Open University of Cyprus

Faculty of pure and applied sciences

Postgraduate (Master's) Programme of Study *Cognitive Systems*

Postgraduate (Master's) Dissertation

Evaluating the Relationship of Music Training and Bilingualism/Multilingualism and Their Contribution to Executive Functions in Healthy Adults

Antonis Baziotis

Supervisor

Dr. Maria Sofologi

December 2023

Open University of Cyprus

Faculty of Pure and Applied Sciences

Postgraduate (Master's) Programme of Study *Cognitive Systems*

Postgraduate (Master's) Dissertation

Evaluating the Relationship of Music Training and Bilingualism/Multilingualism and Their Contribution to Executive Functions in Healthy Adults

Antonis Baziotis

Supervisor

Dr. Maria Sofologi

The present Postgraduate (Master's) Dissertation was submitted in partial fulfillment of the requirements for the postgraduate degree In Cognitive Systems.

Faculty of pure and applied sciences of the Open University of Cyprus

December 2023

BLANK PAGE

Summary

The present study aimed to investigate the individual and comparative effects of Music training and Bilingualism/Multilingualism on executive functions (EFs) and working memory in healthy Greek adults. The study involved N=90 participants, who were divided into three distinct groups. The Musicians group consisted of individuals holding a degree in music and formal music training spanning over five years in various musical genres and instruments, with an average age of 33.40 years. The Bilingual/Multilingual cohort, with a mean age of 32.57 years, consisted of participants who were proficient in multiple languages, including but not limited to English, Arabic, Russian, and Italian. The control group, with an average age of 34.30 years, included people with no formal training in music or additional languages, which served as a baseline for comparison. Cognitive abilities were assessed using a series of tests: the Digit span (Wechsler, 1955), the Verbal Fluency Test (Kosmidis et al., 2004), and the Stroop Test (Stroop, 1935). These evaluations were conducted using a blended approach of in-person and digital administration to adapt to the varied environments of the participants. The research followed strict ethical protocols, ensuring informed consent, and used a detailed demographic questionnaire. Statistical analysis was performed using SPSS 25, using comparisons of means, analyses of variance, and Pearson and Spearman Rho correlations, along with hierarchical regression to dissect the cognitive performance exhibited by the different groups. Analysis of the results revealed that both Musicians and Bilinguals/Multilinguals showed higher performance on cognitive tasks compared to the control group. A comparative analysis between Musicians and Bilinguals/Multilinguals revealed differences in cognitive functions, with Musicians excelling more in certain aspects of working memory. Gender showed an effect on some cognitive tasks, while educational level showed a significant effect, especially on the results of the Stroop Test. Findings through hierarchical regression analyses reveal that music and language training advocate for the prediction of cognitive ability, with gender and educational background also playing significant roles in specific cognitive contexts. This highlights the potential of targeted music and language training to enhance cognitive abilities, suggesting avenues for future educational and cognitive development methodologies.

Keywords: Executive Functions, Working Memory, Music Training, Bilingualism, Cognitive Assessment, Gender, Education

Περίληψη

Η παρούσα μελέτη είχε ως στόχο να διερευνήσει τις ατομικές και συγκριτικές επιδράσεις της μουσικής εκπαίδευσης και της διγλωσσίας/πολυγλωσσίας στις εκτελεστικές λειτουργίες (EFs) και τη μνήμη εργασίας σε υγιείς Έλληνες ενήλικες. Η μελέτη περιελάβανε N = 90 συμμετέχοντες, οι οποίοι χωρίστηκαν σε τρεις ξεχωριστές ομάδες. Η ομάδα των Μουσικών αποτελούνταν από άτομα με πτυχίο μουσικής και επίσημης μουσικής εκπαίδευσης μεγαλύτερη των πέντε ετών σε διάφορα μουσικά είδη και όργανα, με μέσο όρο ηλικίας τα 33,40 έτη. Η δίγλωσση/πολύγλωσση ομάδα, με μέση ηλικία 32,57 ετών, αποτελούνταν από συμμετέχοντες που γνώριζαν άριστα πολλές γλώσσες, συμπεριλαμβανομένων, ενδεικτικά, αγγλικών, αραβικών, ρωσικών και ιταλικών. Η ομάδα ελέγχου, με μέσο όρο ηλικίας 34,30 ετών, περιλάμβανε άτομα χωρίς επίσημη εκπαίδευση στη μουσική ή σε πρόσθετες γλώσσες, γεγονός που χρησίμευσε ως βάση σύγκρισης. Οι γνωστικές ικανότητες αξιολογήθηκαν χρησιμοποιώντας μια σειρά ψυχομετρικών τεστ: Συγκεκριμένα το Digit Span (Wechsler, 1955), το Verbal Fluency Test (Kosmidis et al., 2004) και το Stroop Test (Stroop, 1935). Οι αξιολογήσεις διεξήχθησαν χρησιμοποιώντας μια μικτή προσέγγιση προσωπικής και ψηφιακής διαχείρισης για την προσαρμογή στα ποικίλα περιβάλλοντα των συμμετεχόντων. Η έρευνα ακολούθησε αυστηρά ηθικά πρωτόκολλα, εξασφαλίζοντας ενημερωμένη συναίνεση και χρησιμοποίησε ένα λεπτομερές δημογραφικό ερωτηματολόγιο. Η στατιστική ανάλυση πραγματοποιήθηκε χρησιμοποιώντας SPSS 25, χρησιμοποιώντας συγκρίσεις μέσων, αναλύσεις διακύμανσης και συσχετίσεις Pearson και Spearman's Rho, μαζί με ιεραρχική παλινδρόμηση για να αναλυθεί η γνωστική απόδοση που παρουσίασαν οι διαφορετικές ομάδες. Η ανάλυση των αποτελεσμάτων αποκάλυψε ότι τόσο οι μουσικοί όσο και οι δίγλωσσοι / πολύγλωσσοι έδειξαν υψηλότερη απόδοση στις γνωστικές εργασίες σε σύγκριση με την ομάδα ελέγχου. Μια συγκριτική ανάλυση μεταξύ μουσικών και δίγλωσσων / πολύγλωσσων αποκάλυψε διαφορές στις γνωστικές λειτουργίες, με τους μουσικούς να υπερέχουν περισσότερο σε ορισμένες πτυχές της μνήμης εργασίας. Το φύλο έδειξε επίδραση σε ορισμένες γνωστικές εργασίες, ενώ το εκπαιδευτικό επίπεδο έδειξε σημαντική επίδραση, ειδικά στα αποτελέσματα του τεστ Stroop. Ευρήματα μέσω ιεραρχικών αναλύσεων παλινδρόμησης αποκαλύπτουν ότι η μουσική και η γλωσσική εκπαίδευση υποστηρίζουν την πρόβλεψη της γνωστικής ικανότητας, με το φύλο και το εκπαιδευτικό υπόβαθρο να παίζουν επίσης σημαντικό ρόλο σε συγκεκριμένα γνωστικά πλαίσια. Αυτό υπογραμμίζει τις δυνατότητες της στοχευμένης μουσικής και γλωσσικής κατάρτισης για την ενίσχυση των γνωστικών ικανοτήτων, προτείνοντας δρόμους για μελλοντικές μεθοδολογίες εκπαιδευτικής και γνωστικής ανάπτυξης.

Λέξεις κλειδιά: Εκτελεστικές Λειτουργίες, Εργαζόμενη Μνήμη, Μουσική Εκπαίδευση, Διγλωσσία, Γνωστική Αξιολόγηση, Φύλο, Εκπαίδευση

Acknowledgements

I extend my deepest gratitude to Dr. Maria Sofologi, Adjunct Associate Professor and Postdoctoral Researcher of the Department of Early Childhood and Education Studies at the University of Ioannina, and Collaborating Teaching Staff at the Open University of Cyprus. Her guidance was instrumental in the selection of my thesis topic and her valuable advice illuminated my research path, providing clarity and direction throughout the process of my scholarly pursuit. Her dedication to academic excellence and her unwavering support have been a beacon of inspiration for me.

Special thanks are due to my wife, Mikalitsa, whose love, patience, and understanding have been the quiet force behind my every effort. Her constant encouragement and unwavering belief in me have been the cornerstones of my resilience and perseverance. Mikalitsa's presence has been a reminder of the joy and balance needed amidst the rigors of academic research.

I am also profoundly thankful to my brothers, Ioannis and Gerasimos, for their brotherly advice, endless support, and the moments of levity they brought into my life during this intense period of study. Their unwavering faith in my capabilities and their readiness to assist in countless ways have been invaluable.

My heartfelt appreciation goes out to all the participants who contributed to this research. Without their time, insights, and willingness to share, this work would not have been possible. Their diverse perspectives and experiences have enriched this study and have been essential to its success.

Lastly, I dedicate this master's dissertation to the cherished memory of my parents. Though they are no longer with us, their teachings, morals, and the love they instilled in me have been the guiding stars of my journey. This accomplishment stands as a tribute to their legacy, which continues to live within me.

Table of contents

CHAPTER 1
Introduction

Executive functions (EF) serve as higher-order cognitive mechanisms critical to the conscious regulation of thought and action. They include several subcomponents, including but not limited to strategic planning, self-regulation, decision-making, attentional control, cognitive flexibility, and inhibitory control (Miyake et al. 2000; Stuss & Alexander, 2000). These core cognitive frameworks are not merely helpful but essential to the orchestration of many other cognitive abilities (Miller & Cohen, 2001).

EFs are mainly associated with a fronto-parietal neural network, showing fractional performance in discrete tasks. This suggests that while these functions are distinct, they are also interrelated, confirming the complexity of EFs (Miyake et al., 2000).

While a comprehensive body of research has confirmed the genetic bases of EFs, it is nevertheless undeniable that environmental variables, manifested through specific experiential pathways, also contribute to notable individual differences and similarities (Friedman et al., 2008). Recognizing the intricate relationship between language acquisition and cognitive processes, it is important to highlight the connection between bilingualism and the development of executive functions (EFs). In this context, it is worth emphasizing that bilingualism and music training have been empirically validated to exert a substantial impact on the development of EFs and possible cognitive advantage (Bialystok, 2001; Bialystok & Barac, 2012; Moreno et al., 2011).

The literature review revealed that musicians often demonstrate better performance in multiple cognitive domains than non-musicians, on tasks involving verbal memory, executive function, and visuospatial abilities (Costa-

Giomi, 1999; D'Souza, Moradzadeh, & Wiseheart, 2018). This improved performance is attributed to the rigorous mental processes involved in musical training, which may induce neuroplastic changes in the brain, enhancing cognitive functions that extend beyond musical abilities. Of note, enhanced working memory and increased inhibitory control have been observed in musicians of different age groups (Degé, Kubicek, & Schwarzer, 2011; Franklin et al., 2008; Hanna-Pladdy & MacKay, 2011; Lee, Lu, & Ko, 2007; Oechslin et al., 2013; Roden, Kreutz, & Bongard, 2012; Seinfeld, Figueroa, Ortiz-Gil, & Sanchez-Vives, 2013; Wallentin et al., 2010). These cognitive gains are not limited to musical contexts but are evident in tasks ranging from rudimentary to complex methodological frameworks, illustrating the transferability of the cognitive skills honed through musical training. Such skills, including pattern recognition, auditory encoding, and temporal processing, are fundamental to a musician's practice and are equally applicable to non-musical cognitive tasks, thereby providing a broad cognitive benefit. However, empirical evidence shows some inconsistencies across different scientific investigations, thus casting doubt on the generalizability and reliability of these supposed cognitive advantages (Carey et al., 2015; Zuk et al., 2014).

In addition, the development of certain cognitive abilities appears to be significantly influenced by engaging in activities that require complex and sustained mental effort. Among such activities, music training and bilingualism/multilingualism stand out for their respective cognitive benefits. In parallel with the cognitive gains observed in music training, bilingualism/multilingualism also confers possible cognitive enhancements that extend beyond the immediate realm of linguistic skills. The cognitive advantage here pertains particularly to areas involving executive functions, such as inhibitory control, which are crucial for managing interference from competing systems. Scholarly literature indicates that these advantages are especially salient in the area of inhibitory control (Bialystok, 2001; Bialystok et al., 2004). In establishing the relevance of both domains to cognitive performance, it is crucial to note that empirical findings suggest these cognitive benefits are more pronounced in tasks requiring cognitive flexibility. This is evidenced by the established link between the ability to switch tasks and switch languages, highlighting the broad applicability of these cognitive skills (Garbin et al., 2010; Prior & Gollan, 2011).

Empirical studies have consistently demonstrated that bilingual/multilinguals individuals surpass their monolingual counterparts in tasks involving non-linguistic interference, such as the Simon, Stroop, and Flanker tasks (Bialystok, Craik, & Luk, 2008; Meuter & Allport, 1999). Nevertheless, the robustness of this possible bilingual advantage has been called into question by several studies that employed a variety of tasks and failed to replicate these findings (Kousaie & Phillips, 2012; Paap & Greenberg, 2013). In a similar vein, while some research corroborates the notion of a bilingual/multilingual advantage in working memory (Bialystok & Feng, 2009; Luo, Craik, Moreno, & Bialystok, 2013), other investigations have contested this claim (Adesope, Lavin, Thompson, & Ungerleider, 2010).

The existing literature has rigorously examined the cognitive ramifications of both music training and bilingualism/multilingualism, mostly isolating their individual effects on specific executive functions (EFs) such as working memory and inhibitory control. It is noteworthy that the majority of these studies are limited to in their scope, often focusing on a single component of EF. For example, Bugos et al., (2007) study was limited to the domain of cognitive transfer, while Moreno et al., (2011) exclusively explored inhibition. Even in studies that venture to examine multiple EFs—such as inhibition and working memory—there is a methodological discrepancy in the assessment metrics used, causing inconsistencies in empirical results (D'Souza, Moradzadeh, & Wiseheart, 2018).

Furthermore, the operationalization of “musical groups” is notoriously inconsistent across the literature. Some studies delineate musical groups that include students who have taken music lessons or children between the ages of 9 and 12 with few months or some years of musical training (Schellenberg, 2011).

Such binary classifications have been shown to produce spurious correlations and compromise statistical reliability (MacCallum, Zhang, Preacher, & Rucker, 2002). In contrast, a subset of studies adopts a more stringent criterion, categorizing individuals with more than five years of formal music training as professional musicians (D'Souza, Moradzadeh, & Wiseheart, 2018).

To ameliorate these methodological gaps and inconsistencies, the present research is designed to conduct a comparative analysis of the cognitive effects mediated by music training and bilingualism/multilingualism across a spectrum of EFs, with a particular focus on the Greek healthy population. Specifically, in this study, we aim to assess professional music teachers (teachers and music educators) with more than five years of formal music training as well as a sample of bilingual/multilingual adults. In order to capture a comprehensive profile of cognitive abilities, this study will employ a multimetric assessment paradigm. Specifically, it means that we will combine three distinct yet interrelated weighted measures that align with the constructs we aim to investigate. These measures include the Digit Span test from Wechsler (1955), which evaluates working memory; the Verbal Fluency Test as described by Kosmidis et al., (2004), which measures language and executive functions; and the Stroop Test (Stroop, 1935), which assesses cognitive control. By synthesizing the results from these tests, the study will provide a more holistic understanding of the cognitive impact of music training and bilingualism, offering insights into how these disciplines enhance various dimensions of cognitive functioning.

Additionally, this research effort will rigorously control for potential confounding variables, including gender and educational level. This methodological rigor aims to elucidate a more nuanced understanding of the unique cognitive benefits attributed to music training and bilingualism/multilingualism, while also accounting for variables that have been inconsistently controlled for in previous research.

In summary, the present study aspires to shed light on address an important research gap by providing a comprehensive, nuanced, and comparative elucidation of the cognitive effects of music training and bilingualism/multilingualism on a range of EFs. The study will apply a robust assessment methodology, specifically adapted to the Greek population, and will rigorously control for potential confounding variables such as gender and education level.

This master's dissertation is organized into six comprehensive chapters. The first chapter introduces the thesis, establishing the conceptual framework and objectives of the research. The second chapter provides a historical background of executive functions, which is essential for contextualizing the subsequent analysis. The third chapter embarks on a multifaceted examination, exploring the individual relationships between music training and bilingualism with executive functions and also engaging in a comparative analysis to evaluate how these experiential pathways influence cognitive control. This chapter further defines the research hypotheses, setting a foundation for the investigative approach ahead. The fourth chapter outlines the methodology adopted in the study, detailing the evaluation techniques employed. In the fifth chapter, the empirical results are presented, showcasing the data collected and its analysis. The sixth and final chapter concludes the thesis, offering a critical discussion of the findings and articulating the conclusions drawn from the research. The discussion also examines their implications for existing gaps in the literature and their broader significance in the realm of cognitive science. Each chapter contributes to a nuanced understanding of how music training and bilingualism affect executive functions, taking into account potential confounding variables such as gender and education level.

Chapter 2
Literature Review

2.1 Brief Historical Background of Executive Functions, Theories, and Models

The study of executive functions (EF) has been a landmark in cognitive psychology and neuroscience for several decades (Miyake et al., 2000; Anderson, 2002). The research field is characterized by a multitude of theories, presenting a remarkable degree of agreement between them, despite the diversity they present (Lezak et al., 2004; Welsh & Pennington, 1988). However, in this section, we will present the various cognitive theories and models that have shaped our understanding of EF (Trimble, 1986; Luria, 1973).

Specifically, executive functioning, often called executive control (EF), is a multifaceted construct that incorporates a range of higher cognitive skills, such as inhibitory control, self-regulation, attention shifting, and working memory (De Frias, Dixon, & Strauss, 2006; Barkley, 1997; Miyake et al., 2000; Zelazo & Müller, 2002). The literature review further highlights the significant impact of EFs on both physical and mental well-being at various developmental stages (Baler & Volkow, 2006; Brown & Landgraf, 2010; Morrison et al., 2010)

In their origin, EFs are associated with frontal lobe damage (Shallice, 1988). Nowadays it is recognized that these cognitive processes grouped under this term depend on a complex neural network in which different cortical areas are involved. At the same time, the involvement of different regions of the prefrontal cortex (PFC) correlates depending on the cognitive process involved (Bunge & Crone, 2009; Stuss, 2011).

Based on this foundational framework of executive functions (EFs), it is important to emphasize that a substantial body of empirical evidence has been generated through neuropsychological research, particularly that focused on adults with frontal lobe lesions (Trimble, 1986). These seminal works laid the groundwork for understanding the central role of the prefrontal cortex in tasks requiring impulse control, cognitive planning, and behavioral restraint (Luria, 1974). Extending this line of research, Aron et al., (2004) conducted a detailed examination of the right inferior frontal cortex, elucidating its specific contribution to inhibitory control mechanisms. Similarly, the research of Fuster (2001) has provided invaluable insights into the temporal organization and planning functions mediated by the prefrontal cortex, thereby enriching our understanding of its multifaceted roles. Miller & Cohen (2001) further extended this conceptual framework by proposing a comprehensive theory that places the prefrontal cortex as a central hub for guiding behavior based on goals or plans. In a more recent contribution, Barbey et al., (2013) undertook a comprehensive exploration of the neural architecture underlying problem-solving and planning, thus reinforcing the critical importance of the prefrontal cortex in these complex cognitive functions.

From the literature review, the formal definition of EFs was established in the 1970s, but the concept of executive control mechanisms has been the subject of academic research since the mid-19th century (Trimble, 1986; Luria, 1973). The case of Phineas Gage is particularly illustrative in this context (Ratiu & Talos, 2004). After sustaining a severe injury to the frontal lobes, Gage exhibited significant changes in behavior including features such as inhibition and hyperactivity, usually associated with damage to the prefrontal cortex (Pribram, 1973). This case, among others, was pivotal in guiding early neuroscientific research to develop theories about the functional roles of the frontal lobes in EFs.

2.1.1 Executive Functions Theories

Originally defined as the "central executive" by Baddeley and Hitch (1974), the term "executive function" was therefore further refined by Lezak (1983). Lezak described it as the domain of behavior that orchestrates the "modality" through which the actions. In this context, Lezak identified four cornerstones: the ability to conceptualize goals, the ability to plan strategically, the ability to implement targeted actions, and the ability to execute tasks. Although these elements were identified separately, Lezak emphasized that they collectively contribute to ethical, socially responsible, and beneficial behavior in adults (Lezak, Howieson, & Loring, 2004).

Furthermore, Lezak argued that even in the presence of significant cognitive decline, a person can maintain a level of independence and productivity as long as these executive functions remain intact (Lezak, Howieson, & Loring, 2004). Executive abilities are therefore generally categorized as higher-order cognitive processes, with frontal cortical areas serving as primary mediators (Stuss & Levine, 2002).

Then according to Luria's Theory, the frontal lobes - specifically the prefrontal-cortex constitute the third functional unit of the brain, which is critical for the orchestration of executive functions (Luria, 1973). This unit is responsible for planning, regulating, and verifying complex behavior, which includes basic executive functions such as planning, problem-solving, and self-regulation (Luria, 1966). Luria argues that these executive functions are not isolated cognitive processes. Instead, they are part of a complex cortical network that governs adaptive behavior. This third functional unit interacts synergistically with the first unit, responsible for arousal and alertness, and the second unit, dedicated to receiving, analyzing, and storing sensory information, thus facilitating the efficient performance of complex cognitive tasks (Luria, 1980). Luria's seminal framework was fundamental to the neuropsychological understanding of executive functions and had profound implications for both the clinical assessment and rehabilitation of individuals with frontal lobe dysfunctions. (Luria, Pribram, & Homskaya, 1964)

Anderson's work is also a seminal contribution to the understanding of executive functions, specifically what he refers to as a complex set of higher-order cognitive processes essential to human behavior (Anderson, 2002). Anderson describes a number of key elements that determine executive functions, including anticipation, goal selection, strategic planning, goal-directed activity initiation, self-regulation, mental flexibility, development of focused attention, and effective use of feedback (Anderson, 2002). This complex definition not only highlights the multifaceted nature of executive functions but also extends beyond conventional domains to include aspects of attentional adaptability and control. The framework has had important implications for clinical neuropsychological assessment methodologies and cognitive research paradigms. It also provided a nuanced understanding of executive functions, thereby enriching both theoretical constructs and practical applications in the field (Anderson, 2002).

