001, η_p^2 = .209, with faster performance among musicians (*M* = 480, *SE* = 11.7) than non-musicians (*M* = 545, *SE* = 11.1). Moreover, an independent samples *t*-test examining performance of musicians and non-musicians on the flanker task revealed significant differences in RT on all conditions, including null [*t*(62) = -3.52, *p* = .001], neutral [*t*(62) = -3.18, *p* = .002], congruent [*t*(62) = -3.79, *p* < .001], and incongruent [*t*(62) = -4.74, *p* < .001] trials. The findings for this analysis were consistent with that of the original Flanker analysis.

Stop signal. A 2 x 2 (musician status [musician, non-musician] x language status [bilingual, monolingual]) between-subjects ANOVA was performed on the no signal reaction time component of the stop signal task. Consistent with earlier analyses, the results demonstrated neither a music or language main effect, nor a music by language status interaction (*p*s > .17).

In summary, even when a more stringent classification for bilingualism and musician status was used, the results of follow-up analyses were generally consistent with the original findings. Aside from results for the digit span forward, musician benefits were found for all working memory and interference control measures. Similar to the original findings, no language benefits or combined language and musician benefits were discovered.

Table 5.

Correlations for Executive Function Tasks, IQ, and Musical/Language Experience (Full Sample).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. IQ-M	-	.01	.06	__.28**__	__.17*__	.08	__-.16*__	-.08	-.06	__-.23*__	__-.25*__	-.01	.06	.04
2. IQ- V		-	__.25*__	__.28*__	__.30*__	.05	-.06	-.21	-.12	-.01	-.09	__-.38**__	.09	.11
3. DS-F			-	__.56**__	__.39**__	__.47**__	__-.27**__	.02	.02	-.08	-.09	__-.22**__	.15	__.24*__
4. DS-B				-	__.29**__	__.52**__	__-.25**__	-.12	-.08	__-.28**__	__-.26*__	-.10	.07	__.24*__
5. RSpan					-	__.39**__	__-.28**__	.06	.14	.02	.06	__-.16*__	.17	.02
6. OSpan						-	__-.30*__	.14	.02	-.20	-.20	-.01	__.41*__	-.04
7. Stroop							-	.05	-.02	.09	.07	.06	-.03	-.09
8. SS - NS								-	__.72**__	__.41**__	__.34**__	-.05	.16	.01
9. SS - GS									-	__.30**__	__.25*__	-.14	__.25*__	.04
10. Flank-C										-	__.86**__	.03	-.12	-.02
11. Flank-I											-	.05	-.18	-.10
12. Bil level												-	__-.27*__	.08
13. M-prac													-	__.27*__
14. M-YrsTrng														-

Notes: $*p < .05$, $**p < .01$. IQ-M= KBIT matrices; IQ –V= KBIT verbal; DS-F = digit span forward; DS-B = digit span backward; RSpan= reading span; OSpan= operation span; Stroop = stroop; SS-NS= stop signal no signal trials; SS-GS= stop signal go signal trials; Flank-C= flanker congruent; Flank-I= flanker incongruent; Bil level= level of self assigned bilingualism; M-prac= weekly hours of musical practice; M-YrsTrng= years of formal musical training.

Table 6. *Comparison of Bilingualism and Musical Training Studies on SES, Sample Size, Age Range, and IQ measures.*

Study	Bilingualism/Music	SES (Education) (Y/N)	Age (Years)	Measure/DV	Sample size	IQ tested (Y/N)
Bialystok & Feng, 2009	Bilingualism	No	Exp 1: 7 years Exp 2: 21 years	PPVT, Digit span, Sequencing span, Proactive interference task	Exp 1: N=40 Exp 2: N=109	Yes, receptive vocabulary
Bialystok & Martin, 2004	Bilingualism	No	Exp 1: 4.9 years Exp 2: 4.8 years Exp 3: 4.3 years	PPVT, Digit span, DCCS	Exp 1: N= 67 Exp 2: N=30 Exp 3: N=53	Yes, non-verbal, receptive vocabulary
Bialystok, 1988	Bilingualism	No	Age: 6.5 - 7 years	Arbitrariness, Word concept, PPVT	N= 57	Yes, receptive vocabulary
Bialystok & Shapero, 2005	Bilingualism	No	Exp 1: 6 years Exp 2: 5.5 years	Ambiguous figures task, Children's embedded figures task, Opposite world's task, DCCS, Digit span	Exp 1: N=48 Expe 2: N=53	Yes- non-verbal, receptive vocabulary
Bonifacci et al., 2011	Bilingualism	No	Children: ages 6-12, mean= 9 years Youth: ages 14-22, mean= 18.5	Choice RT, Go/no-go, Memory with number, Memory with symbol, Anticipation	N=68: Children= 36 18 mono, 18 bil Youth=32 16 mono, 16 bil	Yes, non-verbal
Costa et al., 2009	Bilingualism	No	Exp 1: 19.5 Exp 2: 19.8	Attentional network task (ANT)	Exp 1: N=120 Exp 2: N= 124	Yes, non-verbal
Engel de Abreu, 2011	Bilingualism	Yes – parent's education	6.4 years, SD= 2.9 months	Simple and complex span tasks, Test of expressive vocabulary and syntax	N=44	Yes, non verbal

Table 6. *Continued*

Martin-Rhee & Bialystok, 2008	Bilingualism	No	Exp 1: 4.8 Exp 2: 4.5 Exp 3: 8.0	Digit span, PPVT, EVIP, Simon, Stroop picture naming, Corsi blocks, arrows task	Exp1: N=34 Exp 2: N=41 Exp 3: N=32	Yes, receptive vocabulary
Morales et al., 2013	Bilingualism	Yes – parent's education	Exp 1: *M*= 5.5, *SD*= 5.4 Exp 2: *M* = 6.1, *SD* =2.8	Pictures task, Frogs matrices task	Exp 1: N=64 Exp 2: N=125	Yes, non-verbal IQ, receptive vocabulary
Poarch & van Hell, 2012	Bilingualism	Yes - parent's education	Mean age per group: SLL = 6.9; Mono= 7.1; Biling= 6.8; Triling= 6.8	Simon, Attentional Network Task	N=75, 4 groups: SLL: 19 Mono: 18 Biliing: 18 Triling: 20	No
Amer et al., 2013	Music	Yes- education	Ages: 50-77, *M* = 60.1, *SD* = 6.8	Auditory stroop, Simon, Visuo-spatial span task, Go-no/go	N=42	No
Bialystok & DePape, 2009	Music and Bilingualism	No	Ages 18-35, *M* = 23.8, *SD* = 4.1	Auditory stroop, Simon, Spatial span, Trail Making Test	N=95	Yes, non-verbal
Bidelman et al., 2013	Music and Language	Yes– education	Musicians =22.9 +/- 4.5 English speaking non–musicians = 25.4 +/- 4.2 Cantonese= 23.2 +/- 3.5	Pitch perception: speed, memory, & melody discrimination	N=54 (18/group x 3)	Yes, non verbal
Cooper & Wang, 2012	Music and Language	No	Mean age/group: Thai- Mus: 21 Thai - N-mus: 22 Eng- Musician: 21 Eng – N-mus: 24	Tone word learning and identification tasks	N=54	No

Table 6. *Continued*

Franklin et al., 2008	Music	Yes – education	Exp 1: M= 19.5 NM=19.9 Exp 2: M= 21.9, NM= 21.3	Reading span, Operation span, Rey Auditory Verbal Learning Test (RAVLT)	Exp 1: M=12 NM=13 (total=25) Exp 2: M=11, NM= 9 (total =20)	Yes, non-verbal
Fujioka et al., 2006	Music	No	Ages: 4-6	Music (musical discrimination) and digit span tests	N=12	No
George & Coch, 2011	Music	No	Ages: 18-24, *M*= 20.2 yrs, 14.5 mo	Phonological, visuospatial, and executive WM	N=32	No
Hanna-Pladdy & MacKay, 2011	Music	Yes – education	Ages: 60-83 *M*= 70	AMNART, WAIS-III, WMS-III, CVLT, BNT	N=70	Yes
Moreno et al., 2011	Music	Yes- mother's education	Ages: 4-6	WPPSI-III, go/no-go	N=64	Yes, verbal and non-verbal
Strait et al., 2010	Music	Yes – education	Ages: 18-40	Cognitive and perceptual data collected using IMAP battery	N=33	Yes, non-verbal

Chapter 3: Musical Training, Bilingualism, and Executive Function: A Closer Look at Task Switching and Dual Task Performance (Paper 2)

Aspects of this research were presented at the 72nd Annual Convention for the Canadian Psychological Association (Toronto, June 2011) and the 24th Annual Convention for the Association for Psychological Science (Chicago, May 2012).

Preface

The current study investigated whether musical training and bilingualism are associated with enhancements in specific components of executive function, namely task switching and dual task performance. Participants (n = 153) belonging to one of four groups (monolingual musician, bilingual musician, bilingual non-musician, or monolingual non-musician) were matched on age and socio-economic status (SES) and administered task switching and dual-task paradigms. Results demonstrated reduced global and local switch costs in musicians compared with non-musicians, suggesting that musical training can contribute to increased efficiency in the ability to shift flexibly between mental sets. On dual task performance, musicians also outperformed non-musicians. There was neither a cognitive advantage for bilinguals relative to monolinguals, nor an interaction between music and language to suggest additive effects of both types of experience. These findings demonstrate that long-term musical training is associated with improvements in task switching and dual task performance.

Keywords: task switching, dual task performance, transfer of training, bilingualism, musical training, executive function

Musical Training, Bilingualism, and Executive Function: A Closer Look at Task Switching and Dual Task Performance

Research over the past few decades has shown that our experiences not only alter behavior (Feng et al., 2007; Thorell et al., 2009), but also lead to benefits in areas of cognition that are distant from the skill being developed (Colcombe & Kramer, 2003), a concept known as far transfer. Far transfer effects of skill training or experience on cognition have been demonstrated in areas such as physical exercise (Colcombe & Kramer, 2003), video-game playing (Boot et al., 2008; Feng et al., 2007; Green & Bavelier, 2003), bilingualism (Bialystok, Craik, Klein, & Viswanathan, 2004), and musical training (Moreno et al., 2011).

Despite the growing body of literature demonstrating training induced changes in cognitive function, some areas of cognition have received more attention than others. For example, in the musical training literature, areas such as working memory (Lee, Lu, & Ko, 2007), verbal memory (Franklin et al., 2008), verbal intelligence (Moreno et al., 2011), linguistic processing (Moreno et al., 2009), and auditory-visual perception (Fujioka et al., 2006) have received the greatest attention, while task switching and dual task performance have been largely ignored, irrespective of the fact that these constructs play an important role in musical training. A different trend occurs in the bilingualism literature. While there has been adequate focus on bilingualism and task switching, particularly as it relates to cognitive control, the overall pattern of findings is variable (Barac & Bialystok, 2012; Paap & Greenberg, 2013). Moreover, little attention has been given to bilingualism and dual task performance. As for the combined effects of musical training and bilingualism, only recently have studies begun to assess the link between music and language processing (Bidelman, Hutka, & Moreno, 2013; Cooper & Wang, 2012; Lee & Lee, 2010; Lee, Lee, & Shr, 2011; Patel, 2003). However, no studies to date have assessed the additive effects of bilingualism and musical training on task switching or dual task performance.

The goals of the current study were to (a) determine the extent to which musical training is associated with cognitive advantages in task switching and dual task performance (b) contribute to the existing literature on bilingualism and task switching and dual task performance by examining these associations using theoretically motivated paradigms while controlling for critical variables such as SES, and (c) explore the possibility of additive effects of musical training and bilingualism on task switching and dual task performance.

Musical Training, Task Switching, and Dual Task Performance

Musical training. Musical training involves complex motor, auditory, and cognitive processing of information, such as translating symbols to sound and keeping the rhythm and tempo of a musical piece in memory, while simultaneously monitoring one's motor movements. At the cognitive level, musical training involves learning to (a) switch attention between groups of notes, rhythm, tempo, and stylistic elements of a musical piece, (b) simultaneously translate and combine, in real time, visual and auditory stimuli, such as notes on a score and sounds from an instrument, (c) maintain multiple components of the musical piece in working memory, such as notes and variations in tone and rhythm, and (d) ignore or inhibit interference from competing stimuli, such as alternate melodic or harmonic lines generated by other musicians. This list is not exhaustive, however, and additional processes likely are involved in musical training and performance.