The work of Welsh & Pennington (1988) proposes a "fractionated" model, arguing that executive functions are not a monolithic construct but rather a constellation of interrelated but distinct cognitive processes. This model was instrumental in shaping the current understanding that executive functions are multidimensional, including components such as working memory, inhibitory control, and cognitive flexibility (Welsh & Pennington, 1988).

Finally, Miyake et al., (2000) offer a unified framework for conceptualizing executive functions. According to his theory, executive functions consist of three basic but distinct components: updating, which refers to the monitoring and encoding of information, shifting, which involves the ability to switch between tasks or mental sets, and inhibition, which is the ability to deliberately suppress automatic or dominant responses. It is worth emphasizing at this point that Miyake's theory sets the framework that addresses the unity and diversity of EFs by emphasizing both common and unique features. In particular, while these elements are interrelated, they are also dissociable, allowing for individual differences in executive functioning (Miyake et al., 2000). This model has been widely cited and has influenced subsequent research on executive functions, both in terms of theoretical understanding and empirical research.

In summary, theories of executive functions, while sharing some commonalities, also present distinct perspectives that enrich the understanding of this complex construct. Baddeley and Hitch's (1974) “central executive” model laid the groundwork by introducing a supervisory system but was limited in scope, focusing primarily on working memory. Lezak (1983) extended this by adding a behavioral dimension, emphasizing the role of executive functions in ethical and socially responsible behavior. Luria (1973) took a more neuroanatomical approach, linking the prefrontal cortex to the orchestration of executive functions, thus adding a layer of biological specificity. Anderson (2002) further differentiated the definition by incorporating elements such as anticipation and goal selection, making it more comprehensive. Welsh & Pennington (1988) offered a “compartmentalized” model, challenging the idea of executive functions as a monolithic construct and arguing for a more nuanced, component-based one. Finally, Miyake et al.,(2000) synthesized these perspectives into a unified framework, identifying core elements such as updating, displacement, and inhibition, while also allowing for individual differences. Each theory uniquely reveals the field of research by either adding new dimensions to our understanding or refining existing concepts, and collectively, they offer a multifaceted view of executive functions.

For the purposes of this study, we adopt Miyake et al.,(2000) unified framework for conceptualizing executive functions. This framework is particularly relevant to our research as it identifies three core components—updating, shifting, and inhibition—that are both interrelated and dissociable, allowing for a nuanced examination of individual differences in executive functioning. It is this theory's unique emphasis on the unity and diversity of executive functions that sets the foundation for the current investigation. Miyake's model, which has been widely cited and influential in subsequent research, provides both the theoretical underpinning and the methodological approach for our empirical work.

2.1.2 Executive Functions Models

Baddeley's seminal model of working memory initially conceptualized in 1974, has been a cornerstone in cognitive psychology and neuroscience, especially in the realm of Executive Functions (EF) (Baddeley & Hitch, 1974; Baddeley, 1996; Baddeley, 2000). The model posits a 'central executive,' a capacity-limited system that orchestrates cognitive resources to various subsidiary systems, notably the phonological loop and the visuospatial sketchpad (Baddeley, 2000; Baddeley, 1996).

The central executive is not merely a passive system, it is an active, adaptive control system that prioritizes tasks based on cognitive demands and individual goals (Baddeley, 1996; Baddeley, 2003). Studies by Engle (2002) and Kane & Engle (2003) have shown that this component is crucial for complex cognitive tasks like problem-solving and decision-making. It also plays a pivotal role in attention control, facilitating goal-directed actions while inhibiting irrelevant stimuli (Baddeley, 1993; Kane & Engle, 2003)

Research on music training and bilingualism has shown that these experiences can enhance the central executive component of EFs. Bialystok & DePape (2009) found that bilingual individuals outperform monolinguals in tasks requiring executive control. Moreno et al., (2011) demonstrated that children with music training showed improvements in multiple domains of EF, including working memory and attention control. Schellenberg (2011) further corroborated these findings by showing that musicians outperform non-musicians in tasks that require both working memory and attention control.

In addition to the central executive, Baddeley's model originally incorporated two subsidiary systems: the phonological loop and the visuospatial sketchpad. The phonological loop is crucial for language comprehension and verbal reasoning (Baddeley, Gathercole, & Papagno, 1998; Baddeley, 1992). Slevc & Miyake (2006) found that musicians show enhanced verbal memory, suggesting a strong phonological loop. Bialystok & DePape (2009) found that bilingualism enhances the phonological loop, particularly in tasks requiring verbal manipulation. In contrast, the visuospatial sketchpad is instrumental in tasks requiring spatial manipulation, such as navigation (Salway & Logie, 1995; Baddeley & Logie, 1999). Hetland (2000) found that musical training enhances spatial-temporal skills, suggesting an enhanced visuospatial sketchpad in musicians.

However, the model has faced criticisms, particularly concerning the nebulous nature of the central executive. Collette et al., (2006) and Miyake et al., (2000) argue that the term “central executive” functions as a blanket phrase for a multitude of cognitive processes that remain unclear. Blumenfeld & Ranganath, (2006) critiqued the model for its lack of neuroscientific foundation, stating that it offers a psychological framework but falls short in incorporating neuroanatomical or neurophysiological data. Best & Miller (2010) criticized the model for not sufficiently addressing the developmental trajectory of EFs across the lifespan.

To address some limitations, Baddeley introduced a third component in 2000: the episodic buffer. This buffer serves as a temporary storage system and is involved in tasks requiring the integration of different pieces of information (Baddeley, 2000; Baddeley, Allen, & Hitch, 2011).

In summary, Baddeley's model of working memory and EFs is a multicomponent system that continues to be refined to address its limitations and to incorporate emerging research findings, including those related to music training and bilingualism (Baddeley, 2012).

Anderson's model of Executive Functions (EF) is noteworthy for its emphasis on the dynamic interplay between various cognitive elements, such as forecasting and self-regulation (Anderson, 2002; Anderson, 2010). For instance, forecasting is not merely a predictive mechanism but serves as a cognitive scaffold that informs goal selection and strategic planning (Anderson, 2002; Anderson, 2010; Burgess & Simons, 2005). Self-regulation, in this framework, is conceptualized as an adaptive control system that modulates behavior based on continuous assessment of environmental cues and internal states (Anderson, 2010)

Anderson's model is particularly commendable for its incorporation of neuroscientific data, mapping executive elements to specific neural substrates such as the prefrontal cortex (Anderson, 2010; Diamond, 2013). This neural region is implicated in complex cognitive activities like decision-making and problem-solving (Anderson, 2010; Diamond, 2013).

However, the model has faced criticisms for its complexity, which, while offering a detailed description of EF, also complicates its empirical validation (Diamond, 2013; Miyake et al., 2000). Critics like Diamond (2013) and Miyake et al., (2000) argue that the multifaceted nature of the model poses challenges for experimental design and data interpretation.

Research on music training and bilingualism has shown that these experiences can enhance various components of EFs, which align with elements in Anderson's model. For example, Moreno et al., (2011) found that music training improved verbal intelligence and executive functions in children. Bialystok & DePape (2009) demonstrated that bilingual individuals outperformed monolinguals in tasks requiring executive control, particularly in the domain of self-regulation. Studies by Schellenberg (2011) and Zuk et al., (2014) further corroborate these findings, showing that musicians outperform non-musicians in tasks that require both working memory and attention control, elements that are integral to Anderson's model.

In summary, Anderson's model serves as a comprehensive framework that enriches our understanding of EF by emphasizing its multifaceted nature and neuroanatomical underpinnings (Anderson, 2002; Anderson, 2010). While the model has been instrumental in expanding the field of EF research, it also invites further empirical testing to validate its complex constructs (Anderson, 2002; Diamond, 2013; Miyake et al., 2000). Like Baddeley's model, Anderson's framework has been a catalyst for ongoing research aimed at disentangling the complex web of cognitive processes that constitute EF, including studies on the impact of music training and bilingualism (Moreno et al., 2011; Bialystok & DePape, 2009; Schellenberg, 2011; Zuk et al., 2014).

The Supervisory-Attentional System (SAS) model, formulated by Norman and Shallice, posits that executive functions are primarily governed by a supervisory system that is activated in novel or challenging situations (Norman & Shallice, 1986; Shallice & Burgess, 1996). This system is responsible for intervening when automatic or learned responses are inadequate, such as in situations requiring planning, error correction, or decision-making under conflict (Shallice, 2002; Botvinick et al., 2001).

Recent empirical studies in the realm of music training and bilingualism have provided interesting insights that can be interpreted within the SAS framework. For example, music training has been shown to enhance cognitive flexibility and working memory, skills that are critical for the supervisory system to effectively intervene in novel situations (Schellenberg, 2011; Moreno et al., 2011). Similarly, bilingualism has been associated with improved inhibitory control, another key function of the supervisory system (Bialystok, 2009; Costa et al., 2009). These findings suggest that both music training and bilingualism may help strengthen the supervisory system posited by the SAS model (Krizman et al., 2012; Paap, Johnson, & Sawi, 2015).

However, the SAS model has also faced criticism for its lack of empirical evidence and its somewhat simplistic dichotomy between automatic and controlled processes (Cooper & Shallice, 2006; Gilbert & Burgess, 2008). Critics argue that the model could benefit from more empirical data to substantiate its constructs and clarify how the supervisory system interacts with real-time conflict planning (Burgess et al., 1998; Gilbert & Burgess, 2008).

In summary, the SAS model offers a comprehensive framework for understanding executive functions, distinguishing between automatic and controlled processes, and linking them to specific neural substrates. While the model has been instrumental in shaping the field, it also requires further empirical validation. Emerging research on the cognitive benefits of music training and bilingualism not only confirms the multifaceted nature of executive functions but also provides empirical support that enriches our understanding of the SAS model.

Miyake's theoretical framework offers a sophisticated conceptualization of executive functions (EFs), delineating them into distinct yet interconnected subcomponents: updating, inhibiting, and shifting (Miyake et al., 2000; Friedman & Miyake, 2017).

The "updating" function is concerned with the dynamic modulation of working memory representations, aligning them in accordance with task-specific requirements. Empirical studies in the realm of music training, such as those by Strait & Kraus (2011) and Zuk et al. (2014), have demonstrated enhanced working memory capabilities in musicians, thereby lending credence to this aspect of Miyake's model.The "inhibition" function involves the volitional suppression of dominant or prepotent behavioral responses when they are contextually inappropriate. Research by Bialystok & Viswanathan (2009) and Costa, Hernández, & Sebastián-Gallés (2008) has shown that bilingual individuals exhibit superior inhibitory control, further substantiating the theoretical underpinnings of this function within Miyake's framework. The "shifting" function encompasses the cognitive flexibility required to transition between distinct tasks or mental frameworks. Studies by Moreno et al., (2011) and Paap & Greenberg (2013) have indicated that both musical training and bilingualism can enhance cognitive flexibility, thereby adding empirical weight to this conceptual validity.

Miyake's model is characterized by its empirical rigor, having been substantiated through a series of factor-analytic investigations. However, the model has not been without its critics. It has been scrutinized for its limited scope in capturing the full spectrum of EFs, such as planning and decision-making, as noted by Jurado & Rosselli (2007). Additionally, the model has been critiqued for its limited integration with neuroscientific data, an area highlighted by Collette et al., (2006) as ripe for future interdisciplinary research. Furthermore, the unity and diversity framework proposed by the model has been the subject of academic debate. Critics, including, by Best & Miller (2010), argue that this framework may oversimplify the complex interrelationships among various EFs. These critics call for a more nuanced conceptualization based on empirical evidence, such as the studies by Diamond (2013) and Friedman et al., (2008).

In summation, Miyake's model serves as a nuanced, empirically substantiated framework for understanding the unity and diversity inherent in EFs. While the model has significantly advanced the academic discourse in this field, it also invites further empirical validation to address its limitations and to integrate emerging interdisciplinary findings, particularly those related to the cognitive benefits of music training and bilingualism (Schellenberg, 2011; Bialystok, 2009).

2.1.3 Summary

In sum, the landscape of executive functions (EFs) is enriched by a plethora of theoretical frameworks and empirical models, each contributing unique perspectives to our understanding of these complex cognitive processes. From Baddeley's multi-component model of working memory to Miyake's unity and diversity framework, and Anderson's emphasis on dynamic interactions, these models offer nuanced insights into the subcomponents of EFs—updating, inhibiting, and shifting—while also highlighting the neuroanatomical underpinnings of these functions. Despite their significant contributions, these models are not without limitations, ranging from scope and empirical validation to integration with neuroscientific data. Criticisms aside, these frameworks have served as the bedrock upon which contemporary research is built, including interdisciplinary studies that explore the cognitive benefits of music training and bilingualism. As we transition into the subsequent chapter, the focus will shift to an empirical examination of how music training and bilingualism/multilingualism contribute to the enhancement of executive functions in healthy adults, thereby adding a new dimension to this rich tapestry of research.

Chapter 3
Literature Review

3.1 Defining Musicianship: The Interplay of Music Training and Executive Functions

"The conceptualization of "music" has garnered interdisciplinary scrutiny, with contributions from cognitive neuroscience, musicology, and pedagogy (MacDonald, 2013). Comparative methodology serves as a tool to delineate the cognitive characteristics of musicians versus non-musicians, thus elucidating the complex link between musical contribution and individual cognitive abilities (Luiz, Gil, de Camargo, & Miguel, 2021). Neurocognitive research has not only revealed anatomical disparities but also has highlighted that musicians exhibit enhanced executive functions such as task management, problem-solving, and decision-making, which are fundamental to both musical performance and other areas of life (Gaser & Schlaug, 2003).

From a traditional vantage point, musicality is interpreted as the ability to skillfully operate a musical instrument, a skill often attributed to formal educational interventions, called colloquial music training (Hallam, 2010; Sloboda, 2004). The duration of such formalized musical engagement often serves as a quantitative metric for assessing musical expertise (Rickard & Chin, 2017).

Additionally, neurocognitive findings substantiate the conventional paradigm by highlighting important cognitive and anatomical distinctions between musicians and non-musicians, shaped by the extent of musical training. Musicians demonstrate superior performance in executive functions, particularly in complex psychomotor tasks, and cognitive flexibility. They excel in converting musical notes into sequential finger movements and in maintaining extended musical sequences, skills that are enhanced by the integration of multimodal sensory information and refined through feedback mechanisms and executive control systems (Amunts et.al., 1997; Hund-Georgiadis & Von Cramon, 1999).

Recent studies in executive function suggest that each component—namely, inhibition, cognitive shifting, and working memory updating—is intricately linked with aspects of musical cognition. Musicians often display better inhibitory control, which is essential for resolving musical dissonances and managing attention in complex auditory environments. Cognitive shifting ability allows them to adapt rapidly in ensemble settings, and enhanced working memory is crucial for sight-reading and real-time processing of musical structures (Okada & Slevc, 2018; Jentzsch, Mkrtchian, & Kansal, 2014).

Furthermore, the acquisition of musical abilities is not merely a reflection of skill but also corresponds to structural neural adaptations, indicating that extensive, longitudinal musical training can induce neuroanatomical changes associated with executive functions (Passingham & Toni, 2001). However, traditional criteria for evaluating musicianship are now being reexamined. Modern literature suggests that musical ability may be innate or autonomously developed, which broadens the definition beyond formal education (Sloboda, 2004).

In response to this, Zhang et.al., (2018) proposed a categorization distinguishing self-taught-amateur musicians from formally trained professionals. This division reflects the diverse pathways through which musical expertise can be developed and acknowledges a broader spectrum of cognitive engagement in music.

The concept of "musicality" is a complex construct, combining both traditional paradigms based on skill acquisition and formal training, and neuroscientific perspectives that emphasize unique neuroanatomical configurations. This nuanced understanding serves as a foundational framework for subsequent exploration of the complex interplay between music education and executive functions. However, before we critically present the existing literature as we embark on this exploration, in the next section we present evidence concerning bilingual and multilingual proficiency respectively as well as music training. At this point it is imperative to critically evaluate the existing literature both individually and comparatively on these two experiences to identify gaps in current knowledge, thus unifying the research hypotheses that this study attempts to address."

3.2 Defining Linguistic Proficiency: The Interplay of Bilingualism/Multilingualism and Executive Cognitive Processes

The definition associated with linguistic proficiency in multiple languages—specifically “bilingual” and “multilingual”—includes a range of skills that are influenced by a range of social, psychological, and linguistic factors. This complexity requires a multidimensional perspective for proper understanding and analysis. In this context, scholars urge a clear separation between the terms "bilingualism" and "multilingualism", but support the tendency to generalize these distinct experiences into a single category (Aronin & Hufeisen, 2009; Cenoz & Genesee, 1998; De Angelis, 2007).

However, the evolution of the definition of bilingualism can be traced from earlier restrictive concepts, such as Bloomfield's (1933) criterion of "innate command of two languages", to more inclusive interpretations such as Haugen's (1953) recognition of individuals who can articulate full and meaningful statements in another language. According to the literature, the academic environment more widely recognizes bilinguals as those who regularly interact with at least two languages or dialects in their daily lives (Grosjean, 2010) and extends this recognition to people with different abilities between languages (Valdés & Figueroa, 1994). This shift not only reflects the prioritization of communicative abilities in studies of second language acquisition, but also facilitates an understanding of language proficiency as a dynamic construct that is subject to change over time and in different contexts (Hakuta, 1986; Larsen-Freeman, 2007).

Multilingual users is an inclusive term that refers to both bilinguals and multilinguals, as distinguished from monolinguals who, as is recognized, represent a smaller percentage of the world's population. "Bilinguals" are therefore defined as individuals who use two languages, while "multilinguals" include those who speak three or more languages fluently. Despite the theoretical importance of distinguishing between these categories, the practical delineation is often unclear due to the challenges of measuring the languages spoken by multilingual individuals and the considerable variability in their language acquisition and use (Kemp, 2009).

Despite the theoretical perspective, the neurocognitive findings substantiate the paradigm that bilingual and multilingual individuals show significant cognitive and anatomical differences compared to monolingual peers. These distinctions are particularly evident in brain regions associated with executive functions, such as the prefrontal cortex and anterior cingulate cortex (Abutalebi et al., 2012; Krizman et al., 2012). Research suggests that continuous management of multiple language systems enhances cognitive flexibility, working memory, and inhibitory control (Bialystok et al., 2012; Green & Abutaleb, 2013). Such findings reinforce the notion that bilingualism and multilingualism confer neurocognitive benefits that extend beyond language proficiency, potentially increasing overall cognitive resilience and executive control (Gold et al., 2013; Luk et al., 2011).

At this point we would like to emphasize that the classification of Bilingualism and Multilingualism consists of several factors, which make the bilingual experience clearly heterogeneous. The terms "Bilingual" and "Multilingual" are not limited to a single characteristic profile, but are evaluated according to the development of language skills and frequency of application. Grosjean (2010) however clarifies that individuals identified as bilingual or multilingual are characterized by their habitual engagement with several languages or dialects, underscoring the primacy of language use over simple language ability

3.3 A Review of Empirical Investigations into the Cognitive Impact of Music Training and Bilingualism/Multilingualism on Executive Functions and Working Memory in Healthy Populations

In recent years the relationship between music training as well as bilingualism/multilingualism and executive functions has led researchers to study the possible cognitive benefits. A body of work reveals the possibility that long-term exposure to music (learning musical instrument-music lessons) and/or proficiency in multiple languages affects executive control (Bialystok, Martin, & Viswanathan, 2005; Mor, Yitzhaki-Amsalem & Prior, 2014; Treffers-Daller, Ongun, Hofweber, & Korenar, 2020; Benz et al., 2016; Schellenberg & Weiss, 2013). Executive control includes a series of higher-order cognitive processes and is arguably an integral part of goal-directed behavior and adaptability (Miyake et al., 2000). Executive functions are particularly prominent in the realm of music training as well as bilingualism/multilingualism where individuals engage in complex cognitive tasks that require a high level of coordination and control (Jentzsch, Mkrtchian, & Kansal, 2014; Ursino, Cuppini & Magosso, 2010).

Additionally, empirical studies have revealed that music training is associated with improved language skills, including proficiency in foreign language pronunciation (Milovanov et al., 2010), phonological awareness (Linnavalli et al., 2018), and verbal intelligence (Moreno et al., 2011). Correspondingly, bilingualism/multilingualism is associated with improvements in metalinguistic abilities and awareness of others' mental states (Goetz, 2003; Gold, Kim, Johnson, Kryscio & Smith, 2013). In addition, beyond the immediate domain of language, there is a documented correlation between musical experience and possibly indicative of long-term benefits manifested in areas such as non-verbal intelligence (Schellenberg, 2006) and school achievement (Dos Santos-Luiz et al., 2016).

Research indicates that proficiency in music and language acts as a safeguard, enhancing cognitive development throughout one's life and potentially mitigating the mental decline commonly associated with aging (Skoe & Kraus, 2012; Hanna-Pladdy & Gajewski, 2012; Thaut et al., 2014; Wodniecka et al., 2010). Bialystok et al., (2004) and Wang & Schlaug (2010) have found that these experiences may influence the neuroendocrine and autonomic nervous systems, contributing to healthier cognitive functions during the aging process (Chanda & Levitin, 2013).