Expert musicians spend at least 10,000 hours practicing and performing music requiring this wide range of cognitive skill sets by the age of 21 (Ericsson, Krampe, & Tesch-Romer, 1993). Thus, playing a musical instrument on a regular basis not only might improve performance on specific and directly related skills, such as low-level auditory pitch and rhythm processing, but also could extend its effects to improving higher cognitive processes, which are exercised continuously during musical learning and practice (Schlaug, Norton, Overy, & Winner, 2005). In fact, evidence for far transfer effects of musical training has been observed in relation to general intelligence (Schellenberg, 2006), interference control (Bialystok & DePape, 2009), verbal memory (Ho, Cheung, & Chan, 2003), and working memory (Lee et al., 2007). In contrast, there are few studies that have directly explored the relationship between musical training and task switching or musical training and dual task performance.

Task switching. Task switching is the ability to switch between tasks or mental sets (Jersild, 1927) and may reflect cognitive flexibility (Meiran, 2010). Studies have consistently found that switching or alternating between tasks results in higher reaction times (or switch costs) compared to repeatedly performing the same task (Allport, Styles, & Hsieh, 1994; Rogers & Monsell, 1995). Two types of switch cost can be measured in a task-switching paradigm. Local switch cost (also referred to as specific or switching cost) can be defined as the reaction time difference between a switch trial and a non-switch trial within a mixed-task block (i.e., a block that contains both switch and non-switch trials), while global switch cost (also referred to as general or mixing cost) can be defined as the difference in reaction time between non-switch trials within a single-task block (i.e., a block that contains a single, repeated task) and non-switch trials in a mixed-task block (Braver, Reynolds, & Donaldson, 2003; Mayr, Diedrichsen, Ivry, & Keele, 2006; Philipp, Kalinich, Koch, & Schubotz, 2008). These two types of switch cost are associated with separate cognitive processes (Philipp et al., 2008; Prior & MacWhinney, 2010; Rubin & Meiran, 2005). Local switch cost is thought to reflect the cognitive effort required to shift from one mental set to another (Verhaeghen & Basak, 2005), while global switch cost is thought to reflect the ability to maintain and activate two or more competing task sets in memory (Braver et al., 2003; Dibbets & Jolles, 2006).

The few studies that have examined musical training and task switching have looked at this relationship indirectly and used paradigms with poor construct validity. For example, Hanna-Pladdy and MacKay (2011) administered a neuropsychological battery to a sample of older adults varying in musical ability. The battery included the Trail Making Test, a task requiring participants to draw a line connecting letters and numbers in numerical and alphabetical sequence as quickly as possible (Reitan &

Wolfson, 1993). They reported musician benefits on the Trail Making Test, especially in high activity musicians, who had at least 10 years of musical experience and played a musical instrument on a regular basis. Similarly, Bugos, Perlstein, McCrae, Brophy, and Bedenbaugh (2007) used the Trail Making Test as a measure of cognitive flexibility with a sample of older adults who received piano training for six months compared with controls. Results demonstrated that older adults who had received musical training performed better on the Trail Making Test and Digit Symbol paradigms compared with healthy controls. Finally, Bialystok and DePape (2009) used the Trail Making Test as part of a larger battery in their investigation of executive function in musicians, bilinguals, and monolinguals. Although, they reported musician benefits on other executive function tasks, such as Simon and auditory Stroop, they did not find any musician or bilingual advantages on the Trail Making Test. The Trail Making Test is generally used as a diagnostic tool in clinical settings to measure impairment in executive function, and appears to tap working memory ability to a greater extent than task switching ability (Salthouse, 2011; Sanchez-Cubillo et al., 2009). Moreover, this paradigm only consists of univalent stimuli (in which the stimuli are associated with a single task), which, unlike bivalent stimuli (in which the stimuli are associated with two tasks), typically do not produce switch costs (Finkbeiner, Almeida, Janssen, & Caramazza, 2006).

Taken together, examining shifting ability using the Trail Making Test has produced mixed results. Moreover, evidence suggests that this paradigm measures more than just task switching ability, and may primarily tap working memory ability. To effectively assess the relationship between musical training and task switching ability, valid paradigms are needed that allow for more accurate measurement of this construct. The present study aimed to study task switching using a contemporary, theoretically motivated paradigm.

Bilingualism and Task Switching

Bilingualism. Bilingualism, or the ability to communicate in two languages, is a type of skill that has been suggested to offer metalinguistic advantages (i.e., benefits that extend beyond language; Bialystok, 2009). The effects of bilingualism on executive function have been extensively investigated over the past several decades, and according to this literature, bilinguals appear to have certain cognitive advantages compared to monolinguals, such as improved selective attention and cognitive flexibility resulting from the experience of having to coordinate the cognitive demands of two or more languages (Bialystok et al., 2004; Bialystok & Shapero, 2005). This process could involve, but is not limited to, (a) inhibiting the non target language in order to speak the target language fluently, (b) maintaining information from both languages in working memory, (c) switching from one language to another, and (d) simultaneously accessing and manipulating multiple language components, such as grammar, pronunciation, and meaning. Evidence for a bilingual advantage has been observed in constructs such as inhibitory control (Green, 1998), task switching (Prior & MacWhinney, 2010), selective attention (Costa, 2005), and working memory (Just & Carpenter, 1992). Moreover, the bilingual advantage has been observed in various cultures (Bialystok & Martin, 2004; Costa, 2005) and across the lifespan (Bialystok et al., 2004).

Task switching. Bilinguals often need to switch between two or more languages (called language or code switching; Meuter & Allport, 1999), which can produce switch costs. A dominant theory of language switching involves the role of inhibition. According to the inhibitory account, an individual's first language (L1) needs to be suppressed in order for the second language (L2) to become activated (Meuter & Allport, 1999). Moreover, if L1 is the dominant language, it might be more difficult to suppress this language, and higher switch costs would be incurred when switching back to L1, presumably because it is difficult to overcome the high degree of inhibition initially used to suppress the dominant L1 (Meuter & Allport, 1999). This description is consistent with Allport's task set inertia theory (Allport et al., 1994).

Several studies have investigated the role of task switching ability in bilingualism, with some demonstrating bilingual advantages. Bialystok and Martin (2004), for example, demonstrated bilingual advantages on the dimensional change card sort task (Zelazo, Resnick, & Pinon, 1995) in preschool children. At the simplest level, this paradigm involves shifting from one dimension to another, such as color to shape or vice versa, and requires activation of the current sorting rule, inhibition of the previous criterion, and the ability to switch mental sets. Bialystok and Martin, however, also included conditions such as color-object (e.g., red flowers and blue rabbits), which involved identifying objects rather than geometrical shapes, and function-location, where stimuli represented a function (e.g., things to wear) or location (e.g., things to wear inside or outside the house). Data showed that bilingual children were able to perform better on the color-shape and color-object conditions, which required sorting based on perceptual features, compared to monolingual children. However, performance between the two groups did not differ in the function-location condition, where sorting was based on a semantic dimension.

Prior and MacWhinney (2010) demonstrated a bilingual advantage in task switching in a study of 88 young adults attending university. These participants were tested on a non-linguistic task-switching paradigm that required them to respond to shapes or colors on a computer screen. Results showed that bilinguals had a smaller local switch cost compared to monolinguals on this task, even after controlling for working memory and SAT performance. However, SES was poorly controlled in this study despite research showing that it is an important confounding factor in bilingualism research (Morton & Harper, 2007).

Barac and Bialystok (2012) provide further evidence of a bilingual advantage in task switching ability. In this study, three separate bilingual groups (Chinese-English, French-English, and Spanish-English bilingual children) were compared to SES-matched monolingual children on a task-switching paradigm. Results showed that all three bilingual groups had smaller global switch costs than monolinguals, and no differences were found between the groups on local switch cost.

Taken as a literature, investigations of task switching benefits in bilinguals versus monolinguals have produced inconsistent results. Moreover, it is not clear which aspect of task switching produces bilingual benefits. Some studies support task switching benefits in local switch cost (e.g., Prior & MacWhinney, 2010), and others provide support for benefits in global switch cost (e.g., Barac & Bialystok, 2012), despite using similar color-shape tasks with non-verbal task cues. The current research aims to provide greater insight into the relationship between task switching and bilingualism while addressing some of the limitations in previous research by using paradigms with appropriate task difficulty and controlling for SES.

Bilingualism and Dual Task Performance

Dual task performance is another component of executive function, and it refers to the ability to perform two or more tasks concurrently (Pashler, 1994). Performing two or more tasks simultaneously can be challenging because one task can interfere with the performance of the other (e.g., talking on a cell phone and driving). Like task switching, the literature identifying the exact cognitive mechanisms involved in dual task performance is complex, and conflicting views surrounding the contribution of activation and/or interference to performance costs also extend to dual task performance.

Bilingualism involves the use of a multitude of interrelated executive processes (Garbin et al., 2010; Meuter & Allport, 1999). Dual task performance (or multitasking) is one of these cognitive processes, and appears to play an important role in language production. Whether an individual is translating text or speech in mind, they must simultaneously attend to and manipulate many components of language (we can call these modules) within working memory, including phonology (e.g., rules of pronunciation), syntax (e.g., rules of grammar), and semantics (i.e., meaning). In the case of bilinguals, as the individual switches from one language to another, they will need to access these modules more frequently and in a more complex manner as compared to someone who is only using one language. This process may, therefore, strengthen the cognitive (i.e., dual-tasking) system required to produce or access these modules. Moreover, the individual likely will need to inhibit one set of modules for L1 in order to access another set of modules for L2, and the challenge of switching between modules might serve to further strengthen dual task performance in bilinguals. Though switching is involved in this process as a person alternates between languages, an important dimension is dual task performance since an individual must simultaneously access and discriminate between multiple language components in order to produce the correct language outputs. However, task switching and dual task performance are not entirely discrete constructs. Some research suggests that dual task performance consists of multiple and rapid task switches; thus, at the core of dual task performance is task switching (Rubenstein, Meyer, & Evans, 2001).

There is scant research examining the role of dual task performance in bilingualism. Some research suggests a dual task advantage for bimodal bilinguals, who use sign language alongside a spoken language (Emmorey, Borinstein, Thompson, & Gollan, 2010). Little research has investigated dual task performance in unimodal bilinguals, who speak two spoken languages. Preliminary reports indicate dual task performance benefits in unimodal bilinguals compared with monolinguals in a driving simulation task where individuals are required to drive and simultaneously speak on a cell phone (Telner, Wiesenthal, Bialystok, & York, 2008). In another study by Bialystok, Craik, and Ruocco (2006), unimodal bilinguals outperformed monolinguals on a dual-task paradigm consisting of concurrently classifying visual images and auditory information, but the bilingual benefit was only found using relatively simple letter and number stimuli, and more complex animal and music stimuli failed to show a language group effect. Taken together, evidence for a bilingualism benefit in dual task performance is unclear.

Musical Training, Bilingualism, and Executive Function

A central goal of the current study was to explore the potential interaction between musical training and bilingualism with respect to task switching and dual task performance. Music and language processing appear to involve overlapping cortical networks (Patel, 2003; Patel & Iverson, 2007). However, music and language processing also are known to activate non-overlapping neural regions (Rogalsky, Rong, Saberi, & Hickok, 2011). To the extent that different regions or networks process music and language (Rogalsky et al., 2011), and to the extent that these regions are used during executive function task performance and thus music and/or language experience have strengthened associations between neurons that are relevant to executive function task performance (Posner & Patoine, 2009), we predict that music and language experience should confer differing, additive benefits during executive function task performance. We were interested in exploring this possibility as it extends to higher-level cognition using behavioral measures.

Current Study

There were several predictions for the current study. First, we expected musicians to outperform non-musicians on task switching ability and dual task performance. In terms of task switching performance, we expected musicians to show smaller global switch costs compared with non-musicians due to the high working memory demands involved in musical training and the association between the ability to maintain and activate competing task sets in memory and global switch cost (Braver et al., 2003). We expected musicians to show smaller local switch costs compared with non-musicians. Musician advantages have been found on tasks that require continual switching between task sets (e.g., Hanna-Pladdy & MacKay, 2011), and studies have shown better interference control among musicians compared to controls (e.g., Bialystok & DePape, 2009). We expected musicians to perform better than non-musicians on response incompatible trials, in which the same stimuli are associated with a different response for each task, because musical training involves learning to efficiently decode symbols and attend to multiple cues. We had no reason to expect musical training to have an effect on response compatible trials, in which no interference is involved. Finally, we expected musicians to have better accuracy on dual task paradigms compared with non-musicians, given the need for continuous multitasking during musical performance.

Second, we expected bilinguals to outperform monolinguals on task switching ability and dual task performance. The literature on bilingualism and task switching demonstrates local switch cost benefits in some cases and global switch cost benefits in other cases. While we expected benefits, it should be noted that bilingualism benefits are inconsistent even with similar paradigms, so we made this prediction hesitantly. We expected bilinguals to outperform monolinguals on response incompatible trials, and bilinguals and monolinguals to perform similarly on response compatible trials, based on previous work showing interference control benefits in bilinguals. Evidence supporting a bilingualism benefit at dual-task performance is ambiguous; thus, we hesitantly predicted a bilingualism benefit.

Finally, we were interested in examining whether there would be additive effects of musical training and bilingualism on task switching and dual task performance. Some research suggests that music and language access overlapping neural regions, while other studies point to non-overlapping regions. Here, we explored the possibility that being both musically trained and bilingual may confer additive benefits compared to having only one skill set.

Method

Participants

Participants consisted of 153 university students ranging from 18 to 31 years of age (*M* = 22.01, *SD* = 2.86)**.** There were four experimental groups consisting of monolingual musicians (*n* = 45), monolingual non-musicians (*n* = 36), bilingual musicians (*n* = 36), and bilingual non-musicians (*n* = 36). Bilinguals were fluent in English plus at least one other language (Arabic, Armenian, Bulgarian, Cantonese, Farsi, French, German, Ghanian, Greek, Gujarati, Hebrew, Hindi, Italian, Indonesian, Japanese, Kachi, Korean, Mandarin, Portuguese, Punjabi, Romanian, Russian, Serbian, Sinhalese, Spanish, Tibetan, Turkmen, Twi, Urdu, Vietnamese, Yoruba, Zulu). Among bilinguals, who were asked to describe their bilingualism on a 5-point scale (i.e., 1 = speak only one language, 2 = weak bilingual, 3 = unbalanced bilingual, 4 = practical bilingual, and 5 = fluent bilingual), 55% described themselves as fluent bilinguals (i.e., they are able to converse fluently, and they actively use two languages every day), 37% described themselves as practical bilinguals (i.e., they can carry out conversation fluently but do not use their second language daily), and 8% considered themselves unbalanced bilinguals (i.e., they are able to carry out basic conversation with minor grammatical errors, without the speaker repeating the sentence, but are not fully fluent). Musicians had an average of 12 years of formal musical training (range 6 to 22 years). Moreover, 90% had music theory training, 83% had ear training, and on average musicians rated themselves 3.25 or having "good" sight-reading ability on a 5-point scale where 1 = "beginner" and 5 = "expert." Musicians consisted of instrumentalists (88.4%) who played at least 1 of 17 instruments (bass, cello, clarinet, drums, flute, guitar, keyboard, organ, piano, saxophone, shamisen, steel drum, trombone, trumpet, ukulele, viola, violin) and vocalists (11.6%). Participants were recruited using posters disseminated at Toronto universities and by word of mouth, and they were paid $30 for their time.

Tasks

Language and musical background questionnaires. Participants completed a self-report questionnaire regarding their musical, language, and demographic background prior to completing the experimental tasks. The musical background questionnaire included questions regarding the age at which participants began taking music lessons and the duration of their training, the frequency and duration at which they practiced music on a weekly basis, and the level of sight-reading, ear training, and music theory achieved. The language background questionnaire included questions regarding what languages the participant could speak and understand, the frequency of language use, and the context and proportion of use of the languages spoken (i.e., percentage of time spent talking, listening, and reading, and the language(s) used at home and work/school). Finally, demographic questions inquired about the level of education completed by the participant and the participant's parents, their family income, the participant's daily use of computer or video games, involvement in sports and other physical activities, as well as general health.

Intelligence and vocabulary. Vocabulary and non-verbal intelligence were assessed using the Kaufman Brief Intelligence Test 2 (K-BIT-2; Kaufman & Kaufman, 2004). The Matrices subtest of the K-BIT-2 is a standardized measure of non-verbal fluid intelligence. In this task, a series of abstract images were presented, and participants were required to complete visual analogies by indicating the relationship between images. The Verbal Knowledge subtest of the K-BIT-2 was used to examine receptive vocabulary. In this task, participants were presented with a word or phrase, and they were required to choose a picture that corresponded to that word or phrase. This task required no reading or spelling on the part of the participant. Both the Matrices and Verbal Knowledge subtests were administered and scored according to the K-BIT-2 manual, and standardized Matrices scores were obtained for participants. We did not administer the Riddles subtest, so Verbal Knowledge scores are raw, not standardized.

Task-switching paradigm. Task switching performance was assessed using the Quantity/Identity task, which was also used in Cepeda, Cepeda, and Kramer (2000; Exp. 1). The task consisted of three separate blocks. In the first block, participants were required to indicate (when prompted by a cue) how many numbers (i.e., the quantity) were presented on the screen, and the correct response included one of two answer choices (either 1 or 3). In the second block, participants indicated the value of the digit(s) or what number (i.e., identity) was presented on the screen, and they selected the value from two answer choices (either 1 or 3). During the third block, participants switched between indicating the quantity and identity of the numbers on the screen predictably every third trial, and similarly to blocks 1 and 2, the correct response included one of two answer choices (either 1 or 3). Across all three blocks, the trials consisted of both response incompatible and response compatible stimuli. A response incompatible trial occurred when stimuli required different responses for each task (i.e., 3 and 111). In contrast, in a response compatible trial both tasks required the same response for a given stimulus (i.e., 1 and 333). The first two blocks of this task contained 24 trials and the third block contained 72 trials, with eight practice trials per block, and the response-stimulus interval randomly varied between 300 and 600 milliseconds. Cue-stimulus interval was 0 ms, meaning the cue was displayed simultaneously with the stimulus. Trials were self-paced; a participant's response on one trial instigated the next trial. The task took ~10 min to complete.

Dual-task paradigms. Dual task performance was assessed using two tasks. First, participants completed the Krantz paradigm (Krantz, 2007), a rapid serial visual presentation task combined with a motor tracking task. In this task, participants were required to track a moving white dot (4 pixels in diameter, moving at a speed of 8 pixels per update and varying in degree of angle from 0 to 360°) with a target box (size = 16 pixels), which was controlled using the mouse. At the same time, they attended to single capitalized serif letters (font size = 24 pt) flashing one at a time in the center of the computer screen (duration of letter stimuli was 150 ms; average time between letters was 500 ms). Participants were required to click the mouse button whenever they saw the target letter X. After two practice trials, participants completed 10 experimental trials. Each trial lasted 20 seconds and the task took about four min to complete. The tasks produced three measures of accuracy, namely average tracking error (i.e., average distance of the target box from the moving dot), the proportion of target responses (i.e., hits) in response to letter X, and the proportion of non-target responses (i.e., false alarms) in response to letter X. False alarms can be characterized as when a participant inaccurately reports the presence of letter X when another letter is present.

Second, participants completed a dual n-back task (Jaeggi, Buschkuehl, Jonides, & Perrig 2008), specifically, Brain Workshop (http://brainworkshop.sourceforge.net/). The task contained two main sections: 1-back and 2-back. Each main section contained three sub-sections: position single task, audio single task, and dual task. First, participants were required to remember the position of blue squares as they were presented one-by-one on a grid. They were required to press "A" on the keyboard every time a blue square appeared in the same position as the blue square just before it ("1-back position"). Second, participants heard letters (played through speakers), and they had to press "L" every time the letter they heard was the same as the letter that came just before it ("1-back audio"). Third, participants were required to perform the first and second parts at the same time ("dual 1-back"). Following the 1-back section, the procedure was repeated, however, participants were required to remember items presented the time before the previous item, or 2-back. The 1-back and 2-back conditions focus on measuring working memory while dual 1-back and dual 2-back focus on measuring attentional control and dual task performance. Cards showing "A = position" and "L = audio" were placed on top of the keyboard to remind the participant which key corresponded to a particular response. Each of the six subsections had 56 trials, and each trial lasted 2.6 seconds. The task took about 15 min to complete.

Procedure

It is noteworthy that the Quantity/Identity and Krantz paradigms were a part of a larger battery consisting of 11 tasks that measured seven different cognitive constructs. It took approximately two hours for participants to complete this battery of tasks, including a 10 to 15 minute break in the middle. The order of tasks was kept consistent, beginning with informed consent by participants, followed by musical, language, and demographic questionnaires, the task battery, and lastly, debriefing of participants. The dual n-back paradigm was not a part of the original test battery. Participants were contacted one year after the initial testing session to return for a follow-up session where additional cognitive tasks were administered, including the dual n-back paradigm. Of the 153 participants who were contacted at year two, 54 participants agreed to partake in the follow-up session, and of those, 48 participants had usable data (six participants were dropped from this pool because they no longer met the research criteria). Of this subset, all participants had partaken in the first testing session and demographic variables for this group were consistent with the initial 153 participants. All of the tasks were presented using a Microsoft Windows XP computer with Core i5 CPU and were displayed on a 15-in (1280 by 1024 pixels) LCD monitor.

Data Analyses

Data cleaning was performed for the n-back task, where scores that were greater than + or – 3 standard deviations from the mean were removed. No outliers were removed for task switch (Quantity/Identity) or the Krantz paradigm. For the Krantz paradigm, data showing proportion of hits and false alarms were negatively skewed. However, calculation of d-prime resulted in correction of the skewness level for these data. Mean scores for all the tasks can be found in Table 1. Moreover, there were no ceiling or floor effects for any of the measures.

Table 1.

Mean Scores (SD) for Task Switching and Dual Task Performance Measures

	Measures	Mean	*SD*
Task Switching (Quantity/Identity)	Non-switch trial in Non-switch block (ms)	431	92
Compatible	Switch trial in Switch block (ms)	870	202
	Non-switch trial in Switch block (ms)	823	226
Incompatible	Non-switch trial in Non-switch block (ms)	456	102
	Switch trial in Switch block (ms)	971	228
	Non-switch trial in Switch block (ms)	893	234
Dual Task Performance	Krantz (average z-scores)	.03	.70
N-back:	1-back (mean percent accuracy)	91	13
	2-back (mean percent accuracy)	68	21
	dual 1-back (mean percent accuracy)	86	14
	dual 2-back (mean percent accuracy)	44	21

Results

Demographic Variables

Participants were not significantly different in age, *F*(3, 148) = 1.63, *p* = .185, or SES (as measured by mother's education), *F*(3, 149) = 2.24, *p* = .086 (Table 2). As an additional check of SES matching, non-verbal IQ did not differ between groups, *F*(3, 148) = .255, *p* = .857. Receptive vocabulary score was significantly higher in musicians compared to non-musicians, *t*(70) = 2.88, *p* < .005, *d* = .68, a finding that is consistent with previous literature demonstrating a link between musical training and verbal ability (Moreno et al., 2011; Schellenberg, 2006). In addition, receptive vocabulary was higher among monolinguals compared to bilinguals, *t*(70) = 3.47, *p* < .001, *d* = .82, a trend that has been demonstrated regularly in these groups (Ben Zeev, 1977; Bialystok & Craik, 2010). Within the musician group, there were no significant differences in mean years of musical experience between monolingual and bilingual musicians, *t*(80) = .33, *p* = .740, or mean age at which monolingual and bilingual musicians began training, *t*(79) = .26, *p* = .797. However, monolingual musicians spent significantly more hours per week practicing music at the time of participating in this study, compared to bilingual musicians, *t*(76) = 2.52, *p* = .014, *d* = 0.57.

Table 2.

Participant Characteristics. Mean (SD).

Variable	Musician		Non-Musician	
	Monolingual	Bilingual	Monolingual	Bilingual
Age (years)	21.5 (3.1)	22.5 (3.2)	22.6 (2.6)	21.5 (2.3)
SES (mother's education)	3.4 (1.1)	3.4 (1.4)	2.7 (1.3)	3.4 (1.3)
K-BIT-2 Vocabulary (raw)	51.0 (3.4)	49.2 (3.6)	49.7 (4.4)	45.0 (4.4)
K-BIT-2 Matrices (normed)	102.8 (22.3)	104.6 (14.7)	103.7 (15.2)	101.2 (12.5)
Musical Training (years)	12.0 (4.7)	12.4 (5.6)	-	-
Age Started Musical Training (years)	7.7 (2.9)	7.9 (3.5)	-	-
Weekly Musical Practice (hrs)	9.8 (7.0)	5.7 (7.3)	-	-

Note: SES = socioeconomic status. Mother's education ranged from 0 to 5 (0 = high school not completed, 1 = high school diploma, 2 = some college, 3 = college diploma, 4 = Bachelor's degree, 5 = graduate or professional degree).