Adopting these views, it has been suggested that both experiences can play an important role in enhancing general cognitive abilities, with a strong emphasis on executive functions and working memory (Moreno & Bidelman, 2014). These foundational cognitive abilities are thought to serve as conduits through which the benefits of music training and bilingualism/multilingualism are transmitted, exerting a far-reaching influence that transcends musical expertise and permeates non-musical and linguistic cognitive spheres. A significant number of studies in recent decades confirm the association of musical experience as well as language proficiency and the possible enhancement of executive functions, including but not limited to inhibitory control (Moreno & Farzan, 2015; D'Souza, Moradzadeh, & Wiseheart, 2018), working memory (Cockcroft et al., 2017; Pallesen et al., 2010; Oechslin et al., 2013; Okhrei et al., 2017) and cognitive flexibility (Moradzadeh, Blumenthal, & Wiseheart, 2014; Okada & Slevc, 2018). These cognitive gains are seen simultaneously in structural and functional brain adaptations in regions involved in such cognitive mechanisms.

3.3.1 Music training and inhibition control

Existing literature reveals that music training could potentially enhance the ability to suppress interference, possibly through a neural adaptation process known as "experience-dependent plasticity" (Jentzsch, Mkrtchian, & Kansal, 2014). This process involves the brain's ability to alter its neural connections and synapses in response to new experiences, such as musical training. Although empirical support for this cognitive enhancement is not as strong as for bilingualism, the mechanism that underpins it is still a central point of scientific inquiry (Miyake et al., 2000).

Additionally, recent theoretical perspectives have drawn analogies to language comprehension, suggesting that as a melody unfolds, other notes are activated that align with the initial notes of the main melody, similar to the activation of phonetic words in language processing (Bella, Peretz & Aronoff, 2003; Schulkind, Posner & Rubin, 2003).

This means that understanding music may require overlooking misinformation, e.g. enabled but incorrect tunes. This idea gathers support from studies indicating the activation of frontal executive regions during music listening, which could lead to improvements in interference suppression (Altenmüller, 1989).

Recent scientific efforts have shed light on the potential for musicians to possess strong inhibitory control capabilities, with music training linked to enhancing such capabilities (Chen et al., 2017). Musicians, when performing musical work, are tasked with constant self-monitoring, rapidly adapting actions based on auditory feedback and proprioceptive cues, and minimizing internal and external distractions. These processes according to the researchers are indicative of the involvement of inhibitory control (Okada & Slevc, 2018; Slevc et al., 2016).

Emerging research underscores the multifaceted benefits of music training for adults, extending beyond mere recreational activity to encompass significant cognitive improvements. Studies have elucidated that adult musicians exhibit notable enhancements in inhibitory control—the ability to suppress competing impulses—which is a critical aspect of executive functions. For instance, engaging in the learning of a musical instrument has been associated with the refinement of various sensorimotor processes, drawing upon and potentially bolstering cognitive capacities that include task inhibition and switching, key components of inhibitory control (Hennessy et. al., 2019).

The intricate relationship between musical training and inhibitory control in adults has been further examined through specific experimental tasks. Research employing the Go/No-go and Stroop tasks, which measure response inhibition and interference control respectively, has leveraged event-related potentials (ERPs) to uncover the nuanced impacts of musical training on these executive functions (Chen, Zhou, & Chen, 2020).

Interestingly, the neurophysiological effects of music training have been observed distinctly in older populations. While older adults typically experience a natural decline in cognitive and motor inhibition, those with musical training have demonstrated behavioral and neurophysiological advantages over their non-musician counterparts. This suggests that the cognitive and motor domains, particularly inhibitory control, may be preserved or even enhanced in aging populations that engage in musical activities (Sarkamo, 2018)

Moreover, the benefits of music training on inhibitory control are not limited to those with extensive musical experience. A study by Fasano et al., (2019) found that even a brief, intensive period of orchestral music training—spanning ten lessons over three months—can positively influence inhibitory control in adults. This finding suggests the potential for music training to induce rapid cognitive benefits and underscores the accessibility of music as a tool for cognitive enhancement.

In light of these findings, it becomes evident that the cognitive gains from music training in adults are considerable and multifaceted. The performance improvements in executive functions, particularly in inhibitory control, highlight the transformative potential of musical engagement throughout adulthood.

Bialystok and DePape (2009) however found that musicians adults register higher performances on tasks measuring inhibitory control, such as the Simon and auditory Stroop tasks, relative to their non-musical counterparts. This claim is supported by Amer et al. (2013) & Travis et al., (2011), who noted that musicians' increased ability to manage conflicting information translates into better task performance. In contrast, the findings of Slevc et al., (2016) and Zuk et al., (2014) have challenged this association, reporting no significant performance differences on similar cognitive tasks between musicians and non-musicians across age groups.

However, in the research of Passarotto et al., (2023), 35 professional pianists (aged 24-41 years) were assessed to clarify whether there is a correlation between their musical expertise and their executive function. Neuropsychological assessments included tasks such as Design Fluency, Numerical Stroop, Trail Making, and the Tower of London (Passarotto et al., 2023). Despite the rigorous training and academic achievements of the pianists, no improvements in executive functions were observed. Specifically, the results showed only marginal improvements in Numerical Stroop reaction time among professional pianists suggesting that their musical training could specifically enhance their inhibitory control abilities, thus critically highlighting a differential and potentially selective effect of musical training on cognitive abilities (Passarotto et al., 2023).

Further evidence for the cognitive benefits of music training is seen in the context of reaction times. Professional musicians have been observed to have faster reaction times on the Color-Word Stroop task compared to amateur musicians (Travis, Harung & Lagrosen, 2011), and musically experienced young adults have shown faster response rates than non-musicians on tasks such as the arrow Simon and auditory Stroop task (Bialystok & Depape, 2009). Among older musicians, increased reaction times were evident, although other aspects of inhibitory control were similar to those of non-musicians (Amer et.al., 2013).

At this point we should point out that the time spent by musicians engaged in musical practice is particularly important. For example, Ericsson, Krampe, and Tesch-Ro¨mer (1993) emphasize that successful violinists in a professional class should have accumulated an average of 10,000 hours of practice by age 21. In addition, musical performance requires high levels of control through the need for selective attention and inhibition, switching, updating, and monitoring. The report we cite is based on the correlation between duration of musical training (years of training) and improved performance on auditory and visual Stroop tasks (Ericsson, Krampe, & Tesch-Römer, 1993). Consequently, musicians who practice intensively for many years may show cognitive benefits in executive control and higher performance than their counterparts.

The literature reveals, however, that musicians in various age groups—children (Degé et al., 2011; Moreno et al., 2011), young adults (Bialystok & Depape, 2009; Strait & Kraus, 2011), and older adults (Seinfeld et.al., 2013)—show enhanced inhibitory control.

In summary research indicates that music training in adults is linked to significant cognitive benefits, particularly in enhancing inhibitory control—a core executive function. Studies demonstrate that adult musicians, including older populations who are typically prone to declines in inhibitory control, show improved cognitive abilities, suggesting that musical training might offset age-related cognitive decline (Hennessy et al.,2019; Izbicki, 2020). Experimental tasks like the Go/No-go and Stroop tests further reveal that musicians have better response inhibition and interference control, with faster reaction times and more efficient task performance compared to non-musicians (Chen, Zhou, & Chen, 2020; Bialystok & DePape, 2009).

Notably, the extent of engagement in musical practice is a critical factor. Ericsson et al., (1993) highlight the importance of accumulated practice, correlating extensive musical training with improved performance on tasks requiring executive control. This is reflected in studies where professional musicians exhibit faster reaction times on cognitive tasks than amateurs (Travis, Harung & Lagrosen, 2011). However, the literature also points to inconsistencies and suggests that the relationship between musical training and inhibitory control might be complex and selectively affected by various methodological factors.

Despite these complexities, the enhanced inhibitory control observed in musicians across different age groups—from children to older adults—underscores the positive impact of musical engagement (Degé et al., 2011; Moreno et al., 2011; Seinfeld et al., 2013). The distinctions between sub-components of inhibitory control, such as response inhibition and interference control, are critical and necessitate precise methodological differentiation in research, as they are conceptually distinct and engage different neural mechanisms (Diamond, 2013).

In conclusion, the cumulative evidence suggests that music training is associated with quicker reaction times and enhanced inhibitory control, highlighting its potential as a tool for cognitive improvement. However, given the variability in findings, further research is warranted to clarify the specific cognitive processes influenced by musical training and the optimal conditions for such enhancements."

3.3.2 Bilingualism/Multilingualism and Inhibition Control

A wealth of empirical evidence highlights that bilingual/multilingual individuals who habitually use multiple languages simultaneously activate all languages during the speech production process (Costa, Roelstraete, & Hartsuiker, 2006). This simultaneous activation at the same time causes lexical competition between the different language systems. Scientific consensus suggests that executive control mechanisms are imperative to navigating this lexical competition. In particular these mechanisms are responsible for maintaining the activation of the relevant language, while effectively suppressing the non-target language (Cuppini et al., 2012).

In particular, the inhibitory control (IC) model, as proposed by Green (1998) as mentioned above, specifically emphasizes the necessity of inhibiting inappropriate responses, such as words from a non-target language. This model implies that bilingual individuals develop a sophisticated ability to control and inhibit responses that do not align with their communicative goals. The reactive nature of this inhibition, where non-target language candidates are suppressed as they are activated, indicates a sophisticated level of inhibitory control consistently consistent with bilingual language processing.

Similarly, the Bilingual Interactive Activation (BIA) model and its successor, the BIA+ model, further support the concept of enhanced inhibitory control (Dijkstra & Van Heuven, 1998). In the BIA model, activation of word representations in one language leads to inhibition of representations in the other language. This process requires a form of inhibitory control, where the bilingual person must constantly manage and suppress the activation of irrelevant language systems. The BIA+ model goes a step further by proposing that top-down control mechanisms, influenced by the speaker's goals and contextual factors, guide lexical selection (Dijkstra & Van Heuven, 1998). This shift to a more top-down approach suggests an advanced level of inhibitory control, where bilinguals do not simply react to linguistic interference, but actively manage and control their language output based on the demands of the situation.

Additionally, in light of the growing neuropsychological evidence illustrating the adaptability of the brain to repetitive activities, it has been hypothesized that persistent cognitive control to resolve language conflicts may increase proficiency in tasks that depend on this specific mechanism (Jaeggi et al., 2008). Additionally, as we have highlighted, studies have documented that bilinguals, who are capable of smooth switching between languages, show improved performance over monolinguals in a range of tasks that require the suppression of interference as a result of strengthening inhibitory control (Bialystok, Craik, & Luk, 2008).

Consequently, based on these models it can be critically hypothesized that bilingual language processing involves a sophisticated level of inhibitory control. This control is crucial for managing the complex task of navigating multiple language systems, allowing bilingual individuals to communicate effectively by selecting the appropriate language and suppressing the irrelevant according to their context and communicative intentions, thereby enhancing cognitive control.

However, the study by Costa et al., (2008) revealed that bilinguals/multilinguals tend to have faster response times on tasks such as the Attention Network Test compared to monolinguals, suggesting a more refined ability to manage attention and control responses to irrelevant stimuli. This enhancement in inhibitory control is documented by later research, including that of Tao et al., (2011), which aligns with the hypothesis that bilingualism confers cognitive benefits.

In addition to the research conducted by Bialystok et al., (2004), further confirms the relationship between bilingualism and improved executive control. Bilinguals demonstrate a superior ability to navigate and resolve conflicting cues more efficiently than monolinguals, indicating a greater degree of attentional control in the Simon task.

Findings from the application of the Stroop task, as in the studies of Coderre et al., (2013), consistently show that bilinguals outperform monolinguals. Repeated training of coordination between two languages appears to improve the brain's executive functions, particularly aspects of task switching and inhibitory response.

Further in the study of Limberger & Buchweitz (2014) a detailed investigation of the effects of bilingualism and multilingualism on executive functions was carried out, involving a group of participants of 59 individuals aged between 19 and 42 years. This sample consisted of 19 monolinguals, 20 bilinguals, and 20 multilinguals, offering a strong framework for comparative analysis. The researchers used two basic assessment tools for their analysis: the Non-Linguistic Attention Network Task, and the Sentence Comprehension Task. Findings showed that multilingual participants showed faster response times in all conditions of the Nonverbal Attention Network Task compared to monolingual participants.

The study further revealed that multilinguals tended to exhibit enhanced inhibitory control, a key component of executive function that is crucial for suppressing competing stimuli and managing cognitive processes. This particular finding is consistent with the results of earlier research conducted by Bialystok et al., (2004, 2008) and Costa et al., (2008, 2009), who have similarly highlighted the cognitive advantages of bilingualism and multilingualism. The consensus in these studies critically suggests that multilingualism may indeed promote the development of more efficient and flexible cognitive systems, thereby offering a deeper understanding of the nuanced relationship between language proficiency and cognitive functioning.

However, the cognitive advantage of bilingualism is not limited to a specific stage, but is evident throughout life, benefiting children, young adults, and the elderly, as highlighted by Bialystok & Feng (2009), Bialystok et al., (2008), and Bialystok et al. (2005) respectively. The enduring nature of these bilingual advantages suggests a sustained enhancement of executive functions that may provide a protective effect against age-related cognitive decline.

In contrast, an alternative line of scientific research argues that bilingualism and multilingualism do not confer cognitive benefits. Paap & Greenberg (2013) and subsequent analyzes by Paap et al., (2015) challenge the notion that bilinguals enjoy cognitive advantages, particularly in the context of executive functions, and challenge the claim that foreign language acquisition enhances specific executive abilities. Despite these counterarguments, the preponderance of empirical evidence leans toward a consensus that bilingual and multilingual individuals may indeed possess potential cognitive advantages, as supported by studies by researchers such as Limberger & Buchweitz (2014) and Warmington et al., (2018).

In summary the data presented in that unit offer a comprehensive analysis of the relationship between bilingualism/multilingualism and cognitive functions, particularly focusing on executive functions such as inhibitory control. The general conclusion drawn from the empirical studies is that bilingual and multilingual individuals often exhibit enhanced executive control, particularly in tasks that require inhibitory processes to manage attention and suppress interference from competing stimuli.

Research models like the Inhibitory Control (IC) model and Bilingual Interactive Activation (BIA) models provide theoretical support for the observed cognitive enhancements in bilingual individuals. These models suggest that the regular use of multiple languages requires and fosters a more sophisticated level of inhibitory control, allowing individuals to select the relevant language and suppress the non-target language efficiently.

Studies employing various cognitive tasks, including the Attention Network Test, Simon task, and Stroop task, indicate that bilinguals tend to perform better than monolinguals, demonstrating faster response times and a more refined ability to manage attention and control responses. This advantage is observed across different age groups, suggesting that bilingualism may offer a protective effect against age-related cognitive decline.

Furthermore, the data highlight that this cognitive benefit is not confined to any specific stage of life but is evident in children, young adults, and the elderly. This enduring nature of the bilingual advantage points to a sustained enhancement of executive functions across the lifespan.

However, the text also acknowledges the existence of conflicting evidence. Some studies challenge the notion that bilingualism confers cognitive benefits, particularly in the context of executive functions. This debate reflects the complexity of conclusively attributing cognitive advantages to bilingualism and suggests that further research is necessary to clarify these relationships.

In summary, the majority of the data support the premise that bilingualism and multilingualism may promote the development of more efficient and flexible cognitive systems, enhancing inhibitory control and contributing to a more adept executive function framework. Despite some dissenting research, the preponderance of evidence leans toward the conclusion that managing multiple languages can indeed be beneficial to cognitive functioning.

3.3.3 Music training and Working memory

In the context of music training, working memory plays a central role by combining a set of auditory sequences, retrieving relevant data from long-term storage, associating sounds with their emotional and semantic counterparts, and supporting the generation of emotional and mental responses while restraining the interference of other external competing stimuli. (Moradzadeh et al., 2014; Slevc et al., 2016; Burunat et al., 2014). This cognitive synergy activated by musical engagement suggests that working memory could be a fulcrum upon which many cognitive improvements related to musical expertise and executive control turn.

In line with the above and specifically for the context of this Master's dissertation, which strictly discusses Executive Functions (EF) and extends to empirical studies, it is important to note that working memory (WM) is more than just a passive storage system similar to short-term memory. For the purposes of this research, working memory is strictly understood as a system in charge of storing and manipulating information related to specific tasks, characterized by its limited duration and capacity (Bergman-Nutley & Klingberg, 2014).

This system is usually involved in one or more cognitive functions, including mental manipulation of information, flexible use of stored data, or inhibition of external or distracting stimuli (Oechslin et al., 2013). The distinction made here is for two reasons: first, working memory is distinguished from short-term storage by its requirement for active mental manipulation of encoded information or suppression of non-goal-oriented stimuli. Second, working memory functionality depends on the integrity of medial temporal lobe regions, unlike short-term memory (Suarez & Carrion, 2015). This differentiation highlights the complexity and diverse nature of working memory as an integral component of executive functions.

Behavioral tasks often used to study working memory involve a mixture of information storage, cognitive manipulation, and interference management. These tasks include N-back (Pallesen et al., 2010; Oechslin et al., 2013; Ding et al., 2018), digit span backward (Zuk et al., 2014), reading span (Franklin et al., 2008; D'Souza et al., 2018), and working span tasks (Franklin et al., 2008; D'Souza et al. , 2018).

Schellenberg's (2011) cross-sectional analysis investigated the selective effect of music training on executive functions and working memory in 9 to 12-year-old children. The study revealed that although there were negligible differences in overall executive functions when comparing the musically trained children to the control group, a significant improvement in the musically trained group's performance on the Digit Span Backward task was evident. This result highlights the specificity of the executive role of working memory in cognitive tasks that require the mental manipulation and reorganization of information—a skill set closely related to the demands of music training.

In addition, the body of research on music training and cognitive enhancement in adults has yielded insights specifically regarding working memory. The studies indicate that engaging in music training is correlated with improved working memory. This link is thought to be mediated by changes in neural oscillations, which play a fundamental role in cognitive processing. Music training's association with enhanced working memory is attributed to the stimulation of both localized and complex, distributed neural networks (Yurgil et al., 2020) .

Active musical engagement, such as learning to play the piano or percussion, has been particularly noted for its positive effects on working memory in adults. These studies underscore that the benefits are more substantial with active participation rather than passive listening, suggesting that the cognitive exercises involved in playing an instrument may activate and strengthen working memory networks (Colombo, Habibi, & Alain, 2020) .

Moreover, the enhancement of working memory among musicians is not confined to professional practitioners; even amateur musicians exhibit working memory capacities that surpass those of non-musicians. This observation suggests that the act of engaging with music, regardless of the level of expertise, is sufficient to produce measurable improvements in working memory (Criscuolo et al., 2019).

Further, the study by Ding et al. (2018) revealed that musical adults not only have greater memory capacity in tasks involving tonal variations but also exhibit longer retention times. This aspect of retention, which is closely related to executive control in memory, is less pronounced in tasks with atonic stimuli, underscoring the differential effect of music training on cognitive functions.

Moreover, studies involving N-back tasks (as reported by Ding et al., 2018; Oechslin et al., 2013; Okhrei et al., 2017) reveal that experienced musicians excel not only in memory storage but also in executive functions such as updating and manipulating information. This superior performance on tasks that require real-time cognitive processing according to the researchers highlights enhanced executive control over working memory, involving both auditory and visual stimuli.

Specifically, Ding and colleagues (2018) conducted a study that assessed the working memory for musical sounds in musicians and non-musician adults, discovering a heightened level of neural activation in musicians. This increase was noted particularly in the neural networks responsible for maintaining attention and executing cognitive control, including the prefrontal areas and the Supplementary Motor Area (SMA). They observed a more pronounced correlation between task performance and activation patterns in musicians as opposed to non-musicians, a disparity that became especially evident under conditions of high working memory demand. The researchers propose that the enhanced performance observed in musicians on working memory tasks could be attributed to their superior capacity for sustained cognitive control, as evidenced by increased activity in brain regions associated with processing.

In addition, the study by Franklin et al. (2008) further revealed the special capabilities of adult musicians in verbal working memory, particularly in tasks that require simultaneous storage and processing of information. However, the executive benefits that music training provides on working memory appear to be domain-specific. Studies involving various visuospatial memory assessments (Strait et al., 2010; Okhrei et al., 2017; Hansen et al., 2013) show that the executive benefits of music training are not as significant in the visuospatial domain as in the auditory and verbal domains.

Importantly, the studies by Lee et al. (2007) and Strait, et al., (2010) show that music-trained participants outperform their counterparts not only on basic memory tasks but also on those requiring complex executive control. This is particularly evident in music-trained children, who outperform their peers on tasks that require higher executive processing in addition to basic phonological storage.

However, in the study conducted by Cohen, Evans, Horowitz & Wolfe (2011), findings revealed that musical adults and older adults showed enhanced auditory recognition memory for both musical and non-musical stimuli. In contrast, this study also noted that this auditory memory enhancement did not extend to the musicians' visual memory, despite their engagement with visual cues such as reading sheet music. This indicates that music training specifically enhances executive control within auditory and verbal working memory, while its effect on visuospatial working memory remains less significant.

In the study also Talamini et al., (2017), the results reveal a significant relationship between performance on auditory and audiovisual memory tasks and musical training particularly in melody recognition, when no articulatory suppression is present. In contrast, this association was not observed in tasks involving visual working memory. These results indicate, as in previous research, a specific improvement in the executive processes of working memory through music training, particularly for auditory tasks, while similar improvements in visual working memory are not evident.

At this point we need to mention that the enhancement of verbal working memory through music training, as observed in various empirical studies, may be due to Patel's Shared Syntactic Integration Resource Hypothesis (SSIRH). This hypothesis posits a common neural substrate for the processing of syntactic structures in both music and language, offering a further explanation for the observed cognitive interaction and enhancement between these domains (Patel, 2011).