Task Switching

Global switch cost. Global switch cost was calculated as the difference in mean reaction times (RTs) between non-switch trials from the single-task blocks (i.e., average of block 1 and 2 means) and non-switch trials in the mixed-task block. To explore how different levels of switch block type and response compatibility interact with music and language, a 2 x 2 x 2 x 2 (switch block type [non-switch trials in switch blocks, non-switch trials in non-switch blocks] x response compatibility [compatible, incompatible] x musician status [musician, non-musician] x language status [bilingual, monolingual]) repeated-measures ANOVA was run. Results (Table 3) showed a main effect of switch block type, *F*(1,

146) = 733.96, $p < .001$, $\eta_p^2 = .834$, with faster RTs on non-switch trials in single-task blocks ($M = 444$, $SE = 8$) versus non-switch trials in mixed-task ($M = 865$, $SE = 17$) blocks. A main effect of response compatibility, $F(1, 146) = 72.91$, $p < .001$, $\eta_p^2 = .333$, was also demonstrated, with faster RTs on compatible ($M = 630$, $SE = 11$) versus incompatible ($M = 679$, $SE = 11$) trials. Moreover, a significant interaction between musician status and switch block type was demonstrated, $F(1, 146) = 13.15$, $p < .001$, $\eta_p^2 = .083$ (Figure 1). Follow up *t*-tests revealed faster RTs for musicians versus non-musicians on non-switch trials in both mixed task, $t(148) = -4.48$, $p < .001$, [$M_{mus} = 788$, $SD = 192$ vs. $M_{n\text{-}mus} = 940$, $SD = 224$], and single task, $t(148) = -2.27$, $p = .025$, [$M_{mus} = 427$, $SD = 75$ vs. $M_{n\text{-}mus} = 463$, $SD = 112$], blocks.

Additionally, a significant interaction was demonstrated between switch block type and response compatibility, $F(1, 146) = 16.83$, $p < .001$, $\eta_p^2 = .103$. Follow- up paired samples *t*-tests revealed faster performance on non-switch versus switch blocks for both compatible, $t(149) = 23.45$, $p < .001$, [$M_{switch} = 823$, $SD = 226$ vs. $M_{n\text{-}switch} = 431$, $SD = 92$], and incompatible trials, $t(149) = 25.19$, $p < .001$, [$M_{switch} = 893$, $SD = 234$ vs. $M_{n\text{-}switch} = 456$, $SD = 102$]. Moreover, participants displayed faster performance for compatible versus incompatible trials for both switch, $t(149) = -6.62$, $p < .001$, [$M_{comp} = 823$, $SD = 226$ vs. $M_{incomp} = 893$, $SD = 234$], and non-switch blocks, $t(149) = -7.44$, $p < .001$, [$M_{comp} = 431$, $SD = 92$ vs. $M_{incomp} = 456$, $SD = 102$]. In terms of bilingualism, the results did not reveal any significant interactions between language status and other variables such as switch, compatibility, or musician status (*p*s > .21), and no main effects of language status were demonstrated ($p = .70$).

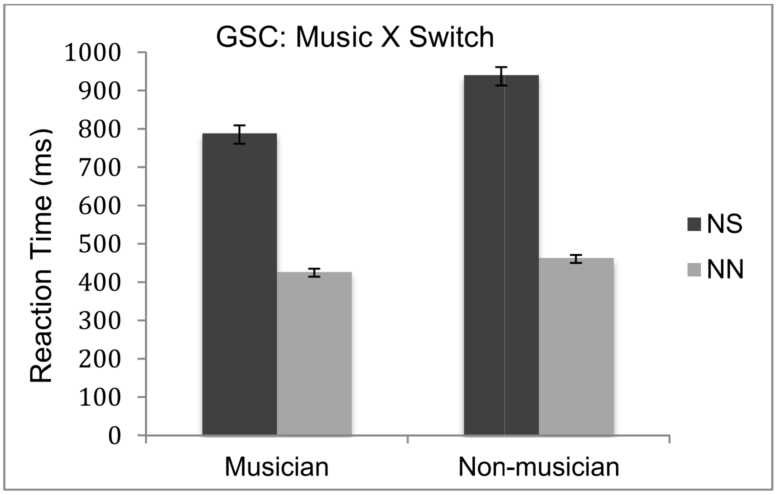

Figure 1. Music by switch interaction in Global Switch Cost (GSC). *Note:* NN = Non-switch trial in Non-switch (single task) block; NS = Non-switch trial in Switch (mixed task) block.

Local switch cost. Local switch cost was calculated as the difference in mean RTs between switch and non-switch trials in mixed task blocks. To explore how different levels of switch status and response compatibility interact with musician status and language status, a 2 x 2 x 2 x 2 (switch status [switch trials in switch blocks, non-switch trials in switch blocks] x response compatibility [compatible, incompatible] x musician status [musician, non-musician] x language status [bilingual, monolingual] repeated-measures ANOVA was run. Results (Figure 2) showed a main effect for switch status, $F(1, 146) = 44.49$, $p < .001$, $\eta_p^2 = .234$, with faster RTs on non-switch ($M = 865$, $SE = 17$) versus switch ($M = 924$, $SE = 17$) trials in a mixed-task block, and a main effect of response compatibility, $F(1, 146) = 119.03$, $p < .001$, $\eta_p^2 = .449$, with faster RTs on compatible ($M = 851$, $SE = 16$) versus incompatible ($M = 939$, $SE = 17$) trials. Findings also demonstrated a significant interaction between musician status and switch status, $F(1, 146) = 11.64$, $p = .001$, $\eta_p^2 = .074$. Follow up *t*-tests revealed faster RTs for musicians versus non-musicians on switch, $t(148) = -2.72$, $p = .007$, [$M_{mus} = 879$, $SD = 196$ vs. $M_{n\text{-}mus} = 969$, $SD = 207$], and non-switch trials, $t(148) = -4.43$, $p < .001$, [$M_{mus} = 788$, $SD = 192$ vs. $M_{n\text{-}mus} = 940$, $SD = 224$], in mixed task blocks. However, the size of local switch cost (difference between switch and non-switch trials in mixed task blocks) was larger for musicians than non-musicians. Thus, despite musicians' faster response times than non-musicians on both types of trials, they nevertheless took longer to switch between the two types of trials resulting in larger local switch costs.

Finally, a significant interaction was demonstrated between switch status and response compatibility, $F(1, 146) = 4.63$, $p = .033$, $\eta_p^2 = .031$. Follow-up paired samples *t*-tests revealed faster performance on non-switch versus switch trials for both compatible, $t(149) = -4.05$, $p < .001$, [$M_{switch} = 870$, $SD = 202$ vs. $M_{n\text{-}switch} = 823$, $SD = 226$], and incompatible trials, $t(149) = -6.68$, $p < .001$, [$M_{switch} = 971$, $SD = 228$ vs. $M_{n\text{-}switch} = 893$, $SD = 234$]. Moreover, participants displayed faster performance for compatible versus incompatible trials for both switch, $t(149) = -9.38$, $p < .001$, [$M_{comp} = 870$, $SD = 202$ vs. $M_{incomp} = 971$, $SD = 228$], and non-switch trials, $t(149) = -6.62$, $p < .001$, [$M_{comp} = 823$, $SD = 226$ vs. $M_{incomp} = 893$, $SD = 234$]. In terms of bilingualism, the results did not reveal any significant interactions between language status and other variables such as switch, compatibility, or musician status (*p*s > .26), and no main effects of language status were demonstrated ($p > .47$).

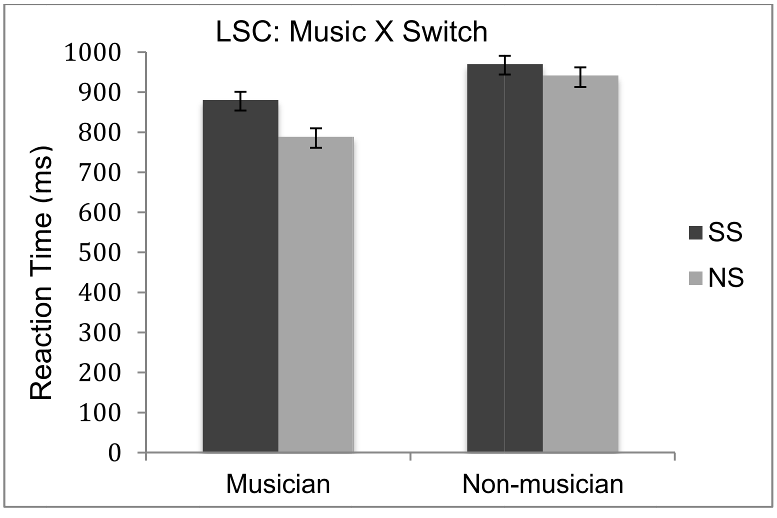

Figure 2. Music by switch interaction in Local Switch Cost (LSC). *Note:* SS = Switch trial in Switch (mixed task) block; NS = Non-switch trial in Switch (mixed task) block.

Table 3.

Mean Scores (SD) for Task Switch Measures by Participant Group.

Trial/Block Type			Non-switch trial in Non-switch block	Switch trial in Switch block	Non-switch trial in Switch block
Compatible	Musician	Monolingual	429 (77)	835 (207)	747 (206)
		Bilingual	403 (71)	903 (214)	764 (198)
	Non-musician	Monolingual	442 (111)	829 (179)	891 (255)
		Bilingual	451 (105)	926 (193)	916 (196)
Incompatible	Musician	Monolingual	450 (83)	915 (234)	805 (215)
		Bilingual	417 (71)	1007 (263)	843 (193)
	Non-musician	Monolingual	477 (118)	940 (199)	962 (258)
		Bilingual	481 (124)	1043 (189)	993 (216)

Percent error rates were calculated for global and local switch cost. A 2 x 2 x 2 x 2 (switch status [switch trials in switch blocks, non-switch trials in switch blocks] x response compatibility [compatible, incompatible] x musician status [musician, non-musician] x language status [bilingual, monolingual] repeated-measures ANOVA was run. There were no significant differences found between musician or language groups on accuracy for global or local switch cost (*p*s > .05). However, results showed main effects of compatibility on percent error rates for global switch cost, $F(1, 146) = 148.0$ $p < .001$, $\eta_p^2 = .503$, with higher percent error on incompatible ($M = 5.84$, $SE = .42$) versus compatible ($M = 1.16$, $SE = .17$) trials. Next, percent accuracy results for local switch cost demonstrated a main effect of switch, $F(1, 146) = 49.44$, $p < .001$, $\eta_p^2 = .253$, with higher percent error on switch ($M = 6.42$, $SE = .42$) versus non-switch ($M = 3.56$, $SE = .32$) trials. In addition, a main effect of compatibility, $F(1, 146) = 177.85$, $p < .001$, $\eta_p^2 = .549$, was demonstrated for local switch cost where percent error was higher on incompatible ($M = 8.65$, $SE = .56$) versus compatible ($M = 1.33$, $SE = .17$) trials. Finally, a switch by compatibility interaction was demonstrated for local switch cost, $F(1, 146) = 44.66$, $p < .001$, $\eta_p^2 = .234$. Follow-up paired samples *t*-tests revealed a significant difference in percent error between switch ($M = 11.30$, $SD = 9.31$) and non-switch ($M = 5.93$, $SD = 6.61$) trials but only for incompatible trials, $t(149) = 7.55$, $p < .001$. This difference in accuracy did not occur for compatible trials ($p > .27$). Results did not reveal any main effects or interactions for musician or language status for global (*p*s > .20) or local switch cost (*p*s > .19).

Dual Task Performance

The Krantz paradigm involves measuring accuracy on two tasks that are presented simultaneously: (1) following a moving dot on a computer screen with a mouse, and (2) responding to the letter X (which flashes intermittently with other letters) with a mouse click. To obtain a single accuracy measure for dual task performance that incorporated participants' performance on both tasks, an average dual task score was computed. First, *d*-prime was computed for responses to letter X, from hits (identifying letter X when X appears) minus false alarms (identifying letter X when another letter appears). Second, the average distance between the moving dot and the tracking box location was computed. Then, to obtain an average dual task score, the mean of the normalized scores for these measures was obtained. Since z scores, which have a mean of zero, are the result of subtracting a data point from the population mean and then dividing this value by the population standard deviation, this formula will by necessity produce both positive and negative values. Given that the average dual task score is composed of normalized z scores for both d-prime and average tracking error, this dual task score also contains both positive and negative values. For both tasks and modalities, d-prime for auditory and tracking for visual, raw scores were positive, on average, for each group.

A 2 x 2 (musician status [musician, non-musician] x language status [bilingual, monolingual]) between-subjects ANOVA showed a main effect of musician status, $F(3, 147) = 8.60$, $p = .004$, $\eta_p^2 = .055$, with musicians ($M_{mus} = .174$) outperforming non-musicians ($M_{n\text{-}mus} = -.156$) on the average dual task score (Figure 3). There was neither a main effect of language status nor an interaction between musician and language status (ps > .36).

The dual n-back is another paradigm that measures dual task performance. Accuracy data (Table 4) were provided for four conditions, including 1-back, 2-back, dual 1-back, and dual 2-back. Performance on the 1-back (the average of 1-back position and audio) was compared to the 2-back (the average of 2-back position and audio; and the dual 1-back was compared to the dual 2-back. First, a 2 x 2 x 2 (musician status [musician, non-musician] x language status [bilingual, monolingual] x difficulty level [1-back, 2-back]) repeated measures ANOVA was run which demonstrated a main effect of difficulty level, $F(3, 44) = 71.22$, $p < .001$, $\eta_p^2 = .62$, where participants had higher percent accuracy on 1-back ($M = 93$, $SE = 1.3$) compared to 2-back ($M = 68$, $SE = 3.1$). No interactions between difficulty level and musician or language status were demonstrated (ps > .12). Tests of between-subjects effects demonstrated a marginal interaction between musician and language status, $F(3, 44) = 3.34$, $p < .07$, $\eta_p^2 = .07$. However, follow up *t*-tests comparing 1 and 2-back performance did not demonstrate significant differences between musicians and non-musicians, nor between bilinguals and monolinguals (ps > .14).

A similar analysis was used to explore participants' performance on the dual n-back conditions. A 2 x 2 x 2 (musician status [musician, non-musician] x language status [bilingual, monolingual] x difficulty level [dual 1-back, dual 2-back]) repeated measures ANOVA was run. Results showed a significant main effect of difficulty level, $F(3, 44) = 221.84$, $p < .001$, $\eta_p^2 = .83$, where participants performed better on dual 1-back ($M = 86$, $SE = 1.6$) versus dual 2-back ($M = 44$, $SE = 2.8$). No interactions between difficulty level and musician or language status were demonstrated (ps > .35). Tests of between-subjects effects demonstrated a significant interaction between musician and language status, $F(3, 44) = 7.25$, $p = .010$, $\eta_p^2 = .14$ (Figure 4). A follow up *t*- test demonstrated higher accuracy in musicians ($M = 70$, $SD = 12$) compared to non-musicians ($M = 62$, $SD = 14$) on this task, $t(46) = -2.01$, $p < .05$. Additionally, a follow-up *t*-test for language status demonstrated marginally higher accuracy on this task in monolinguals ($M = 70$, $SD = 14$) relative to bilinguals ($M = 63$, $SD = 11$), $t(46) = 1.78$, $p < .08$[2].

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[2] Data analyses for all tasks were performed using more stringent classification criteria for bilingualism and musician status (Appendix A). The secondary analyses produced results consistent with those reported in the primary text.

Table 4.

Mean percent accuracy (SD) on the Dual N-back Task by Participant Group

Group	Difficulty Level			
	1-back	2-back	Dual 1-back	Dual 2-back
Monolingual musician (n = 19)	97 (5)	76 (21)	94 (5)	56 (22)
Monolingual non-musician (n = 9)	88 (10)	62 (24)	81 (17)	38 (15)
Bilingual musician (n = 10)	92 (11)	65 (18)	85 (11)	38 (15)
Bilingual non-musician (n = 10)	94 (8)	67 (19)	85 (12)	45 (16)

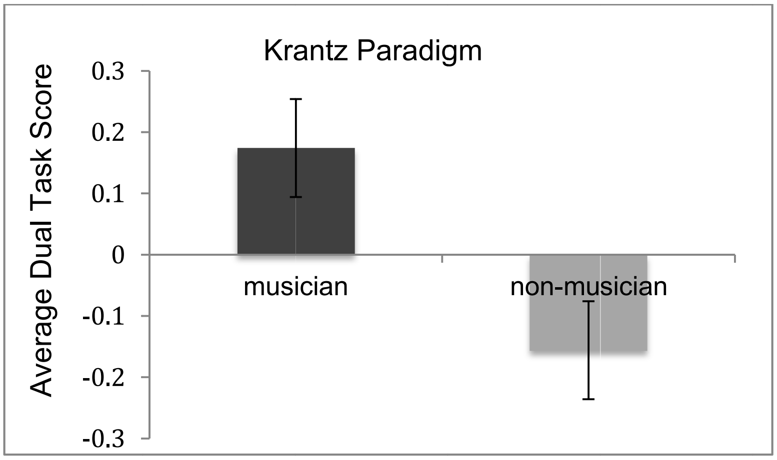

Figure 3. Main effect (*p* = .004) of musician status in Krantz paradigm.

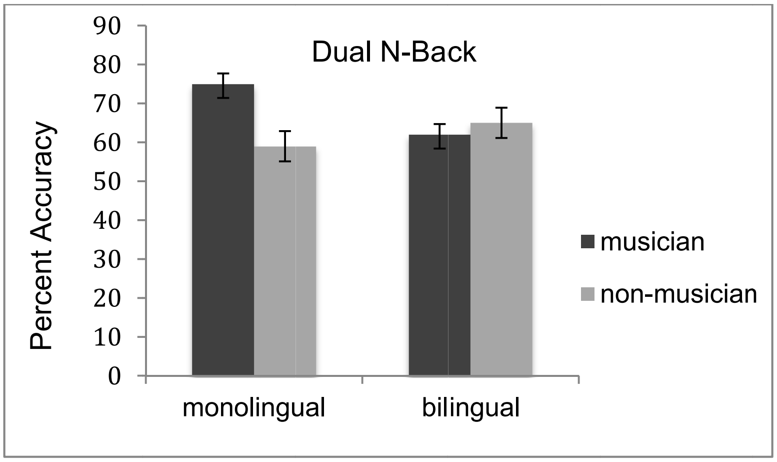

Figure 4. Language X Music Interaction in dual n-back.

Controlling for Hours of Weekly Music Practice

Given that a significant difference was found between monolingual and bilingual musicians on current weekly hours of music practice, it was important to account for this variable in the analysis. Consequently, participants were split into three groups, consisting of non-musicians, low practicing musicians, and high practicing musicians, and to classify musicians as high or low practicing, the median number of hours of weekly music practice was used to split the musician sample into two equal sized groups.

The results of the task switching analysis demonstrated that despite differences in hours of weekly music practice, there continued to be significant musician benefits on global switch cost compared to non-musicians. The findings showed a music by switch interaction, $F(1, 146) = 4.88$, $p = .009$, $\eta_p^2 = .063$, indicating that both high ($p = .001$) and low ($p = .001$) practicing musicians performed significantly better than non-musicians on both switch, $F(2, 147)= 9.98$, $p < .001$, and non-switch, $F(2, 147)= 3.36$, $p < .03$, blocks. Post-hoc comparisons using the Tukey HSD test indicated that the mean score for global switch cost in high practicing musicians was not significantly different from that of low practicing musicians ($p = .825$), but there was a significant difference between high practicing musicians (p = .003) and non-musicians, and low practicing musicians and non-musicians (p < .001).

Results for local switch cost were also consistent with initial findings. A music by switch interaction was maintained, $F(1, 146) = 5.53$, $p = .005$, $\eta_p^2 = .071$, indicating that both high (and low practicing musicians performed significantly better than non-musicians on non-switch trials, $F(2, 147)= 9.98$, $p < .001$. However, only low practicing musicians outperformed non-musicians on switch trials, $F(2, 147)= 4.05$, $p < .02$. Post-hoc comparisons using the Tukey HSD test indicated that performance of high practicing musicians was not significantly different from that of low practicing musicians (p = .984) on non-switch trials. In contrast, there was a significant difference between both high practicing musicians and non-musicians (p = .001), as well as low practicing musicians and non-musicians (p = .001) on non-switch trials. On switch trials, however, only a significant difference between low practicing musicians and non-musicians was demonstrated (p < .021). Moreover, a larger local switch cost was still present in both high and low practicing musicians compared to non-musicians.

The impact of hours of weekly music practice on dual task performance was assessed using the same technique demonstrated earlier. Results of this analysis maintained a main effect of musician status in that musicians outperformed non-musicians on dual task performance. However, a closer look at the groups using the Tukey HSD multiple comparison test indicated that it was the difference between high practicing musicians and non-musicians (p = .005) on dual task performance that was significant, and not between low practicing musicians and non-musicians (p = .162) or between high and low practicing musicians (p = .448). Due to insufficient sample size, this analysis was not performed on n-back data.

In summary, controlling for weekly hours of music practice did not change the pattern of findings for task switching or dual task performance. However, whereas the task switching results indicate that both high practicing and low practicing musicians perform significantly better than non-musicians on the task switch paradigm, findings for dual task performance indicate that only high practicing musicians perform significantly better on the dual task paradigm than non-musicians. This finding indicates the importance of degree or intensity of music practice in influencing cognitive functioning, particularly as it relates to dual task performance. As some studies suggest, intensity of musical practice may even be associated with structural brain differences among high practicing, low practicing, and non-musicians (Gaser & Schlaug, 2003).

Discussion

The present study investigated the association between musical training, bilingualism and two aspects of executive function, namely task switching and dual task performance. Our results demonstrated that long-term musical training was associated with benefits in task switching and dual task performance, while bilingualism was not related to such benefits. Moreover, there were no additive effects of musical training and bilingualism in these cognitive domains.

Task Switching

Our findings were in line with the prediction that musicians would show advantages on global switch cost compared with non-musicians. Results showed an interaction between musician and switch status, indicating that musicians produced significantly smaller global switch cost than non-musicians. Specifically, musicians were more efficient than non-musicians in processing non-switch trials in mixed-task blocks (~150 ms faster), demonstrating musicians' superior ability to maintain and manipulate competing information in memory, allowing for efficient global processing. Musicians' extensive training requires maintenance and manipulation of complex stimuli in memory, such as notes, melody, pitch, rhythm, dynamics, and the emotional tone of a musical piece, which may help them to develop superior control in order to respond efficiently to stimuli in an environment where both switching and non-switching components exist. This trend is consistent with studies demonstrating superior working memory in musicians relative to non-musicians (Lee et al., 2007).

Results also demonstrated significant main effects for switch and compatibility, and a significant interaction between switch and compatibility. This result is common in task switching studies, as individuals typically perform better on non-switch trials as compared with switch trials (Meiran, 2010), and better on compatible versus incompatible trials (Rogers & Monsell, 1995). Similarly, individuals performed better on non-switch, compatible trials compared to ones that involved switching or incompatible stimuli.

Results demonstrated a significant interaction between musician and switch status, indicating that musicians were more efficient than non-musicians on switch and non-switch trials within a mixed-task block. However, where switching was required between switch and non-switch trials, musicians demonstrated faster reaction times that also resulted in larger local switch costs. That is, despite musicians' faster response times than non-musicians on both types of trials, they nevertheless took longer to switch between the two types of trials resulting in larger local switch costs. Previous research has alluded to the connection between global switch cost and working memory (i.e., the maintenance and manipulation of task goals), as well as between local switch cost and inhibitory control. One possible explanation for the above trend may be that musicians' training may to a greater extent target and improve their working memory ability rather than inhibitory control, thereby resulting in lower global but not local switch costs.

Our findings demonstrate that musical training is related to improvements in task switching performance, specifically global switch costs. A few studies have indirectly assessed task switching ability between musicians and non-musicians using paradigms such as the Trail Making Test (Bugos et al., 2007; Hanna-Pladdy & MacKay, 2011), which do not permit measurement of both global and local switch costs. Our study is unique in that it directly examined the association between musical training and task switching ability using a valid and theoretically driven paradigm. Moreover, the findings for a music advantage in task switching are maintained even after controlling for variables such as hours of weekly music practice.