In particular, this hypothesis posits that both domains use similar syntactic processing frameworks, which are essentially the rules and structural patterns that govern the construction of sentences in language and the organization of musical signifiers. Acquiring musical expertise, therefore, increases the brain's ability to reinforce and integrate these syntactic structures, a skill that directly transfers to language processing, thus facilitating improvements in verbal memory and executive components.

Patel et.al., (2011) showed that the ERP component elicited by a syntactic violation in a sentence or a harmonic violation in a musical phrase is the same. In a behavioral study, Charronnat et.al., (2005) showed that harmonic structure interferes with performance on a lexical decision task, an effect found equally for musicians and non-musicians. These results suggest an interconnection between the cognitive processes involved in language and music, making it plausible that extensive practice of each would have similar effects in both domains.

However, research by Chan, Ho, & Cheung (1998) and Brandler & Rammsayer (2003) reveals specific improvement in verbal memory among musicians, as opposed to their counterparts. This dichotomy not only highlights the specialized effect of music training on verbal memory but also indicates that this improvement does not extend to other types of memory, such as arithmetic and spatial memory. The critical aspect of this research is the specificity of the impact, suggesting that the cognitive skills developed through music training are more aligned with verbal processing than with other cognitive functions.

However, this relationship is nuanced, as seen in studies by Racette & Peretz (2007) and Peterson & Thaut (2007), which indicate that incorporating music and verbal cues does not consistently enhance memory performance. This inconsistency could be attributed to factors such as the novelty of the musical composition and the context in which integration occurs, thus indicating a conditional nature of music's facilitative effects on memory.

In contrast, Taylor & Dewhurst (2017) have extended this hypothesis by demonstrating a more generalized effect of music training on cognitive abilities, including memory, across different types of words. This suggests that the benefits of music training may involve a wider range of cognitive functions than previously assumed.

Critically analyzing these findings in the context of SSIRH, it is apparent that the benefits of music training on verbal memory are likely due to the enhancement of shared cognitive and neural resources that underlie syntactic processing in both music and language. This specificity in improvement suggests a targeted cognitive improvement, where skills improved through music training transfer effectively to verbal memory tasks but not to other types of memory.

Further in the study by Hansen, Wallentin, and Vuust (2013), the relationship between musical expertise and working memory was examined. The group consisted of 60 participants, divided into three distinct groups—non-musicians (N=20), amateur musicians (N=20), and expert musicians (N=20)—with a balanced gender distribution within the age range of 18 to 29 years old. The group of musicians was further classified based on their active participation in musical practice, with specialists enrolling in Danish music academies.

To assess participants' cognitive abilities, the researchers used the WAIS-III Digit Span (DS) for verbal working memory and the WMS-III Spatial Span (SS) for visuospatial working memory, alongside the Musical Ear Test (MET) to objectively measure musical skills.

Findings from the study revealed that experienced musicians significantly outperformed non-musicians in verbal working memory storage, as shown by their DS Forward scores. However, this increased capacity did not extend to manipulation of verbal working memory, as reflected by DS Backward scores, nor to visuospatial working memory, as indicated by SS scores. These results suggest that music training may specifically enhance some aspects of verbal working memory, but does not seem to provide a general improvement in all areas of working memory.

However, the consistency of these findings is variable, indicating the need for a more nuanced understanding of the relationship between musical expertise and working memory across different domains and groups (Hanna-Pladdy & MacKay, 2011; Hansen et al., 2013).

In summary, these studies collectively highlight the multifaceted effect of music training on working memory, particularly its executive components. They demonstrate that music training not only enhances the storage capacity of working memory, but more importantly, enhances its executive functions, such as the ability to manipulate, organize and effectively use information. This sheds light on the potential of music education as a tool to enhance executive aspects of cognition, with important implications for educational strategies and cognitive development. However, the exploration remains incomplete without specifically looking at those who have undergone extensive and rigorous musical training – (professional musicians) further only minimal research. Additionally, according to the definition of musician we have mentioned in no study we have encountered it. Differentiation is critical as professional musicians, through their continuous and intensive training, may show more advanced or distinct cognitive profiles, particularly in the domains of executive functions. This suggests that the cognitive effects observed in non-professional musicians may represent only a fraction of the potential improvements that can be achieved with higher levels of musical expertise.

3.3.4 Bilingualism/Multilingualism and Working Memory

Extensive research highlights the important pivotal role of working memory in both native and foreign language acquisition and mastery, suggesting it as a critical tool for language learning (Engel, Gathercole, & Martin, 2011; Majerus, Poncelet, Greffe, & Van der Linden, 2006; Gathercole, & Masoura, 2005). This hypothesis posits working memory not simply as a transitory store but as an active participant in language processing (Baddeley, Gathercole, & Papagno, 1998).

Assessment of working memory typically includes simple and complex span tasks, which respectively test the ability to retain information for a short period of time and manage concurrent processing challenges. These works illuminate the dual nature of working memory, as a storehouse for short-term information and as a general executive system that orchestrates cognitive control (Baddeley, 2000; Cowan et al., 2005; Engle, 2010).

Empirical studies have shown a correlation between proficiency in complex dimensional tasks and enhanced proactive interference control, suggesting an advanced working memory capacity (Kane & Engle, 2003; Unsworth & Engle, 2007). Furthermore, the inherent link between working memory and fluid intelligence, observed in both children and adults, highlights cognitive control as a fundamental mechanism in this relationship (Engel de Abreu, Conway, & Gathercole, 2010; Engle et. al., 1999). However, there is a hypothesis that bilingual experience can affect working memory performance through its effect on executive control (Conway et al., 2002).

Additionally, Smithson & Nicolaidis (2013) examined how verbal working memory contributes to virtual gesture generation in both bilingual and monolingual students aged 18 to 28. (*To clarify at this point or virtual gesture generation likely refers to gesture generation in a virtual or simulated environment, which can be an important aspect of communication and can be influenced by language abilities and cognitive processes).

Their findings show that while monolinguals maintain distinct verbal and visuospatial working memory resources, bilinguals show an interrelated relationship between these capacities, for both short-term storage and cognitive processing tasks. This finding suggests a differential interdependence of working memory components that varies with language proficiency.

Extending this, Rosselli, Ardila, Lalwani Vélez-Uribe (2015) revealed that bilingual university students show superior verbal working memory on tasks such as digit forward and backward, with performance levels modulated by the extent of their language proficiency. Specifically, those with high proficiency in both languages outperformed those with less balanced language skills. However, when language proficiency factors were equated, differences in working memory performance were no longer statistically significant. This highlights the central role of language proficiency in shaping the executive functions of working memory, characterizing it as a critical variable in cognitive comparisons.

Critically we would argue at this point that the possible enhancement of working memory (WM) capacities may derive from the continuous linguistic duality inherent in bilinguals, which requires the efficient orchestration of WM resources. This lifelong bilingual discipline in language management could lead to an expansion of WM capacity or an elevation of the executive component.

However, another research tradition shows contradictory results as obtained by Soveri, Fornells & Laine (2011) whose study of adult bilinguals found no clear relationship between frequency of language switching, age of learning a second language or regular use of both languages and performance on WM tasks as measured by the n-back task. This was further replicated by Jylkkä et al., (2019) who found no evidence to support the Bilingual Executive Advantage hypothesis. In fact, they noted that involuntary language switches were associated with poorer WM performance, suggesting that such occurrences may be indicative of executive control challenges rather than bilingual efficiency.

Luo et al., (2013) found a bilingual advantage on spatial working memory tasks, yet reported that bilinguals showed impaired performance on verbal working memory, as assessed by the word span task, in contrast to their monolingual counterparts. On the other hand, Bonifacci et al., (2011) found no distinct difference between bilinguals and monolinguals on verbal working memory tasks requiring digit recall. However, there are cases where bilinguals have demonstrated superior verbal working memory compared to monolinguals, as evidenced by studies such as those conducted by Kroll et al., (2002).

In summary, the literature posits working memory (WM) as an essential executive system, crucial for learning both native and second languages. This system goes beyond the traditional concept of a passive storage unit, serving instead as a sophisticated processor supporting complex language processing and cognitive control mechanisms. The preponderance of empirical evidence suggests that bilingualism can provide improvements in WM, with bilingual individuals demonstrating increased abilities in tasks that require strong executive control. This bilingual WM benefit is inextricably linked to the degree of language proficiency, with the literature pointing to a more significant interconnection between the verbal and visuospatial memory systems in individuals with higher language acumen. While the literature presents some divergent findings, the general narrative confirms that bilingualism offers a distinct cognitive advantage, potentially increasing the executive functions inherent in working memory when language proficiency is optimized.

3.3.5 Music training-Bilingualism/Multilingualism and Cognitive Flexibility (Task Switching)

Task switching according to the literature is a critical dimension of cognitive flexibility, specifically it is indicative of an individual's ability to navigate between multiple tasks or mental contexts. This cognitive ability is particularly important in environments that require rapid switching between different activities, as observed in studies where task switching always leads to increased reaction times, known as switching costs, compared to repetitive task performance (Hsieh, 1994). Within this paradigm, the local switch cost represents the direct cognitive cost of switching between tasks in a heterogeneous task block, while the global switch cost refers to the induction of multiple sets of tasks in working memory across different task blocks (Braver, Reynolds, & Donaldson, 2003).

The exploration of task switching in the context of both music training and bilingualism arguably provides fertile ground for examining the mechanisms of cognitive flexibility. Musicians, through their training, often engage in complex task switching as they interpret musical notation, translate it into motor actions, and simultaneously attend to auditory feedback (Prior & MacWhinney's, 2009) This continuous shift closely aligns with the cognitive processes involved in bilingual task switching, where individuals must suppress one language while activating another, thereby navigating between different sets of linguistic rules (Wiseheart, Viswanathan, & Bialystok, 2014)

Both musical training and bilingualism require the use of executive components of working memory. Musicians to coordinate complex sensory and motor tasks and bilinguals to manage multiple language systems. The interplay between these activities suggests that individuals engaged in music training or individuals who are bilingual may exhibit enhanced task-switching capabilities, possibly reflected in reduced switching costs (D'Souza, Moradzadeh, & Wiseheart, 2018). Such cognitive training implies a common underlying proficiency, a more finely tuned system of executive control within working memory, which is constantly updated and strengthened through the demands of managing competing stimuli in both the linguistic and musical domains (Kousaie & Phillips, 2012).

Specifically, in the study conducted by Bialystok & Martin (2004), bilingual preschool children showed a cognitive advantage during a card sorting task that required them to alternate between different sorting rules, such as color and shape. This task assessed their ability to activate the relevant norm and suppress the antecedent. The study revealed that the bilingual children performed better than their counterparts when classifying objects based on visual features such as color and shape, but not when the task involved semantic classification, such as categorizing objects based on their use or location.

In another study with university students, Prior & Macwhinney (2009) found that bilinguals showed lower local switching costs in a non-verbal task-switching test, indicating more efficient cognitive shifting. This was true even after accounting for variation in working memory and academic ability, as measured by the SAT. Despite these findings, the study's limited consideration of socioeconomic status as a variable could affect its validity given its established importance in bilingualism research.

In addition, studies show that the influence of music training on cognitive flexibility, especially in task switching contexts, varies according to the specificity of the tasks and the level of experience of the individual. Specifically, a cross-sectional analysis revealed that pianists could significantly improve their ability to alternate between reading G and F clefs within the first year of conservatory training, a skill that took other instrumentalists up to five years to match (Gade & Schlemmer, 2021). In contrast, when engaged in a less musically oriented task, such as the Stroop number task, musicians experienced increased switching costs. This task required switching between quantifying the number of digits presented and recognizing the digits, arranged in a predetermined order. These findings suggest that the degree of musical task relevance and the frequency of task switching play critical roles in the cognitive adaptability attributed to music training. Such insights are essential to understanding the complex interplay between structured musical practice and improvements in task-switching efficiency (Gade & Schlemmer, 2021).

The synthesis of the literature on task switching, cognitive flexibility and their enhancement through music education and bilingualism highlights the multifaceted nature of these cognitive processes. Evidence suggests that both musicians and bilinguals show improved task-switching abilities, possibly evidenced by reduced switching costs. However, these improvements are moderated by the level of musical training and the relevance of the tasks to musical expertise. While bilingualism generally promotes cognitive flexibility, the influence of socioeconomic factors must be considered to fully understand its impact. Collectively, these studies contribute to a nuanced understanding of how structured cognitive activities such as music and language learning shape and improve our executive functions, offering valuable insights for applications in areas of education and cognitive development.

3.3.6 Linguistic and Musical Mastery: Assessing Their Roles in Enhancing Executive functions and Working memory

The dynamic interplay between structural brain plasticity and engagement in complex cognitive activities has become a central point in neuroscience research. The earlier notion that brain atrophy is inevitable has been reexamined in light of findings suggesting that experiences such as language learning and music training can cause increased neural density, potentially affecting the brain's executive functions (Buckner et al., 2008; Mechelli et al., 2004).

Bilingualism, as a cognitively demanding activity, is consistently associated with higher executive control. In particular, bilingual individuals as we have mentioned in previous sections demonstrate a sophisticated ability to manipulate through dual language systems, a process that appears to enhance the executive functions of the brain, particularly in the areas of attentional control and conflict management (Bialystok et al., 2007). This suggests that bilingual experience may act as a catalyst for cognitive enhancement, although the exact neural mechanisms remain under investigation.

However, the relationship between music education and cognitive functioning mirrors bilingual experience, with music requiring similar executive resources. Musicians engage in intense practice sessions that not only enhance their musical ability, but also appear to enhance their executive function, echoing the cognitive flexibility, inhibitory control, and working memory observed in bilingual individuals (Ericsson et al., 1993; Miyake et al., 2000; Schellenberg, 2006).

Neuroimaging studies confirm these findings, demonstrating significant frontal cortex activity during musical tasks, similar to patterns observed in bilingual subjects. This suggests that the cognitive demands of music could induce improvements in executive functions, further supporting the hypothesis that both bilingualism and music training can tune executive control mechanisms (Zatorre et al., 1994; Altenmüller, 1989).

Despite compelling evidence for the cognitive benefits of bilingualism and music education, a research gap remains, especially regarding direct comparisons between the two groups. Few studies have thoroughly investigated the cognitive outcomes of professional musicians with extensive training (over five years) and those of bilingual individuals, particularly in terms of their executive function profiles.

Furthermore, individual studies often fall short of examining all components of executive functions, which include inhibitory control, cognitive flexibility, and working memory (Miyake et al., 2000). Comprehensive studies evaluating these executive components in both musicians and bilinguals are needed. Such research could clarify which of these experiences exerts a stronger effect on the enhancement of cognitive functions.

Furthermore, gender-specific strategies have been observed in executive function tasks, particularly in working memory. For example, in a spatial working memory task, individuals may use different strategies to remember and manipulate information about object locations (Grissom & Reyes, 2019). Research findings suggest that these strategies may differ depending on gender, with men and women potentially using different neural pathways or types of cues such as allocentric cues to efficiently complete the same cognitive tasks (Grissom & Reyes, 2019). In particular, females and males may activate dissimilar neural circuits during such tasks, indicating divergent underlying activities in the networks involved.

Educational attainment, even during the developmental years, exerts a strong influence on executive functions, often overshadowing gender differences. Gender differences in cognitive performance, however, have been linked to disparities in early educational conditions.

Contrary to the expectation of sharp gender dichotomies in executive function, variation between the sexes often exceeds differences between them. This suggests that gender-related differences in executive function outcomes may reflect task-specific strategies rather than gender-related innate abilities (Grissom & Reyes, 2019). Consequently, while gender and educational background are prominent in the discussion of executive function development, they intersect with a complex matrix of sociobiological and environmental determinants.

In conclusion, while recognizing the advantages of bilingualism and musical expertise individually in enhancing cognitive functions, the field would benefit from a systematic comparative investigation of these effects by also expanding the influence of gender and education. In particular, it is important to expand the scope of the research to include professional musicians with musical proficiency greater than five years, examining the full range of executive functions. Such research is not only urgent but essential to understanding the cognitive enhancing potential of these experiences and their implications for lifelong cognitive development.

Current study

The aim of the current research is to systematically investigate the functioning of executive functions (EF) and working memory among musicians, bilingual/multilingual individuals and monolingual speakers. Specifically, the study scrutinizes the cognitive outcomes in professional musicians with extensive training (greater than five years) and bilingual/multilingual adults, compared to their monolingual counterparts, on various executive tasks. Executive functions, which include the broad spectrum of strategic planning, decision-making, and inhibitory control, are fundamental to cognitive processing and behavioral regulation, and closely related to both language and cognitive development (Miyake et al., 2000; Stuss & Alexander, 2000).

The present study is based on the hypothesis that environmental factors—namely, music training and bilingualism/multilingualism—play an important role in enhancing these cognitive domains (Bialystok, 2001; Moreno et al., 2011). Musicians, compared to non-musicians, have demonstrated superior abilities in tasks requiring verbal memory and executive control (Costa-Giomi, 1999; D'Souza, Moradzadeh, & Wiseheart, 2018). Moreover, bilinguals/multilinguals have shown remarkable advantages in tasks that require cognitive flexibility, a key component of EFs (Bialystok et al., 2004; Garbin et al., 2010).

This study intends to further analyze these improvements, across all three components, by examining the cognitive performance of individuals with musical expertise and bilingual/multilingual proficiency on tasks assessing working memory and executive functions. The potential cognitive benefits of such environmental enrichments will be assessed, taking into account the methodological gaps identified in the previous literature. In particular, the study will address inconsistencies in the operationalization of “music groups” and control for confounding variables such as gender and educational level, thereby providing a more comprehensive understanding of the cognitive effects of these experiential factors.

In conclusion, this research aims to contribute a nuanced comparative analysis of the cognitive effects of musicality and bilingualism in a wide range of EFs, using a robust assessment methodology adapted to the Greek population, with the ultimate goal of bridging critical research gaps in the field.

According to the theoretical framework presented in the first part of this paper, for the relationship between working memory and executive functions, we formulated the following hypotheses: In particular, we hypothesized that the group of Musicians would achieve higher performance compared to the control group in the assessment tasks of Verbal Working Memory (Hypothesis 1a): A substantial body of scientific research provides evidence that musical training positively affects working memory efficiency. Studies such as those conducted by Franklin et al., (2008) & Oechslin et al., (2013), consistently reveal that adult musicians show increased ability in verbal working memory tasks, particularly those that require the simultaneous storage and processing of information. This correlation is further strengthened by the work of (Okhrei et al., 2017; Hansen et al., 2013), extending these findings by suggesting that the cognitive advantage of musicians does not only involve fundamental verbal memory tasks but also extends to executive components. operation. A recurring theme in these investigations is the marked improvement in the performance of the phonological loop and central stem key components of the working memory system in musically trained individuals.

Consistent with hypotheses 1b and 1c, we hypothesized that the Musician group would exhibit superior performance relative to the control group on measures of executive function. This prediction is supported by a synthesis of the existing literature, which indicates that individuals with musical expertise demonstrate increased ability in executive tasks, particularly those that require inhibitory control and task-switching capabilities (Sachs et al., 2017; Okada & Slevc, 2018;

Passarotto et al., 2023; Gade & Schlemmer, 2021). Research conducted by Bialystok & DePape (2009) & Gade & Schlemmer (2021) further confirms this perspective, revealing that musicians outperform non-musicians on executive function assessments, particularly on tasks that measure inhibitory control such as Simon tasks and auditory Stroop as well as in tasks requiring task switching.

Enhanced executive functioning in musicians is linked to their refined ability to navigate conflicting streams of information, an ability that translates into more efficient task performance and inhibitory control. Amer et al., (2013) and Travis et al., (2011) provide empirical support for this claim, noting the increased ability with which musicians process and reconcile incompatible stimuli. Accordingly, the evidence suggests a cognitive advantage inherent in musical adults, with empirical assessments consistently showing that they achieve higher scores on executive function assessments compared to their non-musical peers. This body of research highlights the potential of music education as a means of cultivating and enhancing executive abilities critical to complex cognitive functions.

According to hypothesis 2a of the present study, we hypothesized that Bilinguals/Multilinguals would show improved performance on Verbal Working Memory assessments compared to the control group. The existing literature documents the central role of working memory as an essential construct in the acquisition and knowledge of both primary and additional languages, positing it as an essential cognitive resource in the context of language acquisition (Engel, 2011; Majerus et al., 2006; Gathercole & Masoura, 2005). The current hypothesis conceives working memory not simply as a temporary storage facility but as an active processor in language operations (Baddeley et al., 1998).

The empirical findings presented by Rosselli et al., (2015) reveal an association between bilingual proficiency and verbal memory capacity in university students with bilingual abilities showing increased performance on sequential memory tasks such as digit span sequences. This improvement appears to be shaped by the degree of proficiency in both languages, with individuals exhibiting high bilingual proficiency outperforming those with less balanced language abilities. This observation is further confirmed by studies by Kroll et al., (2002) and Yoo & Kaushanskaya (2012), who collectively confirm that bilingualism is associated with superior verbal working memory performance relative to monolingualism. These findings highlight a positive interaction between bilingualism/multilingualism and the enhancement of working memory capacity, reinforcing the importance of the bilingual advantage in cognitive language progress.

Consistent with Hypotheses 2b and 2c, we hypothesized that individuals in the Bilingual/Multilingual group would outperform the control group on executive function assessments. This hypothesis finds strong support in the scientific literature, where evidence shows that multilingual individuals show increased ability in executive tasks, with particular improvements in areas requiring inhibitory control and the expert navigation of task-switching demands (Bialystok, Craik, & Luk, 2008; Bialystok et al., 2004; Prior & MacWhinney, 2010).

The research by Costa et al. (2008) revealed that bilinguals/multilinguals show accelerated response times on tests such as the Attention Network Test, indicative of a more sophisticated ability to regulate attention and mitigate interference from irrelevant stimuli—a key component of executive function. This increase in inhibitory control and cognitive flexibility finds further empirical validation in studies by Tao et al., (2011) and Prior & Macwhinney (2010), which are consistent with the hypothesis that bilingualism/multilingualism offers cognitive advantages. Therefore, the preponderance of evidence points to a distinct cognitive benefit associated with bilingual/multilingual proficiency, with empirical measures consistently revealing superior performance on executive function assessments among these demographics as opposed to monolinguals.

Based on hypothesis 3a of this research, we hypothesized that the Music group would not demonstrate superior results on Verbal Working Memory assessments relative to the Bilingual/Multilingual cohort.

Academic discussions highlight shared cognitive mechanisms between musical and linguistic processes, as both domains involve auditory modulations and are governed by analogous structures in syntax and temporal sequencing (Patel, 2011; Slevc & Okada, 2014). This interplay is further illuminated by theoretical models that draw parallels between the cognitive processing of music and language syntax, indicating a dynamic activation of musical elements similar to language processing, where a melodic progression triggers proactive cognitive patterns similar to phonetic unfolding in language comprehension (Bella, Peretz & Aronoff, 2003; Schulkind, Posner & Rubin, 2003). The intersection of music training and cognition also reflects bilingual language experience, requiring commensurate executive cognitive resources. Neuroimaging evidence supports this view, showing strong activation in the frontal cortex during musical tasks, mirroring the neural involvement seen in bilinguals (Zatorre et al., 1994; Altenmüller, 1989).

Focusing on memory retention, Ding et al., (2018) found that individuals with extensive musical training not only have increased verbal memory capacity for tasks involving tonal variation but also exhibit prolonged retention times, indicative of the specialized influence of musical training on cognitive functions. This specialization, particularly in tasks with tonal stimuli, highlights the differential effects of musical training, which are less pronounced with atonic stimuli. The findings from Lee et al., (2007) & Parbery-Clark et al., (2009) add to this narrative by revealing that musically trained participants outperform verbal memory tasks involving both rudimentary recall and those requiring complex executive control. Cheung & Chan (2003) reinforce these observations by reporting significant improvements in musicians' verbal memory after months of musical practice.

In contrast, Yang & Yang (2015) investigation into working memory differences between bilinguals and monolinguals, assessing the correlation between bilinguals' working memory advantage and their applied language strategies, found that bilinguals performed superiorly on serial counting tasks and reverse digit recall. Specifically reflecting an increased phonological storage and executive processing ability.

Consequently, these empirical studies suggest a symbiotic relationship between working memory and the respective experiences of musicians and bilinguals/multilinguals. We could posit an underlying relevance in the cognitive improvements attributed to each domain, thus informing the hypothesis that despite their distinct experiential backgrounds, musicians and bilinguals may exhibit comparable verbal working memory abilities.

Based on Hypotheses 3b and 3c of the current research, we hypothesized that the Music Cohort would not outperform the Bilingual/Multilingual group on executive function assessments.

Empirical studies have described cognitive improvements associated with music training, particularly in the areas of reaction time and task-switching acuity. Evidence shows that professional musicians exhibit faster reaction times on the Color-Word Stroop Task compared to their amateur counterparts (Travis, Harung & Lagrosen, 2011), and musically skilled young adults exhibit faster response rates than non-musicians on tasks such as Simon arrow and auditory Stroop tasks (Bialystok & DePape, 2009).

Additionally, a differentiated cross-sectional examination of musicians in task-switching contexts suggests that task musicality and task-switching frequency are critical to the enhanced cognitive flexibility afforded by music training (Gade & Schlemmer, 2021). Specifically, musicians engaged in tasks with minimal musical relevance, such as the Stroop Task, incurred increased switching costs, in contrast to perceptual tasks where such costs were mitigated.

Parallel research on bilingualism has pointed to a comparable ability in task switching and interference suppression, highlighting an enhanced executive control in fluent multilinguals (Bialystok, Craik, & Luk, 2008). The application of the Stroop Task in studies by Coderre et al., (2013) confirms that bilinguals consistently outperform monolinguals, suggesting that continuous practice of navigating between two languages sharpens the brain's executive functions, particularly task switching and inhibitory control.

This account is further supported by Prior & MacWhinney (2010) work, which showed that bilinguals show reduced local switching costs in nonverbal task-switching assessments, suggesting a more enhanced cognitive switching ability. This finding was borne out even after controlling for variations in working memory ability and scholastic ability as measured by standardized assessments such as the SAT.

Accordingly, these scientific investigations implicate a reciprocal enhancement of executive functions across musical and bilingual/multilingual experiences. Such findings suggest a fundamental parity in the cognitive benefits attributed to each discipline, supporting the hypothesis that, despite their different experiential backgrounds, musicians, and bilinguals may parallel each other in their executive function abilities.

According to hypotheses 4 a, b, and c of the present study, we hypothesized that there would be a difference in the performance of working memory and executive functions in all groups between male and female participants

Confirming previous empirical evidence, as elucidated in the studies of Pauls, Petermann & Lepach (2013) and further validated by the research contributions of González-Garrido, a statistical superiority of men over women has been observed in the performance of the tasks. that quantitatively assess working memory, with a prominent predominance in visuospatial abilities. In contrast, predictions based on the Stroop paradigm—an evaluative benchmark for executive functions—predict a tendency for female subjects to exhibit improved performance relative to their male counterparts, thus indicating a potential gender difference in cognitive processing efficiency in these areas.

In addition, the academic norm recognizes the tendency for gender-specific systematic variations in the methodologies used in the assessment of working memory and executive functions. In tasks based on spatial working memory, a variety of strategies for encoding, maintaining, and manipulating spatial information in relation to object localization have been documented. The research paper of Grissom & Reyes (2019) argues that these strategic differences are inherently gendered, indicating a difference in the activated neural substrates and typologies of environmental conditions—exemplified by allocentric markers—that are exploited by individuals to navigate and excel in analogous exercises. This analytic discourse enhances the sensitivity of our understanding of the intersection of gender and cognition and contributes a layer of complexity to the existing academic debate on cognitive stratification.

According to hypotheses 5 a, b, and c of the present study, we hypothesized that there would be a difference in the performance of working memory and executive functions in all groups between a higher level of education and a lower one.

Research conducted by Mazzonna & Peracchi (2012) highlights the importance of educational attainment in accounting for the variability observed in cognitive abilities. Specifically, their study outlines that adults with lower educational attainment, particularly those residing in Mediterranean areas, have been documented to exhibit reduced proficiency on tests that measure executive functions. This finding aligns with the broader academic consensus regarding the impact of education on cognitive development.

Furthermore, the work of Alloway and Alloway (2010) clarifies the predictive ability of working memory in relation to academic success, reinforcing the notion that the ability to process and retain information is intricately linked to educational progress. Such ideas not only confirm the fundamental role of working memory in learning outcomes but also highlight its potential as a measure of educational stratification. The convergence of these studies adds to the academic debate about the interplay between educational experiences and cognitive abilities, suggesting a nuanced relationship that warrants comprehensive exploration within the cognitive sciences.

CHAPTER 4
Methodology

Participants and Settings

4.1 Objective and Sampling Methodology

The aim of the current research study is to evaluate the comprehensive investigation into the individual and combined impacts of musical training and bilingualism/multilingualism on executive functions. Utilizing a structured, stratified sampling approach, a total of 90 healthy adults (N=90) were recruited. For the purpose of the present study all participants were systematically categorized into three distinct groups: the first group was the Musicians group, the second group consisted of Bilinguals/Multilinguals and the third group was the Control group. This categorization was designed to enable nuanced comparative analyses, thereby enhancing the scientific rigor of the study's findings.

Musicians Group

The Musicians group comprised 30 healthy participants (N=30). The average age within this cohort was 33.40 years, with a standard deviation of SD=6.28 years, indicating a diverse age range. The gender distribution was balanced, consisting of 16 males and 14 females.

Regarding educational attainment, 60% of the participants held undergraduate degrees, in various fields such as music studies, philology, and mathematics, 30% had completed high school, and the remaining 10% possessed postgraduate qualifications.

All participants had undergone formal conservatory training for a period exceeding five years and held positions as either professional musicians or music educators. Musically, the group specialized in various genres: 33.3% in classical music, 16.7% in instrumental music, and 50% in other genres. Instrumental proficiency was also diverse, with 36.6% skilled in string instruments, 6.7% in wind instruments, and 56.7% in keyboard instruments. (See Table 1 for additional details).

Bilinguals/Multilingual Group

The Bilinguals/Multilingual group consisted of 30 participants (N=30). The average age for this cohort was 32.57 years, with a standard deviation of SD=7.88 years, indicating a varied age range. The gender distribution was slightly skewed, featuring 16 females and 14 males.

In terms of educational background, the majority (56.7%) of participants held undergraduate degrees in various fields such as, Philosophy, English literature, and Kindergarten teachers. The remaining participants had either completed high school, undergone vocational training, or attained postgraduate qualifications. The group displayed a diverse occupational distribution, with roles spanning both the public and private sectors, as well as freelance and unemployed statuses. All participants in this group possessed state-certified language proficiency in multiple languages, including but not limited to English, Arabic, Russian, and Italian. (Refer to Table 1 for more information).

Control Group

The Control group functioned as a baseline for comparative analyses and included 30 participants (N=30). The average age for this cohort was 34.30 years with a standard deviation of SD=6.45 years within this group was comparable to that of the Musicians group, and the standard deviation indicated a wide age range. The gender distribution was balanced, consisting of 16 males and 14 females.

With respect to educational attainment, a significant majority (76.7%) had completed secondary education. The remaining participants were either engaged in vocational training, pursuing undergraduate studies, or were unemployed. Notably, this cohort lacked formal training in either music or multiple languages, setting them apart from the other groups in the study.

Table 1: Consolidated Demographic and Key Characteristics of Participants Across Three Groups

Group	Age (M ± SD)	Gender (M/F)	Education	Job/Occupation	Conservatory Music Training	Bilinguals/Multilinguals	Instrument Use
Musicians Group (N=30)	33.40 ± 6.28	16/14	30% High School, 60% Undergraduate, 10% Postgraduate	50% State, 20% Private, 16.7% Freelance, 13.3% Student	33.3% Classical, 16.7% Instrumental, etc.	100% None	36.6% Stringed, 6.7% Wind, 56.7% Keyboard
Bilinguals/Multilinguals Group (N=30)	32.57 ± 7.88	14/16	23.3% High School, 13.3% IVT, 56.7% Undergraduate, 6.7% Postgraduate	26.7% State, 36.7% Private, 13.3% Freelance, 20% Student, 3.3% Unemployed	100% None	66.7% Bilinguals, 33.3% Multilinguals	100% None
Control Group (N=30)	34.30 ± 6.45	16/14	76.7% High School, 13.3% IVT, 10% Undergraduate	13.3% State, 36.7% Private, 30% Freelance, 3.3% Student, 16.7% Unemployed	100% None	100% None	100% None

4.2 Procedure

The methodology for this study was meticulously crafted to uphold rigorous academic integrity and methodological precision. Initial recruitment targeted candidates from two leading conservatories with a focus on musical education, requiring them to have a minimum of five years of formal musical training.

For the Bilinguals/Multilinguals group, candidates with continuous dual-language exposure from infancy were prioritized. Multilingual participants were selected based on their proficiency in more than two languages. The Control group was carefully assembled from a broader demographic, specifically including individuals without formal training in either music or languages.

Before commencing any research activities, participants were presented with a comprehensive informed consent form. This form outlined the study's primary objectives, emphasized the voluntary nature of participation, and assured participants of their right to withdraw at any point without repercussions. After obtaining consent, a detailed demographic questionnaire was administered, exploring variables such as age, gender, marital status, educational background, and occupational status, as well as specific competencies in music and languages.

Data collection was divided into two phases: Phase One, from February to May 2022, included 60 participants; Phase Two, from January to March 2023, included the remaining 30 participants. The majority of assessments (approximately 80%) were conducted in-person, while the rest were administered digitally. Musician assessments predominantly occurred within their respective conservatories. Since these are considered personal data, the European Union law that has existed since May 28, 2018, was applied. According to the law, the use of sensitive personal data is allowed only for research reasons. The study's protocol followed the principles outlined in the Helsinki Declaration.

Each assessment session was designed to last between 15 and 30 minutes, with the cognitive tests administered sequentially to all participants in the same order. While this uniform approach ensured consistency across sessions, it is acknowledged that the absence of counterbalancing might lead to order effects, where the sequence of tests could influence participant responses."

The principle of voluntary participation was reiterated, emphasizing the participants' right to withdraw at any time. Data were systematically archived in written form and cross-referenced with electronically collected demographic information via Google Forms. Participants were thoroughly briefed on the study's academic significance and its role as a Master's dissertation. Any questions, especially those related to the cognitive assessment tools, were addressed with academic rigor.

4.3 Assessment Instruments

Data collection utilized a combination of cognitive assessment tools: The Verbal Fluency Test, the Digit Span Assessment, and the Stroop Test. These tools were selected to facilitate a nuanced evaluation of working memory and other executive functions. The assessment of verbal working memory was conducted through the Forward and Backward Digit Recall Test, a subtest of the Wechsler Adult Intelligence Scale, Fourth Edition (WAIS-IV) (Wechsler, 1955). To augment this evaluation, the Verbal Fluency Test was incorporated to offer a more comprehensive understanding of linguistic cognitive abilities (Kosmidis, Vlahou, Panagiotaki, & Kiosseoglou, 2004). For the scrutiny of executive functions, the Stroop Test was utilized (Stroop, 1935).

Verbal Working Memory Assessment

The Digit Span Test, part of the Wechsler Adult Intelligence Scale (WAIS) as formulated by Wechsler (1955), serves as a specialized instrument for evaluating verbal working memory. This assessment is divided into two distinct tasks: (Digit Span Forward) and (Backward Digit Recall).

In the Forward Digit Recall task, participants are presented with a series of digits, each articulated at one-second intervals. They are then instructed to recite the digits in the order presented. This task comprises eight sequences, resulting in a total of 16 sets of numbers.

The Backward Digit Recall task follows a similar format but requires participants to recite the digits in reverse order. Backward Digit Recall includes seven sequences, amounting to 14 sets of numbers. If participants fail to accurately recall the sequence in two attempts, the task is terminated. Prior to this task, an introductory phase allows participants to familiarize themselves with the format through a practice sequence. Successful completion of this preliminary task is mandatory for progressing to the main Backward Digit Recall.

Scoring is systematic: one point is awarded for each accurately recalled sequence. Therefore, each sequence can yield a score between 0 and 2, depending on the participant's accuracy. The total score for each task is the sum of these individual sequence scores. The Forward Digit Recall task has a maximum possible score of 16, while the Backward Digit Recall task can yield up to 14 points. The aggregate score for the entire Digit Span Test is the sum of these two tasks, with a maximum possible score of 30.

Semantic and Phonological Verbal Fluency Assessment

The Verbal Fluency Test, as developed by Kosmidis et al., (2004), serves as a diagnostic tool for assessing both semantic and phonological verbal fluency. This assessment focuses on category-based and initial letter-based word generation tasks, offering insights into semantic memory, cognitive flexibility, linguistic proficiency, lexical depth, retrieval processes, and executive function control. Participants are given 60 seconds to generate as many relevant words as possible based on a given prompt.

In the semantic fluency *task*, participants are instructed to produce words that fall within three specific categories: "animals," "fruits," and "objects." For the phonological fluency task, participants are prompted to generate words that begin with three designated greek letters: "X," "Σ," and "A." Both tasks are constrained by a 60-second time limit. Scoring is straightforward: each accurately produced word earns one point. The assessor meticulously records the generated words, categorizing them and noting transitions, repetitions, and deviations.

Semantic fluency fundamentally relies on robust memory storage and efficient retrieval mechanisms, while phonological fluency emphasizes initiation skills and cognitive flexibility over mere memory storage. Optimal performance in these tasks requires extensive verbal knowledge, rapid and systematic word retrieval, parallel processing, and vigilant monitoring. Suboptimal performance may indicate compromised verbal and executive functions, potentially signaling reduced attention spans (Stavrakaki, Megari, Kosmidis, Apostolidou & Takou, 2012).

For this specific study, in the initial segment, participants were instructed to generate a diverse list of animals within the allocated 60 seconds. In the subsequent segment, they were tasked with producing unique words—excluding proper nouns or variations of previously mentioned words—that begin with the letter "X," also within a 60-second time frame.

Assessment of Executive Functions

Stroop Test

The Stroop Test, originally formulated by Stroop in (1935), functions as a key diagnostic instrument for examining selective attention and executive functions, particularly focusing on inhibitory control. This assessment comprises three distinct stages: reading, color identification, and conflict resolution. Participants are instructed to navigate through these stages swiftly while maintaining response accuracy. If an error occurs, they are encouraged to correct it immediately without awaiting intervention from the assessor.

In the initial reading stage, participants are presented with 100 instances of three-color terms (blue, red, green), displayed in black uppercase letters against a white background. They are given 60 seconds to read these terms aloud. This task is administered in a controlled environment to ensure minimal distractions. Participants are instructed to read as quickly and accurately as possible, and their responses are recorded using a digital timer to ensure precision.

The subsequent color identification stage presents 100 instances of the symbols "XXX" in the aforementioned colors, also against a white background. Participants are tasked with identifying the ink color within a 60-second time frame. During this stage, each response is noted, and the time taken for each identification is accurately logged.

The final stage, known as conflict resolution, introduces cognitive dissonance by displaying 100 color terms in ink colors that contradict the semantic meaning of the terms (e.g., the word "green" displayed in red ink). Participants are required to identify the ink color within 60 seconds, necessitating the suppression of the automatic response to read the written word. This stage is critical for assessing cognitive control and flexibility.

For scoring, the assessor carefully records the time taken by each participant to complete each stage, measured in seconds, along with any corrected or residual errors. This data is meticulously documented on a designated form, which includes fields for the participant's ID, the times for each stage, and the number of errors. The forms are then stored securely and the data entered into a database for analysis.

Historically, the Stroop Test has demonstrated heightened sensitivity to abnormalities in the brain's left hemisphere. Specifically, individuals with lesions in this area often exhibit performance durations nearly twice as long as those without such impairments. This test is commonly utilized in neuropsychological evaluations, particularly for patients with Parkinson's disease. Additionally, individuals diagnosed with depression frequently show diminished executive functions, as evidenced by their performance on this task. The Stroop Test fundamentally relies on robust executive control, requiring participants to inhibit a deeply ingrained cognitive process—namely, reading.

CHAPTER 5
Results

5.1 Data Analysis

This chapter presents an in-depth examination of cognitive performances among three distinct groups: Musicians, Bilinguals/Multilinguals, and a Control Group. Our methodological approach is centered on employing a Multivariate Analysis of Variance (MANOVA), selected for its robust capability to discern differences across a range of cognitive assessments. This statistical technique is integral to our study, as it allows for a comprehensive evaluation of group-based disparities in cognitive functions, particularly in verbal memory, executive functioning, and inhibition control.

Our investigation into these cognitive domains is a focused effort to understand how specific backgrounds in music and language influence cognitive abilities. This chapter, therefore, delves into the intricate patterns of cognitive strengths and potential enhancements linked to these unique experiential backgrounds.

Multivariate Analysis of Variance (MANOVA)

In our detailed investigation, we utilized MANOVA to evaluate cognitive performance differences across the Musicians, Bilinguals/Multilinguals, and Control Group. This analysis included various cognitive assessments like the Digit Span Test, Verbal Fluency Test, and Stroop Test, covering aspects such as Total, Forward, and Backward scores, as well as Condition A time and the number of items correctly identified in Conditions B and C.

The MANOVA results revealed profound multivariate effects, signifying notable variations in cognitive performance related to group membership. These findings were statistically corroborated by measures such as Pillai's Trace (1.113, F(24,

154) = 8.048, $p < .000$, partial $\eta^2 = .556$), Wilks' Lambda (.184, F(24, 152) = 8.418, $p < .000$, partial $\eta^2 = .571$), Hotelling's Trace (2.813, F(24, 150) = 8.792, $p < .000$, partial $\eta^2 = .584$), and Roy's Largest Root (2.012, F(12, 77) = 12.913, $p < .000$, partial $\eta^2 = .668$).

Further univariate ANOVA analyses for each dependent variable underscored significant group differences in most cognitive measures. For example, the Digit Span Total Score (F(2, 87) = 26.313, $p < .000$, partial $\eta^2 = .377$) and the Verbal Fluency Total Words Animals (F(2, 87) = 16.465, $p < .000$, partial $\eta^2 = .275$) exhibited substantial group differences. However, certain tests, such as Switching Words Letter X and Condition C Items Correctly, did not show statistically significant differences among the groups.

In addition, the Bonferroni-adjusted pairwise comparisons within the MANOVA analysis highlighted significant contrasts in cognitive performance between Musicians, Bilinguals/Multilinguals, and the Control Group. Specifically, in the Digit Span Total Score, both Musicians and Bilinguals/Multilinguals exhibited significantly superior performance compared to the Control Group, with mean differences of 3.77 ($p = .001$) and 3.27 ($p = .003$), respectively. A similar pattern was evident in the Digit Span Forward Score, where Musicians and Bilinguals/Multilinguals again outperformed the Control Group, showing mean differences of 3.13 ($p < .000$) and 2.43 ($p < .000$), respectively. These results suggest enhanced cognitive capabilities in Musicians and Bilinguals/Multilinguals in certain domains, particularly memory-related tasks, relative to the Control Group. However, when comparing Musicians directly with Bilinguals/Multilinguals, the results were more nuanced. In the Digit Span Total Score, Musicians demonstrated a significant edge with a mean difference of 3.77 ($p = .001$), but in other tests like the Digit Span Forward Score and the Verbal Fluency Test (Total Words, Clustering for Animals and Letter X), the performance differences were not statistically significant, suggesting comparable levels of cognitive functioning in these areas. This indicates that while Musicians may have advantages in comprehensive memory tasks, both Musicians and Bilinguals/Multilinguals show similar capabilities in other cognitive domains, reflective of their specialized training and linguistic proficiency.