Our investigation of the relationship between bilingualism and task switching predicted bilingual benefits on global and/or local switch costs compared to monolinguals. Previous literature in this area has shown mixed results, with some studies supporting a global switch cost advantage and others supporting local switch cost advantages. However, most of these studies failed to control for SES or used tasks that were too easy for participants. The present study addressed some of these limitations by controlling for SES and utilizing a paradigm with appropriate task difficulty. Despite these improvements, the results did not support benefits of bilingualism in either global or local switch cost. This finding was unusual given that previous literature with theoretically strong tasks has shown benefits of task switching in bilinguals compared with monolinguals (Bialystok & Martin, 2004; Prior & MacWhinney, 2010). The absence of a bilingual advantage in task switching in the current study may be due to the type of paradigm used. In the current task switch paradigm, participants were provided written cues on each trial telling them to indicate “what number?” or “how many?” on the screen. Given that these cues were verbal as opposed to non-verbal, it is possible that they were more difficult for bilinguals to process. In fact, some research suggests that bilinguals have poorer lexical retrieval or access to vocabulary compared with monolinguals (Bialystok, 2009; Gollan, Montoya, Fennema-Notestine, & Morris, 2005). Therefore, it is possible that when bilinguals are exposed to tasks with verbal stimuli, the verbal components from one language might interfere with accessing vocabulary in another language, thereby causing delays in processing. If the absence of a bilingual effect is due to the nature of the paradigm used, where verbal components of the task led to performance deficits in the bilingual group, this limitation can be addressed empirically in future work by replacing the paradigm with one that is more valid.

Alternatively, it is possible that bilingualism may not confer cognitive advantages under certain conditions. For example, Morton and Harper (2007) argue that a potential confound in bilingualism research is SES, and that controlling for differences on this variable (as well as ethnicity) can attenuate the bilingual advantage. However, studies that have controlled for SES using child (Barac & Bialystok, 2012) and adult (Emmorey, Luk, Pyers, & Bialystok, 2008) populations continue to show a bilingual advantage.

Another possible explanation may be that bilingualism does not confer far transfer effects in cognition (Hilchey & Klein, 2011). For example, recent work by Paap & Greenberg (2013) suggests the importance of convergent validity between tasks measuring similar constructs. That is, if bilingual benefits are found on some cognitive tasks but not on others measuring similar constructs, this absence of convergent validity does not provide compelling evidence for domain-general benefits of executive processing in bilinguals.

Additive benefits of musical training and bilingualism on global and local switch costs were predicted in the present study. However, our data neither support nor refute this hypothesis. Given that we did not find a bilingual advantage, the absence of a combined effect may have been influenced by a lack of a bilingual effect in the first place. That is, it is possible that an additive effect may exist, but in this investigation there was not a bilingual effect to ‘add’ to the music effect. It is possible that the tasks used in the current study were not sensitive to differences between bilinguals and monolinguals, and thus, the potential combined effect of bilingualism and musician status could not be adequately examined. These results suggest that the combined effect of musical and language experience may be more complex than expected. This point is highlighted in a study by Cooper and Wang (2012), in which they compared the effects of linguistic and musical experience on Cantonese word learning. The findings demonstrated that native (Thai) tone language listeners who were musically trained did not perform better on (Cantonese) tone word learning relative to non-native (English) tone language listeners with or without musical experience, or native tone language listeners without musical training. Rather, English tone language listeners who were musically trained and Thai tone language listeners who were not musically trained performed better than Thai tone language listeners who were musically trained, as well as English tone language listeners without musical training. Given that having either musical experience or tone language background was shown to lead to performance benefits in this study, it was surprising that individuals with both musical and tone language experience performed worse than those with either of these skills. To explain this trend, the authors proposed that lower than expected performance among Thai listeners who were musically trained may reflect a conflict between the type of strategies they employ based on their musical and linguistic experience and the type of information that is presented to them. Although the results failed to support a combined effect of musical and linguistic experience on word learning, they suggest that contextual factors may play an important role in studies where additive effects of music and language are examined.

Dual Task Performance

Musical training involves simultaneous processing of multiple musical elements such as notes, melody, rhythm, and pitch. Given that musically trained individuals have become experts in carrying out these mental processes as a result of years of practice and training, musicians were predicted to perform better on tasks of dual task performance, which tap these abilities, compared to individuals with no musical training. The Krantz paradigm, a novel measure used to assess accuracy on two simultaneous tasks, was employed as a measure of dual task performance. As predicted, results demonstrated that musicians performed significantly better on the dual task paradigm compared to non-musicians.

Based on prior work demonstrating dual task performance benefits in bilinguals (Bialystok et al., 2006), the bilingual group was predicted to outperform the monolingual group on dual task performance. However, the predictions were not supported; no bilingual benefits were found on the Krantz paradigm.

A potential explanation for why no significant differences were found between bilinguals and monolinguals on the Krantz paradigm may have been due to the nature of the task, that is, the paradigm may not be sensitive enough to detect differences between bilingual and monolingual groups. Moreover, the two task components in the current dual task paradigm (i.e., tracking a moving dot and responding to the letter X) both involved visual stimuli and were similar in terms of task difficulty. This is in contrast to tasks used in other studies measuring dual task performance where the dual task paradigm used consists of a mixture of visual and auditory stimuli and where one task is typically more difficult than a second task (Bialystok et al., 2006; Jaeggi et al., 2003). For example, in Bialystok et al. (2006), bilinguals were more efficient than monolinguals in classifying visual but not auditory stimuli, and this level of efficiency was evident only on the easier of two tasks.

Another explanation for why differences were found between musician and non-musician groups, and not between bilingual and monolingual groups, on the Krantz paradigm may be that there are components of this task that tap into differential skills among the two groups. For example, musical training involves systematic learning of hand and eye movements and their coordination. Though some hand-eye coordination or movement is also involved in language learning, this usually occurs in the form of reading and writing text but does not occur to the same extent as in musical training where individuals are required to move and coordinate their hands and fingers regularly and in a very precise manner. This paradigm involved two tasks that both required considerable hand-eye movements and coordination, such as tracking a moving dot on the screen with a mouse while simultaneously attending to flashing letters and having to click the mouse in response to letter X. These skills may be especially developed in musicians, and may have helped musicians to excel on this particular dual task paradigm. In contrast, bilingualism involves simultaneous activation and manipulation of language modules, which require little motor movement. Thus, the current dual task paradigm may not have tapped this form of dual task process.

A second measure, called the dual n-back task, was employed to assess dual task performance in different modalities (i.e., auditory and visual). Participants demonstrated better performance on conditions with lower memory load (i.e., 1-back and dual 1-back) than those with higher memory load (i.e., 2-back and dual 2-back), a finding consistent with previous research (Jaeggi et al., 2003). Within subjects analyses for the n-back and dual n-back did not show any interactions between difficulty level and musician or language status. However, between-subjects analyses for the dual n-back demonstrated an interaction between musician and language status, where musicians outperformed non-musicians and monolinguals appeared to show an advantage over bilinguals, though the effect was marginal. What these results imply is that being a musician contributes to higher accuracy scores on dual task performance, and bilingualism does not contribute to this effect. The findings in support of a musician advantage in dual task performance is consistent with our predictions and with literature suggesting far transfer effects of musical training on cognition. However, contrary to our predictions, the findings did not support a bilingual advantage in dual task performance. It must be acknowledged that the literature investigating the relationship between bilingualism and dual task performance is scarce. This may be due to a lack of significant findings connecting these domains, to a lack of theoretically valid paradigms to test these concepts, or due to the possibility that this connection simply does not exist. What is clear is that further investigation is needed in order to make definite claims regarding the relationship between bilingualism and dual task performance. Aside from the above justifications, the lack of findings found between these domains may also be due to methodological limitations of the current study.

Limitations

A few limitations to this study should be considered. First, our study consisted of a cross-sectional design and was correlational in nature. As such, it is possible that the findings may be a result of other factors that were not controlled given this type of design, such as motivation or personality. For example, it has been suggested that improvements in cognitive abilities may be due to motivation or personality traits of individuals who pursue music rather than a result of musical training in itself (Corrigall, Schellenberg, & Misura, 2013). Second, we used samples of experienced adults. Despite our efforts to match demographic background and IQ, there may have been characteristics or attributes that were not equivalent across groups. Ideally, future studies examining the relationship between musical training, bilingualism, and cognition will utilize randomized controlled designs, where participants are randomly assigned to groups, and tested before and after training to ensure that any differences in performance can be attributed to the effects of training. Alternatively, investigators may want to examine musical training or bilingualism on a continuum, rather than as discrete variables. Taken together, the present investigation revealed an association between musical training and enhanced dual task performance and global switch costs, with musicians outperforming non-musicians.

Overall Summary

The current findings suggest that musical training is associated with advantages in task switching ability and dual task performance. Contrary to expectations, bilingualism was not associated with benefits in task switching or dual task performance relative to monolinguals, and being both a bilingual and a musician did not appear to offer added benefits in these cognitive domains. Future studies should devote attention to higher-level cognitive benefits of musical training, including complex forms of executive function benefit.

Appendix A

In order to establish that sample selection criteria for the current study was valid and comparable to that of other studies in the field (Bidelman et al., 2013) without influencing the reliability of our results, we conducted further analyses using more stringent classification criteria for bilingualism and musician status. For example, bilinguals in the Bidelman et al. (2013) sample consisted of only fluent bilinguals (i.e., they were able to converse fluently, and they actively used two languages every day), and musicians consisted of instrumentalists who played regularly, had at least 10 years of training beginning at or before the age of 13, and had a least 5 years of formal lessons. A total of 57 subjects in our sample did not meet these criteria and were removed from the sample. With the exception of the dual n-back task, where there was insufficient sample size to conduct a follow-up analysis, the findings produced results consistent with those reported in the main results section of the study.

Task Switching

Global Switch Cost. A 2 x 2 x 2 x 2 (switch block type [non-switch trials in switch blocks, non-switch trials in non-switch blocks] x response compatibility [compatible, incompatible] x musician status [musician, non-musician] x language status [bilingual, monolingual]) repeated-measures ANOVA was run. Results showed a main effect of switch block type, $F(1, 96) = 443.37, p < .001, \eta_p^2 = .822$, with faster RTs (in milliseconds) on non-switch trials in single-task blocks versus non-switch trials in mixed-task blocks. A main effect of response compatibility, $F(1, 96) = 58.40, p < .001, \eta_p^2 = .378$, was also demonstrated, with faster RTs on compatible versus incompatible trials. Moreover, a significant interaction between musician status and switch block type was demonstrated, $F(1, 96) = 8.37$, $p = .005, \eta_p^2 = .080$. Follow up tests revealed faster RTs for musicians versus non-musicians on non-switch trials in mixed task blocks, $t(94) = -4.35, p < .001$, and marginally faster RTs for musicians versus non-musicians on non-switch trials in single task blocks, $t(94) = -1.88, p = .063$.

There was a significant interaction between switch block type and response compatibility, $F(1, 96) = 19.57, p < .001, \eta_p^2 = .169$, with faster performance on non-switch versus switch blocks for both compatible, $t(99) = -19.47, p < .001$, and incompatible trials, $t(99) = -21.07, p < .001$. Moreover, participants displayed faster performance for compatible versus incompatible trials for both switch, $t(99) = -6.06, p < .001$, and non-switch blocks, $t(99) = -6.58, p < .001$. The remaining interactions were all non-significant (ps > .08).

Local Switch Cost. A 2 x 2 x 2 x 2 (switch status [switch trials in switch blocks, non-switch trials in switch blocks] x response compatibility [compatible, incompatible] x musician status [musician, non-musician] x language status [bilingual, monolingual] repeated-measures ANOVA was run. Results showed a main effect of switch status, $F(1, 96) = 24.70, p < .001, \eta_p^2 = .205$, with faster RTs on non-switch versus switch trials, and a main effect of response compatibility, $F(1, 96) = 82.58, p < .001, \eta_p^2 = .462$, with faster RTs on compatible versus incompatible trials. Findings also demonstrated a significant interaction between musician status and switch status, $F(1, 96) = 6.11, p = .015, \eta_p^2 = .060$. Follow up tests revealed faster RTs for musicians versus non-musicians on switch, $t(98) = -2.71, p = .008$, and non-switch trials, $t(94) = -4.35, p < .001$, in mixed task blocks. However, the size of local switch cost (difference between switch and non-switch trials in mixed task blocks) was larger for musicians than non-musicians. Thus, despite musicians' faster response times than non-musicians on both types of trials, they nevertheless took longer to switch between the two types of trials resulting in larger local switch cost. The remaining interactions were all non-significant (ps > .07).