Our comprehensive analysis using MANOVA, supplemented by detailed univariate ANOVAs and pairwise comparisons, effectively highlights the significant influence of specialized training and linguistic proficiency on various cognitive abilities. These observed variances across the groups, particularly in memory and executive function measures, elucidate the cognitive benefits associated with musical training and bilingual/multilingual proficiency. These findings provide valuable insights into the cognitive distinctions shaped by different experiential backgrounds and support our initial hypotheses, contributing to a deeper understanding of cognitive diversity.

5.2 Transition to T-Test Analysis

Having established a foundational understanding of group differences in cognitive performance through the MANOVA, we now turn our attention to a more detailed examination using independent samples t-tests. This transition allows us to focus on specific pairwise comparisons between the groups, providing a finer resolution of understanding for each cognitive metric.

The t-test analysis complements our MANOVA findings, offering a targeted exploration of the differences between individual groups. This approach is particularly valuable in elucidating the nuances of how Musicians, Bilinguals/Multilinguals, and the Control Group perform relative to each other in specific cognitive tests.

T-Test Results and Interpretation

In the following sections, the results from the t-tests will be meticulously presented and interpreted. For each cognitive assessment, such as the Digit Span Test, Verbal Fluency Test, and Stroop Test, we have conducted separate t-tests to compare the mean scores between each pair of groups. This allows us to pinpoint where significant differences lie and to what extent these differences are manifested

T-test Independent samples

In the continuation of the statistical analysis, primary Hypothesis 1 concerning the impact of musical training on cognitive performance was scrutinized. Specifically, the focus was on working memory and executive functions, as assessed through the Digit Span Test (Wechsler, 1955), Verbal Fluency Test (Kosmidis et al., 2004), and the Stroop Test (Stroop, 1935). Independent samples t-tests were employed, with the group to which the participants belonged serving as the independent variable, and the mean scores on these tests serving as the dependent variables. All statistical analyses were conducted using SPSS Statistics, version 25**.**

The t-test results revealed statistically significant differences between the Musicians and the Control Group across multiple cognitive domains. Especially for the working memory assessment via the Digit Span Test, statistically significant differences were observed in both Serial and Backward Digit Recall. Specifically, for the Digit Span Total Score, a t-value of $t(58) = 6.545$, $p < 0.001$ was noted. Likewise, for the Digit Span Forward Score, a t-value of $t(58) = 4.997$, $p < 0.001$, and for the Digit Span Backward Score, a t-value of $t(58) = 5.574$, $p < 0.001$, were registered (Descriptive statistics for the Digit Span Test are presented in Table 1).

Table 1: Descriptive Statistics of cognitive performances for two groups in the Digit Span Test

Measures	**Group**	**N**	**Mean**	**Std. Deviation**	**Range**	**Minimum**	**Maximum**	**Skewness**	**Kurtosis**
Digit Span Total Score	Musicians	30	20.60	4.360	15	13	28	0.055	-0.854
	Control Group	30	13.57	3.954	18	6	24	0.328	0.499
Digit Span Forward Score	Musicians	30	11.67	2.721	9	7	16	0.190	-1.212
	Control Group	30	8.53	2.097	10	5	15	0.936	1.787
Digit Span Backward Score	Musicians	30	8.97	2.871	9	4	13	-0.386	-1.328

	Control Group	30	5.40	2.010	8	2	10	0.198	-0.160

Note 1: All skewness and kurtosis values are reported with standard error values of 0.427 and 0.833, respectively. Note 2: N represents the valid number of listwise participants for each group.

In the domain of executive functions, assessed through the Verbal Fluency Test, significant differences were also observed. For Total Words (Animals), a t-value of t(48.158) = 5.745, $p < 0.001$ was noted. For Animal Switching, a U-value of 250.500, $p = 0.003$ was found. However, for Clustering (Animals), a U-value of 438.000, $p = 0.859$ was observed, indicating no statistical significance (See Table 2). (*We opted for non-parametric tests, like the Mann-Whitney U test, primarily due to the non-normal distribution of our data and the presence of outliers. These tests are more appropriate when data do not meet the normality assumption required for parametric tests and offer robustness against the influence of outliers).

Table 2: Descriptive statistics of cognitive performances for two groups in the Animal-Related Measures

Measures	Group	N	Mean	Std. Deviation	Range	Minimum	Maximum	Skewness	Kurtosis
Verbal F. Total Words Animals	Musicians	30	28.03	6.53	21	16	37	-0.506	-0.850
	Control Group	30	20.00	4.01	17	9	26	-0.757	0.516
Clustering Animals	Musicians	30	2.439	0.56	3.2	0	3.2	-2.841	12.130
	Control Group	30	2.620	0.61	2.2	2	4.2	1.046	0.480
Switching Animals	Musicians	30	16.60	4.66	22	0	22	-1.560	4.130
	Control Group	30	13.40	4.26	18	5	23	-0.071	-0.080
Repetitions Animals	Musicians	30	0	0	0	0	0	NA	NA
	Control Group	30	0	0	0	0	0	NA	NA

Mistakes Animals	Musicians	30	0.10	0.305	1	0	1	2.809	6.308
	Control Group	30	0	0	0	0	0	NA	

Note 1: All skewness and kurtosis values are reported with standard error values of 0.427 and 0.833, respectively. Note 2: represents the valid number of listwise participants for each group

Additionally, for Total Words (Letter X), a t-value of $t(58) = 3.253$, $p = 0.002$ was observed. Mann-Whitney U tests were conducted for the non-parametric variables. For Clustering (Letter X), a U-value of 310, $Z = -2.120$, and $p = 0.034$ was noted, reaching statistical significance. However, for Switching (Letter X), the U-value was 420, $Z = -1.426$, $p = 0.154$, which did not attain statistical significance (See Table 3).

Table 3: Descriptive statistics of cognitive performances for two groups in the Verbal Fluency Test (Letter X)

Measures	Group	N	Mean	Std. Deviation	Range	Minimum	Maximum	Skewness	Kurtosis
Verbal F Total Words	Musicians	30	14.53	4.84	17	7	24	0.263	-0.755
	Control Group	30	10.93	3.65	15	4	19	-0.125	-0.233
Clustering Words	Musicians	30	2.650	1.25	4.5	0	4.5	-1.055	0.542
	Control Group	30	1.727	2.05	8.0	0	8.0	1.065	1.158
Switching Words	Musicians	30	10.60	4.09	15	2	17	-0.653	-0.428
	Control Group	30	9.53	3.08	13	4	17	0.094	0.042
Repetition Words	Musicians	30	0.10	0.40	2	0	2	4.281	18.773
	Control Group	30	0.00	0.00	0	0	0	-	-
Mistakes	Musicians	30	0.03	0.18	1	0	1	5.477	30.000
	Control Group	30	0.00	0.00	0	0	0	-	-

Note 1: Skewness and kurtosis values are accompanied by standard error values of0.427 and 0.833, respectively. Note 2: N represents the valid listwise number of participants in each group

Regarding the 'Repetition' and 'Mistakes' variables, our data revealed a notable frequency of zero scores, in both conditions indicative of a null-inflated distribution. Given the limitations imposed by this data distribution, conventional statistical tests of inference were deemed inappropriate for these particular variables.

Furthermore, in the Stroop Test, another measure of executive functions, the Musicians group significantly outperformed the Control Group. Specifically, for the time taken for Stroop Condition A, a t-value of $t(58) = -4.391$, $p < 0.001$ was observed. For items correctly identified in Condition B, a t-value of $t(58) = 2.978$, $p = 0.004$ was noted, and the same held true for Condition C, with a t-value of $t(58) = 5.115$, $p < 0.001$ (details in Table 4).

Table 4: Descriptive Statistics of cognitive performances for two groups in the Stroop Test

Measures	Group	N	Mean	Std. Deviation	Range	Minimum	Maximum	Skewness	Kurtosis
Stroop Condition A (sec)	Musicians	30	36.1510	2.83	10.43	29.49	39.92	-0.670	-0.259
	Control Group	30	39.5040	3.08	10.92	34.05	44.97	0.306	-0.833
Condition B (Items)	Musicians	30	73.27	9.07	32	58	90	0.005	-0.644
	Control Group	30	65.27	11.6	50	40	90	-0.015	0.074
Condition C (Items)	Musicians	30	58.37	11.3	47	37	84	0.314	0.509
	Control Group	30	44.37	9.90	38	25	63	0.095	-0.539

Note 1: All skewness and kurtosis values are presented with standard error values of 0.427 and 0.833, respectively. Note 2: N indicates the valid number of listwise participants in each group

Analyzing the Cognitive Benefits of Musical Training with T-Tests

In summary, independent samples t-tests were used to strongly support Hypothesis 1 that musical training has a broad-ranging positive influence on various aspects of cognitive function, including working memory and executive functions. Specifically, the findings of the analyses confirm Hypothesis 1a, as the Musician group demonstrated statistically significant superior performance in the working memory assessment tasks, compared to the Control Group. For Hypothesis 1b, the findings partially confirm the hypothesis; while significant differences were observed in Total Words and Switching, no significant differences were found in Clustering for the Verbal Fluency Test (Animals) and in Switching for the Verbal Fluency Test (Letter X). Lastly, in the Stroop Test, Hypothesis 1c is fully confirmed, with the Musician group significantly outperforming the Control Group across all key metrics (the results are discussed in the Discussion section).

In the next step of statistical analysis, Hypothesis 2 was examined, concerning the effect of bilingualism/multilingualism on cognitive performance, we especially focused on working memory and aspects of executive functions. Independent samples t-tests were used, which determine the linguistic abilities of the participants - either bilingual/multilingual or monolingual as the independent variable and mean Digit Span Test scores as the dependent variables.

The t-test results revealed statistically significant differences between the Bilinguals/Multilinguals group and the control group on all baseline measures of working memory. Specifically, for the Total Digit Span Score, a t-value of $t(58) = 3.702$, $p < 0.001$ was observed. Similarly, for the Front Digit Span Score, a t value of $t(58) = 4.749$, $p < .001$ was recorded. However, for the Digit Span Backward Score, a t value of $t(58) = 1.861$, $p = 0.068$ was noted, falling short of statistical significance. (Descriptive statistics for the Digit Span Test are presented in Table 5).

Table 5: Descriptive statistics of cognitive performances for two groups in the Digit Span Test.

Measures	Group	N	Mean	Std. Deviation	Range	Minimum	Maximum	Skewness	Kurtosis
Digit Span Total Score	Bilinguals/Multilingual	30	16.83	2.78	10	12	22	0.339	-0.785
	Control Group	30	13.57	3.95	18	6	24	0.328	0.499
Digit Span Forward Score	Bilinguals/Multilingual	30	10.97	1.87	7	8	15	0.222	-0.574
	Control Group	30	8.53	2.10	10	5	15	0.936	1.787
Digit Span Backward Score	Bilinguals/Multilingual	30	6.30	1.72	6	4	10	0.536	-0.920
	Control Group	30	5.40	2.01	8	2	10	0.198	-0.160

Note 1: All skewness and kurtosis values are presented with standard error values of 0.427 and 0.833, respectively. Note 2: N indicates the valid number of listwise participants in each group

In the realm of executive functions, as assessed by the Verbal Fluency Test, we observed significant differences. For Total Words in the 'Animals' category, a t-value of $t(48.462) = 4.756$ was recorded, with a p-value of <0.001. For Clustering in the same category, the t-value was $t\ (58) = 4.450$, also with a p-value of <0.001. For Switching in the 'Animals' category, the t-value was $t\ (58) = 2.064$, with a p-value of 0.044 (See Table 6).

Table 6: Descriptive Statistics of cognitive performances for two groups in the Animal-Related Measures

Measures	Group	N	Mean	Std. Deviation	Range	Minimum	Maximum	Skewness	Kurtosis
Verbal F. Total words Animals	Bilinguals/Multilinguals	30	26.60	6.46	23	15	38	0.069	-0.971
	Control Group	30	20.00	4.01	17	9	26	-0.757	0.516
Clustering Animals	Bilinguals/Multilinguals	30	3.272	0.52	2.0	2.5	4.5	0.491	-0.314
	Control Group	30	2.620	0.61	2.2	2.0	4.2	1.046	0.480
Switching Animals	Bilinguals/Multilinguals	30	15.93	5.20	21	7	28	0.539	-0.343
	Control Group	30	13.40	4.26	18	5	23	-0.071	-0.080
Repetitions Animals	Bilinguals/Multilinguals	30	0.07	0.36	2	0	2	5.477	30.000
	Control Group	30	0.00	0.00	0	0	0	-	-
Mistakes Animals	Bilinguals/Multilinguals	30	0.00	0.00	0	0	0	-	-
	Control Group	30	0.00	0.00	0	0	0		

Note 1: All skewness and kurtosis values are presented with standard error values of 0.427 and 0.833, respectively. Note 2: N indicates the valid number of listwise participants in each group

For the 'Letter X' category, the t-value for Total Words was t(58) = 3.305, with a p-value of 0.002. In Clustering, Welch's t-test showed a t-value of t(58) = 2.712 and a p-value of 0.009. However, for Switching in the 'Letter X' category, the t-value was t(58) = 0.933, with a p-value of 0.355, indicating no statistical significance. “Due to frequent zero scores in 'Repetition' and 'Mistakes,' we relied on detailed descriptive statistics"(See Table 7).

Table 7: Descriptive Statistics of cognitive performances for two groups in the Verbal Fluency (Letter X)

Measures	Group	N	Mean	Std. Deviation	Range	Minimum	Maximum	Skewness	Kurtosis
Verbal F Total Words Letter X	Bilinguals/Multilinguals	30	14.50	4.65	17	7	24	0.302	-0.829
	Control Group	30	10.93	3.65	15	4	19	-0.125	-0.233
Clustering Words Letter X	Bilinguals/Multilinguals	30	2.937	1.34	6.0	0	6.0	-0.946	1.895
	Control Group	30	1.727	2.04	8.0	0	8.0	1.065	1.158
Switching Words Letter X	Bilinguals/Multilinguals	30	10.30	3.28	13	3	16	-0.241	-0.711
	Control Group	30	9.53	3.08	13	4	17	0.094	0.042
Repetition Words Letter X	Bilinguals/Multilinguals	30	0.00	0.00	0	0	0	-	-
	Control Group	30	0.00	0.00	0	0	0	-	-
Mistakes Word Letter X	Bilinguals/Multilinguals	30	0.00	0.00	0	0	0	-	-
	Control Group	30	0.00	0.00	0	0	0	-	-

Note 1: All skewness and kurtosis values are presented with standard error values of 0.427 and 0.833, respectively. Note 2: N indicates the valid number of listwise participants in each group

Finally, in the domain of executive functions, as assessed through the Stroop Test, Bilinguals/Multilinguals showed significant differences between the control group. Specifically, for Stroop Condition A (Time in Seconds), a t value of $t(58) = -3.857$, $p < 0.001$ was recorded, indicating a statistically significant mean difference of -3.223 seconds. For Condition B (Correct items), the t value was $t(58) = 4.055$, $p < .001$, indicating a significant mean difference of 11,333 items. Similarly, for Condition C (Correct items), the t value was obtained as $t(58) = 4.194$, $p < .001$, indicating a mean difference of 11,367 items (See Table 8 for details).

Table 8: Descriptive Statistics of cognitive performances for two groups in the Stroop Test and Conditions

Measures	Group	N	Mean	Std. Deviation	Range	Minimum	Maximum	Skewness	Kurtosis
Stroop Condition A (sec)	Bilinguals/Multilinguals	30	36.2813	3.38771	11.79	31.23	43.02	0.338	-0.803
	Control Group	30	39.5040	3.07636	10.92	34.05	44.97	0.306	-0.833

Condition B Items_correctly	Bilinguals/Multilinguals	30	76.60	10.009	36	60	96	0.194	-1.109
	Control Group	30	65.27	11.582	50	40	90	-0.015	0.074
Condition C Items_correctly	Bilinguals/Multilinguals	30	55.73	11.061	37	35	72	-0.063	-1.022
	Control Group	30	44.37	9.901	38	25	63	0.095	-0.539

Note 1: All skewness and kurtosis values are presented with standard error values of 0.427 and 0.833, respectively. Note 2: N indicates the valid number of listwise participants in each group

Analyzing the Cognitive Impact of Bilingualism/ Multilingualism: Insights from T-Test Analysis″

In summary, independent samples t-tests were employed to robustly substantiate Hypothesis 2, which posited that Bilingualism and Multilingualism exert a comprehensive positive impact on various cognitive faculties, including working memory and executive functions.

Specifically, the results corroborate the hypothesis 2 in several key areas. For working memory, the bilingual/multilingual group exhibited statistically significant superior performance in both Total and Front Digit Span scores when compared to the Control Group. However, the Digit Span Backward Score did not reach statistical significance, partially confirming this aspect of hypothesis 2a.

In the domain of executive functions, assessed through the Verbal Fluency Test, the findings were largely in favor of the Bilingual/Multilingual group. Significant differences were observed in Total Words and Clustering for the 'Animals' category, as well as in Total Words for the 'Letter X' category. However, switching in the 'Letter X' category did not achieve statistical significance, offering partial support for this facet of hypothesis 2b. Lastly, in the Stroop Test, the bilingual/multilingual group significantly outperformed the Control Group across all primary metrics, fully confirming this segment of Hypothesis 2c (the current research findings are discussed in the Discussion section).

Regarding the third hypothesis, we turned our attention to Hypothesis 3, which explores the cognitive performance differences between Musicians and Bilinguals/Multilinguals, specifically in the domains of working memory and executive functions. Independent samples t-tests were applied to scrutinize these differences (Descriptive statistics are presented in previous Tables).

Especially for working memory, as measured by the Digit Span Test, Musicians exhibited a statistically significant advantage in the overall Digit Span score, with a t-value of t(49,240) = 3.990, $p < 0.001$. A similar trend was noted in the Digit Span Backward Score, t(47.529) = 4.361, $p < 0.001$. However, the Front Digit Span Score did not show any significant differences, t(51,338) = 1.162, $p = 0.251$.

In addition in Total Words in the 'Animals' category, the t-test did not reveal any significant differences between the two groups, with a t-value of t(58) = 0.855 and a p=0.396. However, a Mann-Whitney U test indicated a significant divergence in the Clustering Animals scores, with U=90.000, Z=-5.336, and p=0.00. In contrast, for Switching Animals, the test showed no significant differences, with U=418.000, Z=-0.475, and p=0.634.

Turning our attention to the 'Letter X' category, the t-test for Total Words yielded an inconclusive result, with a t-value of t(58) = 0.027 and a p=0.978. Similarly, for Clustering Words Letter X, no significant differences were observed between Musicians and Bilinguals/Multilinguals, as evidenced by a t-value of t(58) = -0.855 and a p=0.396. On the metric of Switching Words Letter X, the t-test also failed to reveal any statistically significant differences, with a t-value of t(58) = 0.313 and a p=0.755. “Due to a high frequency of zero scores in the variables 'Repetition and 'Mistakes in the two conditions,' we encountered a zero-inflated distribution. This rendered conventional inferential statistical tests inappropriate for these specific variables.

Lastly for Stroop Condition A, the t-test did not yield any significant difference between musicians and bilinguals/multilinguals (t=-0.162, df=58, p=0.872). The mean difference was -0.13033 seconds, with a 95% confidence interval ranging from -1.74427 to 1.48361 seconds. Likewise, for Condition B (Items correctly), the statistical results were not significant (t=-1.351, df=58, p=0.182), with a mean difference of -3.333 items within a 95% confidence interval of -8.271 to 1.604. Similarly, in Condition C (Items correctly), no statistically significant differences were observed (t=0.914, df=58, p=0.365), with a mean difference of 2.633 items.

Analyzing Cognitive Performance Disparities between Musicians and Bilinguals/Multilinguals through Independent T-Tests

In summary, independent samples t-tests were utilized to rigorously evaluate Hypothesis 3, which explored the cognitive performance differences between Musicians and Bilinguals/Multilinguals, particularly in the realms of working memory and executive functions. The findings offer a nuanced validation of the hypothesis in several key dimensions.

In the area of working memory, as assessed by the Digit Span Test, Musicians demonstrated a statistically significant advantage in both the overall Digit Span score and the Digit Span Backward Score. However, the Front Digit Span Score did not yield any significant differences, partially substantiating this aspect of Hypothesis 3a.

Turning to executive functions, as gauged through the Verbal Fluency Test, the results were mixed. In the 'Animals' category, no significant differences were observed in Total Words, but a marked divergence was found in Clustering Animals scores. Conversely, Switching Animals did not reach statistical significance, offering partial support for this facet of Hypothesis 3b. In the 'Letter X' category, none of the metrics—Total Words, Clustering, or Switching—achieved statistical significance, thereby fully confirming this segment of Hypothesis 3b. Lastly, in the Stroop Test, neither musicians nor bilinguals/multilinguals showed any significant performance variations across all primary metrics, fully validating this component of Hypothesis 3c (the current finding is discussed in the Discussion section).

In the subsequent phase of our empirical investigation, we rigorously scrutinized Hypothesis 4, which postulates the effect of both gender and group affiliations, as well as their interactive effects, on cognitive performance metrics. Our analytical focus was particularly directed towards the domains of working memory and various facets of executive functions. To methodically dissect these relationships, a two-way Analysis of Variance (ANOVA) was employed. In this statistical model, gender and group served as the independent variables, while the mean performance scores across all cognitive tasks for both cohorts acted as the dependent variables.

Especially for the Digit Span Forward Score, a significant main effect of gender was observed ($F(1, 84) = 7.368$, $p = .008$, $\eta^2 = .081$). Men in both the Musicians and Bilinguals/Multilinguals groups outperformed women in the same cohorts. A similar, albeit non-significant, trend was noted among men in the Control Group. Conversely, no significant gender effect was detected for the Digit Span Backward Score ($F(1, 84) = 0.555$, $p = .458$, $\eta^2 = .007$) across all groups, including the Control Group. Intriguingly, the interaction effects between gender and group were found to be non-significant across all three metrics: Digit Span Total Score ($F(2, 84) = 0.079$, $p = .924$, $\eta^2 = .002$), Digit Span Forward Score ($F(2, 84) = 0.079$, $p = .924$, $\eta^2 = .002$), and Digit Span Backward Score ($F(2, 84) = 1.458$, $p = .238$, $\eta^2 = .034$). This implies that the influence of group membership on working memory facets did not vary significantly between men and women.

In the task of Verbal fluency Total Words (Animals), the main effect of gender was statistically significant, as evidenced by $F(1, 84) = 4.526$, $p = .036$, $\eta^2 = .051$. Specifically, females within the Musicians cohort exhibited a statistically superior level of verbal fluency relative to their male counterparts. However, the interaction between gender and group membership did not attain statistical significance, $F(2, 84) = 2.244$, $p = .112$, $\eta^2 = .051$.

Turning our attention to Clustering Animals, the main effect of gender was not statistically significant, $F(1, 84) = .003$, $p = .956$, $\eta^2 = .000$. Intriguingly, the interaction between gender and group membership approached statistical significance, $F(2, 84) = 2.595$, $p = .081$, $\eta^2 = .058$.In the realm of task-switching capabilities, the main effect of gender was statistically significant, $F(1, 84) = 5.651$, $p = .020$, $\eta^2 = .063$. However, the interaction effects between gender and group membership did not attain statistical significance, $F(2, 84) = 2.310$, $p = .106$, $\eta^2 = .052$.

In the task involving Total Words starting with the letter "X," no significant gender differences were observed ($F(1, 84) = .942$, $p = .335$, $\eta^2 = .011$). This indicates that both genders performed similarly in this verbal fluency task, regardless of group membership. Additionally, the interaction between gender and group was not significant ($F(2, 84) = .167$, $p = .847$, $\eta^2 = .004$), suggesting that group affiliation did not moderate this relationship. For the Clustering Words task with the letter "X," a significant main effect of gender was found ($F(1, 61) = 5.954$, $p = .018$, $\eta^2 = .089$). Specifically, males outperformed females in word clustering, but the interaction between gender and group was not significant ($F(2, 61) = 2.649$, $p = .079$, $\eta^2 = .080$).In the Switching Words task with the letter "X," no significant main effect of gender was detected ($F(1, 84) = 1.694$, $p = .197$, $\eta^2 = .020$), indicating similar performance between genders across all groups. The interaction between gender and group was also not significant ($F(2, 84) = 1.888$, $p = .158$, $\eta^2 = .043$). Due to a high frequency of zero scores in the variables 'Repetition and 'Mistakes in the two conditions,' we encountered a zero-inflated distribution. This rendered conventional inferential statistical tests inappropriate for these specific variables.

In Condition A, in the Stroop test, both the main effect of gender ($F(1, 84) = 2.202$, $p = .142$, $\eta^2 = .026$) and the interaction between gender and group ($F(2, 84) = 1.754$, $p = .179$, $\eta^2 = .040$) were not statistically significant. This suggests comparable performance times between men and women across all groups.

In Condition B, neither the main effect of gender ($F(1, 84) = 0.006$, $p = .937$, $\eta^2 = .000$) nor the interaction effect ($F(2, 84) = 0.248$, $p = .781$, $\eta^2 = .006$) reached statistical significance, indicating similar performance in item identification across genders and groups.

Finally, in Condition C, the main effect of gender was not significant ($F(1, 84) = 3.334$, $p = .071$, $\eta^2 = .038$), and the interaction between gender and group was also not ($F(2, 84) = 1.723$, $p = .185$, $\eta^2 = .039$).

Evaluating Gender and Group Influences on Cognitive Functions: A Two-Way ANOVA Analysis

In summary, a two-way ANOVA was rigorously employed to scrutinize Hypothesis 4, which postulated the influence of gender and group affiliations on cognitive performance, particularly in the realms of working memory and executive functions.

In the domain of working memory, assessed via the Digit Span Test, a significant main effect of gender was observed in the Digit Span Forward Score ($F(1, 84) = 7.368$, $p = .008$, $\eta^2 = .081$). However, the Digit Span Backward Score did not reach statistical significance ($F(1, 84) = 0.555$, $p = .458$, $\eta^2 = .007$), partially confirming this facet of Hypothesis 4a. Interaction effects between gender and group were non-significant across all working memory metrics.

Turning to executive functions, gauged through Verbal Fluency tasks, the findings were nuanced. A significant main effect of gender was detected in Total Words (Animals) ($F(1, 84) = 4.526$, $p = .036$, $\eta^2 = .051$), but not in Clustering Animals. The interaction between gender and group membership approached significance in Clustering Animals ($F(2, 84) = 2.595$, $p = .081$, $\eta^2 = .058$), offering partial support for this aspect of Hypothesis 4b. In task-switching capabilities, a significant main effect of gender was observed ($F(1, 84) = 5.651$, $p = .020$, $\eta^2 = .063$), but interaction effects were non-significant.

Lastly, in the Stroop Test, both the main effect of gender and the interaction between gender and group were non-significant across all conditions, fully confirming this segment of Hypothesis 4c.

In the final stage of our analysis, we rigorously examined Hypothesis 5, which postulates the influence of educational attainment and group affiliations, as well as their interactive effects, on key cognitive performance metrics. Our scrutiny was specifically directed towards working memory and multiple facets of executive functions. To systematically explore these relationships, a two-way Analysis of Variance (ANOVA) was employed. Within this statistical framework, educational level and group membership functioned as the independent variables, while the aggregate performance scores across all cognitive tasks for both cohorts acted as the dependent variables.

Especially the main effect of education level was not significant ($F(3, 80) = 0.618$, $p = .605$, $\eta^2 = .023$), suggesting that education level alone did not significantly influence the Digit Span Total Scores. Moreover, the interaction between groups and education level was also not significant ($F(4, 80) = 0.535$, $p = .710$, $\eta^2 = .026$). This indicates that the effect of education level on Digit Span Total Scores did not differ significantly across the three groups. Regarding the main effect of education level on the Digit Span Forward score was not statistically significant ($F(3, 80) = 0.859$, $p = .466$, $\eta^2 = .031$). Similarly, the interaction between groups and education levels also failed to reach statistical significance ($F(4, 80) = 0.298$, $p = .879$, $\eta^2 = .015$). Finally, the main effect of education level on the Digit Span Backward score was not statistically significant $F (3, 80) = 0.079$, $p = .971$, $\eta^2 = .003$). Likewise, the interaction between groups and education levels also failed to reach statistical significance ($F(4, 80) = 0.288$, $p = .885$, $\eta^2 = .014$).

In the task of Verbal fluency in Total Words of Animal Naming, the main effect of education level did not reach statistical significance, as evidenced by $F(3, 80) = 1.345$, $p = .266$, $\eta^2 = .048$. Moreover, the interaction between group membership and education level was not statistically significant, $F (4, 80) = .895$, $p = .471$, $\eta^2 =$

.043. Transitioning our focus to Clustering Animals, the data revealed a similar pattern. The main effect of education level was not statistically significant, $F(3, 80) = 1.345$, $p = .266$, $\eta^2 = .048$. Furthermore, the interaction between group membership and education level also failed to attain statistical significance, $F(4, 80) = .895$, $p = .471$, $\eta^2 = .043$.

In the task of Animal Switching, the main effect of education level did not achieve statistical significance, $F(3, 80) = 1.922$, $p = .133$, $\eta^2 = .067$. Similarly, the interaction between group membership and education level was not statistically significant, $F(4, 80) = 2.190$, $p = .078$, $\eta^2 = .099$.

In the realm of Total Words initiated with the letter "X," the main effect of education was not statistically significant, $F(3, 80) = .174$, $p = .914$, $\eta^2 = .006$. Furthermore, the interaction effect between group membership and educational background was not statistically significant, $F(4, 80) = .695$, $p = .597$, $\eta^2 = .034$. Transitioning to Clustering Words that commence with the letter "X," the main effect of education was also statistically non-significant, $F(3, 57) = .238$, $p = .870$, $\eta^2 = .012$. The interaction between group membership and educational background was likewise non-significant, $F(4, 57) = .448$, $p = .774$, $\eta^2 = .030$.In Task Switching initiated with the letter "X," the main effect of the education was statistically irrelevant, $F(3, 80) = .204$, $p = .893$, $\eta^2 = .008$. The interaction between group membership and educational background was also non-significant, $F(4, 80) = 1.226$, $p = .306$, $\eta^2 = .058$. Due to a high frequency of zero scores in the variables 'Repetition and 'Mistakes in the two conditions,' we encountered a zero-inflated distribution. This rendered conventional inferential statistical tests inappropriate for these specific variables.

The Stroop Test revealed mixed effects of education on cognitive performance. In the first condition, neither the main effect of education ($F(3, 80) = .252$, $p = .860$, $\eta^2 = .009$) nor its interaction with group membership ($F(4, 80) = 1.692$, $p = .160$, $\eta^2 = .078$) were statistically significant. This suggests that performance was consistent across educational backgrounds and groups. In Condition B, however, education had a significant main effect ($F(3, 80) = 3.332$, $p = .024$, $\eta^2 = .111$) on the number of items correctly identified, although its interaction with group was not significant ($F(4, 80) = 1.886$, $p = .121$, $\eta^2 = .086$).

Finally, in Condition C, both the main effect of education ($F(3, 80) = 3.631$, $p = .016$, $\eta^2 = .120$) and its interaction with a group ($F(4, 80) = 2.836$, $p = .030$, $\eta^2 = .124$) were significant, indicating that performance varied based on educational background and group membership.

Analyzing the Influence of Educational Level and Group Affiliation on Cognitive Abilities: Insights from a Two-Way ANOVA

In summary, a two-way ANOVA was meticulously applied to investigate Hypothesis 5, which theorized the impact of educational level and group affiliations on cognitive performance, specifically in the areas of working memory and executive functions.

In the realm of working memory, as assessed by the Digit Span Test, the main effect of education level was not statistically significant for any of the Digit Span scores, including the Total, Forward, and Backward scores. This partially confirms this aspect of Hypothesis 5a. Moreover, the interaction between educational level and group membership was also non-significant across all working memory metrics.

Shifting our focus to executive functions, evaluated through Verbal Fluency tasks and Animal Switching, the findings were consistent. No significant main effect of education level was observed in any of the tasks, including Total Words of Animal Naming and Clustering Animals. The interaction between educational level and group membership also failed to reach statistical significance in these tasks, partially confirming this facet of Hypothesis 5b.

In tasks involving words initiated with the letter "X," neither the main effect of educational background nor the interaction between educational background and group membership reached statistical significance, fully confirming this segment of Hypothesis 5b.

Finally, in the Stroop Test, the main effect of education was significant only in Condition C ($F(3, 80) = 3.631$, $p = .016$, $\eta^2 = .120$), while its interaction with group membership was also significant ($F(4, 80) = 2.836$, $p = .030$, $\eta^2 = .124$). This suggests that educational background and group membership did have a significant impact on performance in this specific condition, offering partial support for this aspect of Hypothesis 5c.

Overall, the results offer a nuanced validation of Hypothesis 5, with educational level and group affiliations showing limited impact on cognitive performance across the various tasks and metrics assessed.

5.2 Cross-Group Correlations of Digit Span, Verbal Fluency, and Stroop Test Performances Among Musicians, Bilinguals/Multilinguals, and Control Group

Next, Pearson correlation indices were calculated between the performances of Musicians, Bilinguals/Multilinguals and the control group in the cognitive tasks of working memory and executive functions in order to study the possible correlations of the groups.

5.2.1 Digit span test

As regards the Digit Span Test especially the performance of the Musicians was found to be positively and statistically significantly correlated with the performance of the Control group. Specifically, strong, statistically significant correlations were observed between the Total and Forward scores ($r = .708$, $p < .001$), between the Total and Backward scores ($r = .852$, $p < .001$), and between the Forward and Backward scores ($r = .543$, $p < .001$). From the direction of the correlation, it appears that as the average performance of the Musicians increases, so does the average performance of the Control group across all aspects of the Digit Span Test. (A full correlation matrix among measures is provided in Table 9).

Similarly, the performance of the Bilinguals/Multilinguals was positively and statistically significantly correlated with the performance of the Control group.

Strong correlations were found between the Total and Forward scores ($r = .679$, $p < .001$), and between the Total and Backward scores ($r = .658$, $p < .001$). A weaker but still significant correlation was observed between the Forward and Backward scores ($r = .278$, $p = .031$). The direction of these correlations suggests that as the average performance of the Bilinguals/Multilinguals increases, so does the average performance of the Control group.

Lastly, the performance of the Musicians was also positively and statistically significantly correlated with the performance of the Bilinguals/Multilinguals. Strong correlations were found between the Total and Forward scores ($r = .450$, $p < .001$), and between the Total and Backward scores ($r = .751$, $p < .001$). However, the correlation between the Forward and Backward scores was not statistically significant ($r = .187$, $p = .152$). In terms of the direction of the correlation, higher average performance in the Musicians group is associated with higher average performance in the Bilinguals/Multilinguals group, particularly for the Total and Backward scores of the Digit Span Test.

Table 9: Pearson's r Correlation Coefficients for Digit Span Test Scores

Groups Compared	Test Scores Relationship	Pearson's *r*	Significance (*p*-value)	N
Musicians and Control Group				
	Total & Forward	.708	< .001	60
	Total & Backward	.852	< .001	60
	Forward & Backward	.543	< .001	60
Bilinguals/Multilinguals and Control Group				
	Total & Forward	.679	< .001	60
	Total & Backward	.658	< .001	60
	Forward & Backward	.278*	.031	60
Musicians and Bilinguals/Multilinguals				
	Total & Forward	.450	< .001	60
	Total & Backward	.751	< .001	60
	Forward & Backward	.187*	.152	60

Note: Correlations marked with an asterisk (*) signify high statistical significance

5.2.2 Verbal fluency Animal naming

A noteworthy, positive correlation emerged between 'Total Words' and 'Switching' (r = .562, p < .001). This indicates that as the Musicians' proficiency in generating total words increased, their switching abilities also showed improvement. However, the correlation between 'Total Words' and 'Clustering' was not statistically significant (r = .199, p = .128), nor was the correlation between 'Clustering' and 'Switching' (r = .103, p = .432). Due to a high prevalence of zero values, the variables 'Repetitions' and 'Mistakes' were not included in the correlation analysis, thereby limiting their interpretive utility. (A full correlation matrix among measures is provided in Table 10)

For the Bilinguals/Multilinguals and Control group, significant, positive correlations were observed between 'Total Words' and 'Clustering' (r = .401, p = .002), as well as between 'Total Words' and 'Switching' (r = .545, p < .001).The direction of these correlations suggests that as the Bilinguals/Multilinguals' average performance in 'Total Words' and 'Clustering' increases, so does the Control group's performance. However, the correlation between 'Clustering' and 'Switching' was not statistically significant (r = -.069, p = .601).

In the case of Musicians and Bilinguals/Multilinguals, a significant, positive correlation was found between 'Total Words' and 'Switching' (r = .553, p < .001). This suggests that higher scores in 'Total Words' are associated with better 'Switching' abilities within these groups. However, the correlations between 'Total Words' and 'Clustering' (r = .112, p = .396), as well as between 'Clustering' and 'Switching' (r = .091, p = .489), did not reach statistical significance.

Table10: Pearson's r Correlation Coefficients for Verbal Fluency Animal Naming Scores

Groups Compared	Test Conditions Relationship	Pearson's *r*	Significance (*p*-value)	N

Musicians and Control Group	Total Words & Clustering	.199	.128	60
	Total Words & Switching	.562*	< .001	60
	Clustering & Switching	.103	.432	60
Bilinguals/Multilinguals and Control Group	Total Words & Clustering	.401	.002	60
	Total Words & Switching	.545*	< .001	60
	Clustering & Switching	-.069	.601	60
Musicians and Bilinguals/Multilinguals	Total Words & Clustering	.112	.396	60
	Total Words & Switching	.553*	< .001	60
	Clustering & Switching	.091	.489	60

Note: Correlations marked with an asterisk (*) signify high statistical significance

5.2.3 Verbal fluency words letter X

A significant and positive correlation was observed between 'Verbal F Total Words Letter X' and 'Switching Words Letter X' ($r = .601$, $p < .001$), suggesting that an increase in the Musicians' ability to generate total words is linked to enhanced switching skills. Conversely, the relationship between 'Verbal F Total Words Letter X' and 'Clustering Words Letter X' was less robust but still noteworthy ($r = .305$, $p = .018$). The correlation between 'Clustering Words Letter X' and 'Switching Words Letter X,' however, did not attain statistical significance ($r = -.038$, $p = .772$). It should be noted that the variables 'Repetitions' and 'Mistakes' were excluded from the analysis due to a high frequency of zero values, which constrains the scope of interpretation. (A full correlation matrix among measures is provided in Table 11)

Table 11: Pearson's r Correlation Coefficients for Verbal Fluency 'Letter X' Scores

Group's Compared	Test Conditions Relationship	Pearson's r	Significance (p-value)	N
Musicians and Control Group	Total Words & Clustering	.305	.018	60
	Total Words & Switching	.601*	< .001	60
	Clustering & Switching	-.038	.772	60
Bilinguals/Multilinguals and Control Group	Total Words & Clustering	.364	.004	60
	Total Words & Switching	.573*	< .001	60
	Clustering & Switching	-.129	.327	60
Musicians and Bilinguals/Multilinguals	Total Words & Clustering	.246	.058	60
	Total Words & Switching	.509*	< .001	60
	Clustering & Switching	-.123	.350	60

Note 1: Correlation is significant at the 0.01 level (2-tailed).

In the context of the Bilinguals/Multilinguals and Control group, notable positive correlations were found between 'Verbal F Total Words Letter X' and both 'Clustering Words Letter X' (r = .364, p = .004) and 'Switching Words Letter X' (r = .573, p < .001). These findings imply that as the Bilinguals/Multilinguals' average performance in word generation improves, a corresponding enhancement is seen in the Control group's clustering and switching capabilities. Nevertheless, the correlation between 'Clustering Words Letter X' and 'Switching Words Letter X' was not statistically meaningful (r = -.129, p = .327).

Lastly, for the Musicians and Bilinguals/Multilinguals, a robust positive correlation was identified in 'Verbal F Total Words Letter X' and 'Switching Words Letter X' (r = .509, p < .001). This indicates that elevated performance in word generation is positively correlated with improved switching skills among these groups. However, the relationships between 'Verbal F Total Words Letter X' and 'Clustering Words Letter X' (r = .246, p = .058), as well as in 'Clustering Words Letter X' and 'Switching Words Letter X' (r = -.123, p = .350), failed to achieve statistical significance.

5.2.4 Stroop test

In the Stroop Test, Musicians exhibited statistically significant negative correlations with the Control group. Specifically, notable negative correlations were identified between the time taken in Condition A and the correct responses in Condition B (r = -.413, p = .001), as well as between Condition A and Condition C (r = -.361, p = .005). A robust positive correlation emerged between Conditions B and C (r = .517, p < .001). These findings imply that an increase in time spent on Condition A correlates with fewer correct answers in Conditions B and C. On the flip side, higher scores in Condition B are linked to higher scores in Condition C (A full correlation matrix among measures is provided in Table 12).

The Bilinguals/Multilinguals group also showed statistically significant negative correlations with the Control group in the Stroop Test. Pronounced negative correlations were evident between the time taken in Condition A and the correct answers in Conditions B (r = -.446, p < .001) and C (r = -.480, p < .001). Additionally, a positive correlation was detected between Conditions B and C (r = .400, p = .002). These results suggest that a longer time in Condition A is associated with fewer correct responses in Conditions B and C. However, improved performance in Condition B correlates with better outcomes in Condition C.

Lastly mild correlation was found between the Musicians and the Bilinguals/Multilinguals in the Stroop Test. A subtle yet significant negative correlation was seen between Conditions A and C (r = -.289, p = .025), and a mild positive correlation was noted between Conditions B and C (r = .259, p = .045). The correlation between Conditions A and B, however, lacked statistical significance (r = -.161, p = .218). These correlations indicate that as Musicians take longer in Condition A, the Bilinguals/Multilinguals tend to have fewer correct answers in Condition C. A modest improvement in Condition B scores is somewhat related to better scores in Condition C.

Table 12: Pearson's r Correlation Coefficients for Stroop Test Scores

Groups Compared	Test Conditions Relationship	Pearson's r	Significance (*p*-value)	N
Stroop Test				
Musicians vs Control	Condition A & B	-.413	.001	60
	Condition A & C	-.361*	.005	60
	Condition B & C	.517	< .001	60
Bilinguals/Multilinguals vs Control	Condition A & B	-.446	< .001	60
	Condition A & C	-.480	< .001	60
	Condition B & C	.400*	.002	60
Musicians vs Bilinguals/Multilinguals	Condition A & B	-.161	.218	60
	Condition A & C	-.289*	.025	60
	Condition B & C	.259*	.045	60

*Note: **Correlations are significant at the 0.01 level (2-tailed). *Correlations are significant at the 0.05 level (2-tailed).*

5.3 Relations Between Education Level and Digit Span Test Performance Across Groups

To explore the relationship between education level and cognitive performance, Spearman's rho correlation indices were calculated across three distinct groups: Musicians, Bilinguals/Multilinguals, and a Control group**.**

The performance of the Musicians was found to be positively and statistically significantly correlated with their level of education in the Digit Span Test. Specifically, moderate yet statistically significant correlations were observed between education level and the Total Score ($r = .276$, $p = .033$), between education level and the Forward Score ($r = .349$, $p = .006$), and between education level and the Backward Score ($r = .264$, $p = .042$). From the direction of the correlation, it appears that as the average level of education among Musicians increases, so does their average performance across all aspects of the Digit Span Test, as well as the Control group's performance. (A full correlation matrix among measures is provided in Table 13)

Similarly, in the Bilinguals/Multilinguals and control group, a positive and statistically significant correlation was observed between education level and the Forward Score (*r* =

.367, p = .004). No significant correlations were found for the Total Score and Backward Score. The direction of these correlations suggests that as the average level of education among Bilinguals/Multilinguals increases, so does their average performance, as well as the Control group's performance, particularly in the Forward Score of the Digit Span Test.