Dual Task Performance

Krantz Paradigm. Consistent with our previous findings for this task, the results of a 2 x 2 (musician status [musician, non-musician] x language status [bilingual, monolingual]) between-subjects ANOVA showed a main effect of musician status, $F(3, 96) = 4.89, p = .029, \eta_p^2 = .048$, with musicians ($M_{mus}$= .258) outperforming non-musicians ($M_{n\text{-}mus}$ = -.097) on the average dual task score. However, there was neither a main effect of language status, nor an interaction between musician and language status (*p*s > .32).

n-Back Task. After removing subjects who did not meet the more stringent classification criteria for musician and language status, the sample size for this task was not large enough to run additional data analyses.

In summary, even when a more stringent classification for bilingualism and musician status was used, the results of follow-up analyses were highly consistent with the original findings. Musician benefits continued to be found for both task switching and dual task performance, while no language benefits or combined language and musician benefits were discovered.

Table 5.

Correlations for Executive Function Tasks, IQ, and Musical/Language Experience (Full Sample).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. IQ-M	-	.01	**.29****	.03	**.30***	**.29***	**.27***	**-.21****	-.07	-.08	**-.21***	**-.17***	-.14	-.01	-.06	.04
2. IQ- V		-	.15	.02	.19	-.10	.07	.06	-.13	-.13	.12	-.11	-.11	**-.38****	.09	.11
3. Krantz			-	.17	**.45****	**.42****	**.50****	**-.18***	**-.34****	**-.35****	**-.20***	**-.36****	**-.40****	-.08	.18	.22
4. 1-back				-	**.42****	**.46****	**.31***	-.05	-.18	-.01	-.09	-.18	-.09	.08	.18	.05
5. 2-back					-	**.46****	**.73****	-.05	-.26	-.23	-.09	**-.33***	**-.33***	-.10	-.09	-.04
6. D-1-back						-	**.54****	-.06	-.18	-.07	-.12	-.22	**-.30***	-.15	.15	-.04
7. D-2-back							-	-.01	-.24	-.24	-.06	**-.35****	**-.40****	-.15	.06	.08
8. NNRTC								-	**.42****	**.46****	**.92****	**.41****	**.44****	-.03	**.25***	.03
9. NSRTC									-	**.78****	**.42****	**.84****	**.82****	.02	.14	-.18
10. SSRTC										-	**.45****	**.74****	**.82****	.01	**.23***	-.11
11. NNRTI											-	**41****	**.43****	-.05	**.26***	.01
12. NSRTI												-	**.81****	.08	-.02	-.19
13. SSRTI													-	.06	.06	**-.22***
14. Bil-level														-	**-.27***	.08
15. M-prac															-	**.27***
16. M-YrsTrng																-

Notes: *$p < .05$, **$p < .01$. IQ-M= KBIT matrices; IQ-V= KBIT verbal; Krantz= krantz dual task performance paradigm; 1-back= n-back (average auditory and position score for 1-back); 2-back= n-back (average auditory and position score for 2-back); D-1-back= dual n-back (average auditory and position score for dual 1-back); D-2-back= dual n-back (average auditory and position score for dual 2-back); NNRTC= RT for non-switch trials in non-switch blocks (compatible); NSRTC= RT for non-switch trials in switch blocks (compatible); SSRTC= RT for switch trials in switch blocks (compatible); NNRTI= RT for non-switch trials in non-switch blocks (incompatible); NSRTI= RT for non-switch trials in switch blocks (incompatible); SSRTI= RT for switch trials in switch blocks (incompatible); Bil level= level of self assigned bilingualism; M-prac= weekly hours of musical practice; M-YrsTrng= years of formal musical training.

Chapter 4: General Discussion

Bilingualism and musical training are skills developed through regular practice and exposure. These forms of training or experience are associated with improvements in various components of cognition, including working memory, inhibition, task switching, and dual task performance. While there is some evidence in support of the association between bilingualism, musical experience, and cognitive advantages, there is a need for valid and reliable methods in studies that examine the links between these domains, such as the need to control for age and socio-economic factors, use of valid and theoretically motivated tasks, and the need to measure far transfer in relation to more than one executive function domain given the complexity and interconnectedness of this concept. The current research examined the association between bilingualism, musical training, and executive function, while taking the above concerns into consideration. Moreover, we examined the potential additive effects of bilingualism and musical training on cognition, a subject that has been largely ignored in the literature.

Summary of Major Findings

Working memory and inhibition. This paper investigated the association between bilingualism, musical training, and two areas of executive function, namely working memory and inhibition. The results showed that musical training was associated with advantages in executive and phonological working memory, as well as interference suppression, but not response inhibition. Surprisingly, a bilingualism advantage in working memory or inhibitory control was not demonstrated, and a combined bilingualism and musical training effect was not found.

These findings provide further support for research demonstrating the links between musical training and improvements in executive function, particularly working memory and interference suppression (Bialystok & DePape, 2009; George & Coch, 2011; Lee et al., 2007). In contrast, the current findings for bilingualism and executive function further highlight the inconsistencies in the bilingualism literature, as discussed by Paap & Greenberg (2013).

Further, given the association found between musical training and advantages in interference suppression, but not response inhibition, the findings provide support for the non-unitary theory of inhibitory control (Friedman & Miyake, 2004).

Task switching and dual task performance. This paper also examined the association between bilingualism, musical training, and executive function. However, the two cognitive domains of interest were task switching and dual task performance. Consistent with our previous findings, musical training was found to be associated with advantages in executive function. Moreover, a bilingualism advantage was not demonstrated in either domain of executive function, and a combined effect of bilingualism and musical training was not detected.

The findings provide further support for the association between musical training and executive function, particularly task switching and dual task performance, two areas that have received little or no attention in the musical training literature. This research is novel in that it is the first to examine the association between musical training and dual task performance. Similarly, the link between bilingualism and dual task performance has not been adequately examined in the past. Thus, this study contributes to the literature on bilingualism, musical training, and executive function by examining novel and under-examined constructs in the field.

Absence of a Bilingual Effect

Based on previous literature demonstrating a bilingual advantage in cognition, we predicted that bilingualism would contribute to benefits across executive function domains, including working memory, inhibitory control, task switching, and dual task performance. However, our findings did not support these predictions. There may be several reasons for why there was an absence of bilingual benefits across all of the executive function areas we examined. First, our sample was not randomized and our study was correlational in nature, two design limitations that may have introduced confounds. Second, our tasks may have not been complex or sensitive enough to tap into bilingualism benefits.

Third, perhaps under certain conditions or parameters, bilingualism benefits may be absent. For example, bilingualism can be assessed in terms of both proficiency and usage of two languages (Luk & Bialystok, 2013). It is possible that benefits may be found in certain bilingual groups (e.g., high proficiency and high usage) while absent or less robust in others (e.g., high proficiency, low usage).

While our findings were inconsistent with the dominant bilingualism literature (Barac & Bialystok, 2012; Bialystok et al., 2004; Bialystok & Shapero, 2005; Costa et al., 2009), there have been others who have also failed to replicate the bilingual advantage under certain conditions (Morton and Harper, 2007) or who question the reliability of this advantage (Paap & Greenberg, 2013; Hilchey & Klein, 2011). The inconsistencies regarding the presence and/or robustness of the bilingual advantage may be partly due to a file drawer issue where researchers face challenges in publishing null findings. Perhaps if bilingual researchers had a more inclusive literature source to refer to, they could better determine under which specific conditions bilingualism either produces or fails to produce benefits. Moreover, researchers need to provide more detail regarding the type of bilingualism that comprises their sample. It is misleading to make claims in support of a general bilingual advantage, when this advantage only exists in a particular sub-group of bilinguals.

Another question that might be raised is why we found a musical training advantage but not a bilingual advantage. It is possible that while musical training provides domain-general benefits in multiple areas of cognition and leads to more robust effects, bilingualism may provide benefits in specific areas of cognition, and it’s effects may be more context-specific.

Practical Implications

The current research may have implications for cognitive development and rehabilitation in children, clinical, and older populations. The literature on far transfer effects of musical training has demonstrated advantages in cognitive function in children (Fujioka et al., 2006) and older adults (Hanna-Pladdy & MacKay, 2011), after receiving as little as four weeks of training (Moreno et al., 2011). Though further research is necessary to substantiate the long-term benefits of this training, it is nevertheless indicative of the positive influence of this type of training on cognition. Should older adults and children engage in continued training, they might gain long-term benefits.

Moreover, this type of skill training might be beneficial for clinical populations, such as individuals with ADHD (Shaffer et al., 2001), brain injury (Thaut et al., 2009), dementia (Zendel & Alain, 2012), and addictions (Winkelman, 2003), as a form of rehabilitation or prevention. In contrast to recent controversial brain training regimens, such as working memory training (Jaeggi et al., 2008; Owen et al., 2010), activities such as musical training may be more enjoyable for these populations while providing the additive benefit of improved cognition. Thus, participants might be more likely to continue training than if they were engaged in other types of less motivating brain improvement programs (Diamond, 2012).

This research is also important in helping determine the links between music, language, and the brain. Though further work in this area is required, it is nevertheless a step forward in determining whether musical training and bilingualism experience, both individually and in combination, affect cognitive processing. While our study did not find a combined musical training and bilingualism benefit, it does not mean that the link between music and language does not exist in the brain. Further research is needed in examining these constructs using both behavioural and physiological measures of executive function.

Finally, research examining the association between musical training and bilingualism on executive function is also relevant to researchers who study executive function in university or college samples. For example, participants with bilingualism experience and/or musical training may have qualities that favor performance on executive function measures, which might bias a study’s outcome. Therefore, our work can help researchers identify whether bilingualism or musical training or combined experiences need to be controlled or accounted for in research studies.

Limitations of the Current Studies

The research discussed in this paper further our understanding of the associations between bilingualism, musical training, and executive function. However, some limitations must be acknowledged. First, our study consisted of a cross-sectional design, which precludes causal assertions between skills training and cognitive advantages. Despite our efforts to control for variables, such as age, SES, and other demographic indicators that would potentially influence the findings, there still remains the possibility that other extraneous variables, such as motivation and personality, impacted our results.

Second, our sample consisted of experienced musicians and bilinguals who were required to meet certain inclusion criteria related to music and language ability. Despite attempts to match certain variables, there may have been other characteristics and attributes that were not equivalent across groups. Ideally, participants should be randomly assigned to groups and tested in randomized controlled studies, where any differences across groups can be attributed to the effects of training.

Third, task selection may have impacted the pattern of results. For example, in our investigation of bilingualism and musical training effects on working memory and inhibition, our working memory tasks may have required verbal knowledge or fluency, which are typically more demanding for bilinguals than monolinguals (Bialystok, 2009). As such, we observed higher scores in monolinguals than bilinguals on the reading span. Moreover, it is possible that our tasks were not sufficiently challenging to pick up on differences between bilinguals and monolinguals. Previous studies have noted that the bilingual effect is best demonstrated in tasks that require more demanding executive function requirements (Morales, Calvo, & Bialystok, 2013).

Finally, as previously noted, executive function measures typically suffer from task impurity and poor convergent validity. Given that our results are based on participants' performance on particular tasks, our findings are only as good as the tasks we use. Despite efforts to use the most valid, reliable, and relevant cognitive tasks in the current study, we cannot exclude the possibility that these measures tap into other constructs than what they are meant to measure, or that tasks meant to measure the same construct represent different abilities.

Suggestions for Future Research

In light of the limitations outlined above, future research should take the following into consideration. First, in order for causal claims to be made about the impact of training on cognition, longitudinal or randomized controlled studies are needed, which account for demographic and influential variables. Second, great effort should be made to choose tasks that are appropriate for the sample being studied and which provide sufficient task difficulty. Third, research into the validity and reliability of current cognitive tasks is necessary, as are efforts to develop cognitive tasks that are pure measures of a single construct and which provide better ecological and convergent validity than existing paradigms. Moreover, given difficulties in obtaining pure cognitive measures and limitations with ecological validity, future research might benefit from investigating the impact of skill training on behaviour using measures other than performance-based executive function measures, which may not be necessarily correlated with improvements in real life situations (Toplak, West, & Stanovich, 2013). This assessment can be done using behavioural rating scales and other measures that examine the impact of training outside the lab, such as on academic performance. Fourth, in order to obtain findings that are better representative of the population, future studies should examine types of skill/experience, such as bilingualism and musical training, on a continuum rather than as discrete variables. Finally, given the absence of a bilingual advantage in our study and inconsistencies in the current literature, it is recommended that future research examine bilingualism under varying conditions (e.g., studying the influence of language proficiency and usage in greater detail) and promote the exchange or sharing of null findings in order to enrich the state of the current bilingualism literature.

General Conclusion

In conclusion, the current studies demonstrate an association between musical training and advantages in executive function, including working memory, interference suppression, task switching, and dual task performance. These findings further our understanding of the different domains of cognition that are associated with musical training, including areas that have not been examined thus far. Given the growing literature on far transfer and the potential practical applications of skills training, it is important to understand which types of training have the most impact on cognition and to identify areas of training, such as bilingualism, that require further investigation.

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Appendices

Appendix A

Musical Training and Cognition
Informed Consent Form

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Principal Researchers: Nicholas Cepeda, Jay Rahn, Linda Moradzadeh, and Charisa Ng

This research is about the effects of receiving several years of musical training on higher-level thinking. For this study, you will be asked to complete a series of activities lasting approximately 2 hours. Activities will involve recalling various properties of stimuli, such as a list of words, or will measure speed at making responses, for instance identifying the shape or color of a stimulus.

You will be awarded $30 for your time and participation in this study. There are no risks from participation. Participation is voluntary. You may decline to participate in any part of the study or refuse to answer any questions. There is no penalty for early withdrawal, and you will still receive promised benefits. Rest breaks will be provided. Your decision to not participate will have no influence on your relationship with the researchers, York University, or with any other group associated with this project, either now or in the future.

The information you provide will be safely stored in a locked cabinet in a secure office and/or on a password protected computer. All information collected will be strictly confidential, and data will be linked only to a random ID number; all questionnaire responses will be made anonymous as soon as practicable. Confidentiality will be provided to the fullest extent possible by law. Only the student researchers and supervisors involved in data collection, coding, and analysis will see them. Your responses will be combined with those of other students in a summary report, and individual students will not be identified. Your information will be stored for a minimum of 5 years and archived thereafter in a locked facility and/or on a secure computer. If you withdraw from the study, all associated data collected will be immediately destroyed.

Your signature indicates that you have read this consent form, understand its contents, and agree to participate in this research study. If you wish further information, please contact Dr. Nicholas Cepeda at ncepeda@yorku.ca. This research has been reviewed by the Human Participants Review Sub-Committee, York University's Ethics Review Board and conforms to the standards of the Canadian Tri-Council Research Ethics Guidelines. If you have any questions about the ethics review process, or about your rights as a participant in this study, you may contact Ms. Alison Collin-Mrakas, Manager; Research Ethics; 5th floor York Research Tower; York University (416-736-5914 or acollins@yorku.ca).

I,_________________________________, consent to participate in the study Musical Training and Cognition. I have understood the nature of this project and wish to participate. I am not waiving any of my legal rights by signing this form. My signature below indicates my consent.

_________________________________ ____

Participant's name (please print) Signature

_________________________________ ____

Experimenter's name (please print) Signature

____

Date

YORK UNIVERSITÉ UNIVERSITY

Appendix B

Participant Background Questionnaire

Sex: M F Hand: L R Today's date: ____________________

University Major: ______________ Date of Birth: ____________________

Year of Study : ________ GPA: ____________

Starting from grade 1, how many years of schooling do you have? ____________

What is the highest degree you have earned? __________________________

Do you use a computer regularly? Yes No

Do you play video games? Yes No

How many hours per week do you play video/computer games? ________________

Do you have hearing problems? Yes No

If Yes, do you wear a hearing aid? Yes No

Do you have vision problems? Yes No

If Yes, do you wear glasses? Yes No

Is your vision corrected to 20/20 with glasses? Yes No

Are you colour blind? Yes No

If Yes, what type? __________________

Language Background

Were you born in Canada? Yes No

If No, where were you born? _______________When did you move to Canada? _________________

Have you ever lived in a place where English is not the dominant communicating language? Yes No

If Yes, where? ______________________For how long? __________________________

Do you speak any languages in addition to English? Yes No

If Yes, please specify the language(s): ____

What is the first language you learned? _______________________________

What is the second language you learned? _____________________________

At what age did you learn your second language? _______________________

Where did you learn your second language?
School (formal lessons) ______Years_______
School (no formal lessons)______Years______
Informally (home/community)_____Years______
All of the above_______Years______

At what age did you begin to use your second language regularly? _________________

At what age did you begin to use both languages actively? _______________________

How would you rate your understanding of the **Second Language**?

Poor Fair Good Very good Excellent N/A

How would you rate your speaking ability in this **Second Language**?

Poor Fair Good Very good Excellent N/A

Do you use **both** languages on a daily basis? YES NO N/A

While at home, how often do you **switch** between using the two languages?

Never Rarely Sometimes Frequently Very frequently N/A

Where do you use the other language?__________________________

Home School Family Other N/A

How often do you use the other language?_____________________

Daily Weekly Monthly Occasionally Other N/A

Musical Background

Instrument	Years of lessons	Years since last lessons	Years playing	Years since last played regularly

Have you ever taken music lessons (instrumental or voice)? Yes No If Yes, please indicate:

Instrument	Years of lessons	Years since last lessons	Years playing	Years since last played regularly

How often do you practice (hours per week)? ____________ Have you ever taken instrumental music in school? Yes No If Yes, please indicate:

Have you ever studied music theory? Yes No

If Yes, how extensively? (i.e. levels achieved or courses taken)

____

____

How would you rate your sight reading abilities?

Beginner Fair Good Very Good Expert

Have you ever had ear training? Yes No

Please describe your musical activities (singing, playing instruments, dancing, listening to music, etc.)

Art Form (Painting, Drawing, Sculpture)	Years of lessons	Years since last lessons	Years involved	Years since last regular involvement
______________	____________	____________	____________	____________
______________	____________	____________	____________	____________

____

____

How would you rate your abilities?

Beginner Fair Good Very Good Expert

Extracurricular Activities Background

Have you ever trained in the following extracurricular activities (circle all that apply):

Visual Art Dance/Theatre Physical Activities

Visual Art

If you have taken visual art lessons, please answer the following:

Private Lessons ______ Group Lessons ______ School Instruction _______

Do you practice at home between lessons? Yes No

How many minutes do you practice each day? ______ minutes

How would you rate your abilities?

Beginner Fair Good Very Good Expert

Dance/Theatre

If you have taken dance or theatre lessons, please answer the following:

Private Lessons ______ Group Lessons ______ School Instruction ______

Type of Dance/Theatre (Ballet, Jazz, Modern, Composition)	Years of lessons	Years since last lessons	Years involved	Years since last regular involvement
__________________	______________	_______________	______________	_______________
__________________	______________	_______________	______________	_______________

Do you practice at home between lessons? Yes No

How many minutes do you practice each day? ______ minutes

How would you rate your abilities?

Beginner Fair Good Very Good Expert

Physical Activities

If you have taken formal physical activity training, please answer the following:

Private Lessons/Practices ______ Group Lessons/Practices ______

Do you practice at home between lessons? Yes No

How many minutes do you practice each day? ______ minutes

How would you rate your abilities?

Beginner Fair Good Very Good Expert

Type of Physical Activity (Hockey, Football, Basket Ball, Gymnastics, Figure Skating, Martial Arts)	Years of lessons/training	Years since last lessons/training	Years playing	Years since last played regularly
__________________	______________	_______________	_____________	______________
__________________	______________	_______________	_____________	______________

Please indicate the highest level of education for each parent:

<u>**Mother**</u>	<u>**Father**</u>
_____No high school diploma	_____No high school diploma

_____High school graduate	_____High school graduate
_____Some college	_____Some college
_____College diploma	_____College diploma
_____Bachelor's Degree	_____Bachelor's Degree
_____Graduate or professional degree	_____Graduate or professional degree

Please indicate your parents' occupation?

Mother______________ Father__________________

What is the average annual family income?

_______Under $14,999

_______$15,000 - $29,000

_______$30,000 - $44,999

_______$45,000 - $59,999

________$60,000 - $79,999

________$80,000 - $99,999

________$100,000 - $129,999

________$130,000 - $159,999

________$160,000 - $179,000

________$180,000 - $199,000

________+$200,000

Please answer the following questions about your **health.**

How would you rate your overall health on a scale of 1-5 (1 = poor, 5 = excellent)? _________

Do you exercise on a regular basis? __________________

If yes, how often? ___________What kind of activity/exercise do you do? ______________________

- **These categories allow comparisons to many national databases, especially national health databases.**

Thank you for completing the questionnaire :)

Appendix C

Language and Social Background Questionnaire (LSBQ)

How many years have you been registered at the university? ________________________________

Have you earned any other degree or diploma prior to the current degree? Yes No

If yes, what is the degree/diploma and how long did it take to complete it? ________________

On average, how many hours do you spend on working on a computer every day? ________________

Do you play video games? Yes No If yes, how many hours do you play in a week? ________

Do you speak any languages in addition to English? If yes, please specify the language(s)

____

Do you need to speak/read/write in another language at work/school? Yes No

Have you ever lived in a place where your second language is the dominant communicating language?

Yes No

If yes, where and for how long? ____

Were you born in Canada? Yes No (If yes, skip the next two lines)

If No, where were you born? ____

when did you first move to Canada? ______________________________________

What is your first language? ____

What is your second language? ____

Do you speak any other language(s)? Yes No

If yes, what are the language(s)?____

In each of the scales below, indicate the proportion of use for English and your other language in **daily life**. These scales are set up for different activities at home or at school/work. On one end of the scale, you have 100 which indicates that the particular activity in that environment is carried out in ALL ENGLISH. On the other end, you have 0 which indicates that you do not use English at all to carry out the activity.

At

0 100

Speaking No English ●——|——|——|——● All English

0 100

Listening No English ●——|——|——|——● All English

0 100

Reading No English ●——|——|——|——● All English

0 100

Writing No English ●——|——|——|——● All English

0 100

Watching TV No English ●——|——|——|——● All English

N/A

0 100

Listening to radio No English ●——|——|——|——● All English

N/A

At Work/School

0 100

Speaking No English ●——|——|——|——● All English

0 100

Listening No English ●——|——|——|——● All English

0 100

Reading No English ●——|——|——|——● All English

0 100

Writing No English ●——|——|——|——● All English

Relative to a native speaker's performance, rate your proficiency level in a scale of 0 – 100 for the following activities conducted in your first and second language.

Language # 1: ____________________ (please indicate)

0 100

Speaking Non-native- like ●———|———|———|———● Native-like

0 100

Understanding Non-native-like ●———|———|———|———● Native-like

(Comprehension)

0 100

Reading Non-native- like ●———|———|———|———● Native-like

0 100

Writing Non-native- like ●———|———|———|———● Native-like

Language # 2: ____________________ (please indicate)

0 100

Speaking Non-native- like Native-like

0 100

Understanding Non-native-like Native-like
(Comprehension)

0 100

Reading Non-native- like Native-like

0 100

Writing Non-native- like Native-like

Additional questions about your second language:

Where did you learn your second language? Home School Community Work

At what age did you first start **learning** your second language **informally at home**? ____________

At what age did you first start **learning** your second language **formally at school**? _____________

At what age did you first start **using** your second language actively?________________________

Did you attend a school that primarily used your second language as medium of instruction?

Yes No

What language do you do mental arithmetic in? ________________________________

Global self-assessment:

Overall, how would you describe your levels of bilingualism?

Not bilingual		Non-fluent bilingual		Fluent bilingual
1	2	3	4	5

1 – speak predominantly one language

- – only know a few vocabulary in the other language.

2 – weak bilingual

- – know enough to carry out some conversation to a very limited extent (use key words with not much grammar)
- – need to listen to sentences more than once before understanding.

3 – unbalanced bilingual

- – able to carry out basic conversation with minor grammatical errors
- – without the other speaker repeating the sentence
- – has difficulty producing a fluent conversation.

4 – practical bilingual

- – can carry out conversation fluently
- – does not use the second language everyday

5 – fluent bilingual

- – able to converse fluently and actively use two languages everyday
- – lived abroad in a community that has English as the dominant language

Experimenter's judgment: __________