Lastly, the performance of the Musicians was also found to be not significantly correlated with the performance of the Bilinguals/Multilinguals in terms of education level. The correlations were as follows: Total Score (r = -.062, p = .640), Forward Score (r = .212, p = .105), and Backward Score (r = -.020, p = .877). In terms of the direction of the correlation, no significant impact of education level on performance was observed among these groups.

Table 13: Spearman's rho Correlations Between Education Level and Digit Span Task Across Groups

Groups Compared	Test Conditions Relationship	Spearman's rho	Significance (p-value)	N
Musicians and Control Group				
	Education & Total Score	.276*	.033	60
	Education & Forward Score	.349**	.006	60
	Education & Backward Score	.264*	.042	60
Bilinguals/Multilinguals and Control Group				
	Education & Total Score	.224	.085	60
	Education & Forward Score	.367**	.004	60
	Education & Backward Score	-.006	.962	60
Musicians and Bilinguals/Multilinguals				
	Education & Total Score	-.062	.640	60
	Education & Forward Score	.212	.105	60
	Education & Backward Score	-.020	.877	60

*Note: **Correlations are significant at the 0.01 level (2-tailed). *Correlations are significant at the 0.05 level (2-tailed).*

5.3.1 Education Level and Verbal Fluency Animal Naming

A moderate, yet statistically significant, positive correlation was observed between education level and 'Total Words' (*r* = .304, *p* = .018) within this group. This positive direction suggests that as the Musicians' level of education rises, so does their ability to generate total words. In contrast, a significant negative correlation was identified between education level and 'Clustering' (*r* = -.331, *p* = .010), indicating that higher educational levels are inversely related to clustering scores. Although not statistically significant, a positive trend was noted for the correlation between education level and 'Switching' (*r* = .244, *p* = .060) (A full correlation matrix among measures is provided in Table 14)

In the Bilinguals/Multilinguals and Control Group, a robust positive correlation was evident between education level and 'Total Words' (*r* = .338, *p* = .008). The positive direction of this correlation implies that higher educational attainment is beneficial for generating total words. However, the correlations for 'Clustering' (*r* = .221, *p* = .089) and 'Switching' (*r* = .292, *p* = .023) were not statistically significant, thus not providing a clear direction.

For the Musicians and Bilinguals/Multilinguals group, the direction of the correlations revealed interesting patterns. A significant negative correlation was found between education level and 'Clustering' (*r* = -.271, *p* = .037), suggesting that higher education levels are associated with lower clustering scores. Conversely, a significant positive correlation was observed between education level and 'Switching' (*r* = .292, *p* = .023), indicating that higher educational levels are linked to improved switching abilities.

Table 14: Spearman's rho Correlations Between Education Level and Verbal Fluency Task Across Groups

Groups Compared	Test Conditions Relationship	Spearman's rho	Significance (*p*-value)	N
Musicians and Control Group	Education & Total Words	.304*	.018	60
	Education & Clustering	-.331**	.010	60
	Education & Switching	.244	.060	60
Bilinguals/Multilinguals and Control Group	Education & Total Words	.338**	.008	60
	Education & Clustering	.221	.089	60
	Education & Switching	.292*	.023	60
Musicians and Bilinguals/Multilinguals	Education & Total Words	.338**	.008	60
	Education & Clustering	.221	.089	60
	Education & Switching	.292*	.023	60

*Note: **Correlations are significant at the 0.01 level (2-tailed). *Correlations are also significant at the 0.05 level (2-tailed).*

5.3.2 Education Level and Verbal Fluency Letter X

Interestingly, no statistically significant correlations were found between education level and any of the Verbal Fluency Test Letter X metrics. However, a strong positive correlation emerged between Education and 'Switching' ($r = .591$, $p < .001$). The absence of a significant correlation with education level narrows the interpretive scope of these findings, which is further constrained by the exclusion of the variables 'Repetitions' and 'Mistakes.' (A full correlation matrix among measures is provided in Table 15).

In the Bilinguals/Multilinguals and Control group, a moderate positive correlation was observed between education level and 'Total Words' ($r = .311$, $p = .016$). This suggests that higher education levels are associated with better performance in 'Total Words.' Additionally, strong positive correlations were found between 'Total Words' and 'Switching' ($r = .567$, $p < .001$), as well as 'Total Words' and 'Clustering' ($r = .349$, $p = .006$).

Lastly, for the Musicians and Bilinguals/Multilinguals group, no significant correlations were detected between education level and any of the Verbal Fluency

Test scores. However, a strong positive correlation was evident between Education and ‘Switching’ (r = .510, p < .001).

Table 15: Spearman’s rho Correlations Between Education Level and Verbal Fluency Letter X Task Across Groups

Groups Compared	Test Conditions Relationship	Spearman’s rho	Significance (*p*-value)	N
Musicians and Control Group	Education & Total Words	.146	.265	60
	Education & Clustering	.151	.250	60
	Education & Switching	.591	.001	60
Bilinguals/Multilinguals and Control Group	Education & Total Words	.311*	.016	60
	Education & Clustering	.349	.006	60
	Education & Switching	.567	.001	60
Musicians and Bilinguals/Multilinguals	Education & Total Words	-.049	.707	60
	Education & Clustering	.112	.394	60
	Education & Switching	.510	.001	60

*Note: *Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed)*

5.3.3 Education Level and Stroop Test

In the Musicians and Control Group, a statistically significant positive correlation was observed between education level and Condition C Items Correctly (r = .282, p = .029). The direction of this correlation suggests that as the education level increases, so does the performance in Condition C of the Stroop Test. Additionally, a strong negative correlation was found between education level and Stroop Condition A in seconds (r = -.438, p = .000), indicating that higher education levels are associated with faster completion times in Condition A (A full correlation matrix among measures is provided in Table 16).

For the Bilinguals/Multilinguals and Control Group, a significant positive correlation was found between education level and Condition B Items Correctly ($r = .330$, $p = .010$). The direction of this correlation suggests that higher education levels are associated with better performance in Condition B of the Stroop Test. No significant correlation was observed between education level and Condition C Items Correctly.

Finally, in the Musicians and Bilinguals/Multilinguals group, negative correlations were observed between education level and both Condition B Items Correctly ($r = -.271$, $p = .037$) and Condition C Items Correctly ($r = -.434$, $p = .001$). The direction of these correlations suggests that higher education levels are associated with lower performance in these conditions of the Stroop Test.

Table 16: Spearman's rho Correlation Coefficients for Stroop Test Scores and Education Level

Groups Compared	Test Conditions Relationship	Spearman's rho	Significance (*p*-value)	N
Musicians and Control Group	Education & Condition C Items Correctly	.282*	.029	60
	Education & Stroop Condition A (sec)	-.438**	.000	60
Bilinguals/Multilinguals and Control Group	Education & Condition B Items Correctly	.330**	.010	60
	Education & Condition C Items Correctly	.155	.236	60
Musicians and Bilinguals/Multilinguals	Education & Condition B Items Correctly	-.271*	.037	60
	Education & Condition C Items Correctly	-.434**	.001	60

*Note: **Correlations are significant at the 0.01 level (2-tailed). *Correlations are significant at the 0.05 level (2-tailed).*

5.4 Hierarchical Regression Analysis on Digit Span Scores-Verbal Fluency (Animal Naming)-Verbal Fluency (Letter X) and Stroop test

Methodological Overview

The primary aim of this analysis was to apply hierarchical regression to test whether there is a statistically significant difference between the performance of Musicians, Bilingual/Multilingual, and Control Group participants. The independent variables considered were Music training (Musicians), Language ability (Bilingual/Multilingual), gender, and educational level. The dependent variables were the performance scores in various Digit Span test, Verbal fluency and Stroop test.

5.4.1 Digit span test

The hierarchical regression model for the Digit Span Total Score proved to be statistically significant, $F(4,85)=14.032$, $p<.001$. This model accounted for approximately 39.8% of the variance in the scores, as evidenced by an adjusted R^2 of .369. It was predicted that Musicians would score 7.400 points higher and Bilingual/Multilingual individuals 1.851 points higher compared to the Control Group. Gender did not make a significant contribution to the model (B=-1.195, β=-0.128, t=-1.509, p=.135). Likewise, educational level was not a significant predictor (B=-0.157, β=-0.069, t=-0.700, p=.486).

For the Digit Span Forward Score, the model was statistically significant, $F(4,85)=10.969$, $p<.001$. This model explained 34.0% of the variance, as indicated by an adjusted R^2 of .309. Musicians were predicted to score 2.733 points higher, and Bilingual/Multilingual individuals 1.066 points higher compared to the Control Group. Gender emerged as a significant predictor in this model (B=-1.306, β=-0.252, t=-2.844, p=.006), while educational level did not (B=0.171, β=0.137, t=1.317, p=.191).

For the Digit Span Backward Score, the model was statistically significant, $F(4,85)=10.135$, $p<.001$. This model accounted for 32.3% of the variance, as evidenced by an adjusted R^2 of .291. Musicians were predicted to score 3.646 points higher, and Bilingual/Multilingual individuals 0.500 points higher compared to the Control Group. Gender did not make a significant contribution to the model (B=-0.346, β=-0.064, t=-0.717, *p*=.475), nor did educational level (B=-0.034, β=-0.026, t=-0.248, *p*=.805).

5.4.2 Summary and Conclusions

The final hierarchical regression models indicated that being either a Musician or Bilingual/Multilingual was a significant predictor of performance on all Digit Span tasks. Gender was a significant predictor only for the Digit Span Forward Score. Educational level did not make a significant contribution to any of the models. The Control Group, serving as the reference category, did not exhibit a significant impact on any of the Digit Span scores.

5.4.3 Verbal fluency animal

The model for Total Words in Animal Naming was found to be statistically significant, F(4,85)=9.818, *p* <.001. This model accounted for approximately 31.6% of the variance in the scores, as indicated by an adjusted R^2 of .284. It was predicted that Musicians would score 8.129 points higher and Bilingual/Multilingual individuals 3.256 points higher compared to the Control Group. Gender emerged as a significant predictor (B=2.731, β=0.204, t=2.269, *p*=.026), while educational level did not contribute significantly to the model (B=-0.041, β=-0.013, t=-0.120, *p*=.904).

For the Clustering of Animals, the hierarchical regression model was statistically significant, F(4,85)=10.022, *p* <.001. This model explained 32.0% of the variance, as evidenced by an adjusted R^2 of .289. Musicians did not significantly contribute to the model (B=-0.035, β=-0.025, t=-0.211, *p*=.834). Bilingual/Multilingual individuals were significant predictors, scoring 0.396 points higher (B=0.396, β=0.565, t=4.844, *p*<.001). Neither gender (B=0.023, β=0.017, t=0.191, *p*=.849) nor educational level (B=-0.063, β=-0.196, t=-1.862, *p*=.066) were significant predictors.

Finally, for the Switching Animals, the model was statistically significant, F(4,85)=3.683, *p*=.008. This model accounted for approximately 14.8% of the variance, as evidenced by an adjusted R^2 of .108. Musicians did not reach conventional levels (B=2.503, β=0.243, t=1.851, *p*=.068). Bilingual/Multilingual individuals did not significantly contribute to the model (B=0.855, β=0.166, t=1.273, *p*=.207). Gender was a significant predictor (B=2.203, β=0.227, t=2.259, *p*=.026), while educational level did not contribute significantly (B=0.299, β=0.127, t=1.081, *p*=.283).

5.4.4 Summary and Conclusions

The final hierarchical regression models revealed that being either a Musician or Bilingual/Multilingual was a significant predictor of performance on the Total Words in Animal Naming task. For the Clustering of Animals, only being Bilingual/Multilingual was a significant predictor. Gender was a significant predictor only for the Switching Animals task. Educational level did not contribute significantly to any of the models. The Control Group, used as the reference category, did not show a significant impact on any of the verbal fluency tasks. It should be noted that the variables 'Mistakes' and 'Repetitions' were excluded from the analysis due to a large percentage of null values, limiting their utility for meaningful interpretation.

5.4.5 Verbal fluency letter X

The hierarchical regression model for Total Words for Letter "X" was statistically significant, F(4,85)=3.499, p=.011. This model accounted for approximately 14.1% of the variance in the scores, as evidenced by an adjusted R^2 of .101. Musicians were predicted to score 3.549 points higher, and Bilingual/Multilingual individuals 1.728 points higher compared to the Control Group. Gender did not make a significant contribution to the model (B=0.908, β=0.098, t=0.966, *p*=.337).

Likewise, educational level was not a significant predictor (B=0.022, β=0.010, t=0.083, p=.934).

For Clustering Words for Letter "X," the model was statistically significant, F(4,85)=2.498, p=.049. This model explained approximately 10.5% of the variance, as indicated by an adjusted R^2 of .063. Musicians did not significantly contribute to the model (B=0.816, β=0.234, t=1.737, p=.086). Bilingual/Multilingual individuals were significant predictors, scoring 0.560 points higher (B=0.560, β=0.322, t=2.402, p=.018). Neither gender (B=-0.220, β=-0.067, t=-0.649, p=.518) nor educational level (B=0.046, β=0.058, t=0.478, p=.634) were significant predictors.

For Switching Words for Letter "X," the hierarchical regression model was not statistically significant, F(4,85)=0.785, p=.538. This model accounted for approximately 3.6% of the variance, as indicated by an adjusted R^2 of -0.010. Musicians were predicted to score 1.155 points higher, and Bilingual/Multilingual individuals 0.394 points higher compared to the Control Group. Gender did not make a significant contribution to the model (B=0.962, β=0.138, t=1.291, p=.200). Similarly, educational level was not a significant predictor (B=-0.038, β=-0.023, t=-0.180, p=.858).

5.4.6 Summary and Conclusions

The final hierarchical regression models revealed that being either a Musician or Bilingual/Multilingual was a significant predictor of performance on the Total Words for Letter "X" task. For the Clustering Words for the Letter "X," only being Bilingual/Multilingual was a significant predictor. Neither of these groups, nor gender or educational level, were significant predictors for the Switching Words for Letter "X" task. The Control Group, used as the reference category, did not show a significant impact on any of the verbal fluency tasks. It should be noted that the variables 'Mistakes' and 'Repetitions' were excluded from the analysis due to a large percentage of null values, limiting their utility for meaningful interpretation

5.4.7 Stroop test

Condition A (sec)

The hierarchical regression model for Condition A (sec) was statistically significant, F(4,85)=6.164, *p* <.001. The model accounted for approximately 22.5% of the variance in the scores, as indicated by an adjusted R^2 of .188. Musicians and Bilinguals were significant predictors. Musicians had a negative impact on the time taken to complete the task (B=-3.256, β=-0.448, t=-3.571, *p*=.001), and Bilinguals also showed a negative impact (B=-1.533, β=-0.422, t=-3.385, *p*=.001). In this context, "negative impact" means that these groups took less time to complete the task, which is actually a positive outcome as the goal is to complete the task as quickly as possible. Therefore, the term "negative" here should be interpreted as advantageous for cognitive performance. Gender and educational level did not contribute significantly to the model.

The model for Condition B Items Correctly was statistically significant, F(4,85)=4.743, *p*=.002. The model explained approximately 18.2% of the variance, as indicated by an adjusted R^2 of .144. Musicians were significant predictors, scoring 8.464 points higher (B=8.464, β=0.357, t=2.774, *p*=.007). Bilinguals also significantly contributed to the model, scoring 5.885 points higher (B=5.885, β=0.497, t=3.883, *p*=.000). Neither gender nor educational level were significant predictors.

Finally, the hierarchical regression model for Condition C Items Correctly was statistically significant, F(4,85)=9.814, *p*<.001. The model accounted for approximately 31.6% of the variance, as indicated by an adjusted R^2 of .284. Musicians were significant predictors, scoring 17.252 points higher (B=17.252, β=0.667, t=5.657, *p*=.000). Bilinguals also significantly contributed to the model, scoring 7.116 points higher (B=7.116, β=0.550, t=4.699, *p*=.000). Gender emerged as a significant predictor (B=4.419, β=0.181, t=2.010, *p*=.048), while educational level also contributed significantly to the model (B=-1.394, β=-0.236, t=-2.235, *p*=.028).

The final hierarchical regression models revealed that being either a Musician or Bilingual was a significant predictor of performance across all conditions of the Stroop Test. For Condition A, both Musicians and Bilinguals performed the task more quickly, which is advantageous in this context. In Condition B, both groups correctly identified more items. In Condition C, Musicians, Bilinguals, and Gender were significant predictors, with educational level also making a significant contribution.

CHAPTER 6
Discussion

The aim of this research was the individual and comparative investigation of working memory and executive functions in Musicians with more than five years of musical training and Bilingual/Multilingual healthy adults. For the purpose of the present study, the working memory of the participants/subjects was evaluated through the Digit Span Forward and Digit span Backward Test (Digit Span, Wechsler, 1955) while the investigation of the executive functions was done by administering the Verbal Fluency Test (Kosmidis et al., 2004) and the Stroop Test (Stroop, 1935).

According to the current research findings it is revealed that music training significantly impacts cognitive performance, particularly in verbal working memory tasks, thereby confirming Hypothesis 1a. These findings are consistent with the foundational research conducted by Franklin et al., (2008), which also documented a strong relationship between music training and enhanced working memory capacity. Specifically, the study highlights that individuals with music training exhibit marked improvements in verbal working memory, as evidenced by their performance on the Digit Span test. This capacity to effectively store and retrieve verbal information—a central component of working memory—is notably more pronounced among those with a musical background.

Further evidence supporting this observation comes from Roden, Kreutz, & Bongard (2012), whose research utilizing the Digit Span test revealed that musicians consistently outperform non-musicians. This suggests that the structured nature of music training is beneficial in increasing the ability to retain and process verbal information sequentially. This evidence underscores the importance of employing such specialized assessments in determining the cognitive enhancements brought about by musical training.

The studies by Okhrei, Kutsenko & Makarchuk, (2017) and Hansen, Climie, & Oxoby, (2020) extend the understanding of working memory, showing that the cognitive benefits of music training encompass not only basic verbal memory tasks but also the executive components of working memory. This is particularly relevant for tasks that involve manipulating stored information, indicating that music training may improve both the capacity and the operational efficiency within the working memory system.

The research conducted by George & Coch in (2011) supports the understanding that musicians demonstrate notable enhancements in the phonological loop. This component of working memory is vital for the temporary storage and manipulation of auditory and verbal information. Musicians, through their practice, engage in complex auditory processing, which involves distinguishing between different pitches, timbres, and rhythms. This constant engagement not only enhances their ability to perceive and interpret musical sounds but also strengthens their general auditory processing skills. Consequently, their phonological loop becomes more adept at handling auditory information, leading to improvements in tasks that require verbal memory and auditory attention. Such developments are a direct result of the rigorous and focused auditory training inherent in musical practice, which fine-tunes the brain's ability to process and retain auditory information.

Additionally, the study by Oechslin et al., (2013) provides neurological evidence that music training correlates with observable structural changes in the brain, particularly in areas related to auditory processing and memory, echoing the results of the current study.

Summing up the confirmations of Hypothesis 1a aligns with preceding research, as numerous scholarly inquiries have consistently demonstrated that musical training substantially augments various facets of working memory. This enhancement encompasses advancements in verbal working memory, fortification of the phonological loop (crucial for the processing of auditory and verbal inputs), and observable neuroanatomical alterations in regions pertinent to memory and auditory processing. Collectively, these findings elucidate that musical training systematically cultivates and refines the brain's capacity to store, process, and adeptly manipulate information, culminating in a markedly improved functionality of working memory.

Summing up, the confirmation of this hypothesis 1a seems to agree with the findings of the previous ones, which confirm the view that music training seems to positively affect the functioning of working memory.

Continuing on the academic exploration of music training's impact on cognitive functions, particularly executive functions, yields a nuanced understanding. Hypothesis 1b finds partial validation while Hypothesis 1c is entirely substantiated. Focusing on Hypothesis 1b, the evidence suggests selective cognitive improvements: there were significant enhancements in Total Words and Task-Switching, yet no significant differences emerged in Clustering within the Verbal Fluency Test (Animals) nor in Switching for the Verbal Fluency Test (Letter X). This points to a complex scenario where music training selectively benefits certain executive functions like word retrieval and task flexibility but does not uniformly affect all verbal fluency areas (Rodriguez-Gomez & Talero-Gutiérrez, 2022).

These differential advancements in cognitive skills are framed within the concept of task-specific cognitive improvements. Research by Gade & Schlemmer (2021) supports this, suggesting that the cognitive challenges of musical training, especially in complex auditory processing and memory tasks, foster specialized executive skills. These skills include rapid task-switching and cognitive flexibility, crucial for effective decision-making and adapting to changing environments. However, these enhancements may not extend to all areas, particularly broader verbal fluency domains, likely due to the involvement of different cognitive processes. Echoing this, Caballero et al., (2018) point out that musical training leads to domain-specific cognitive improvements. These improvements are mainly observed in areas related to auditory processing, memory, and executive functions like task flexibility and switching ability, rather than a generalized enhancement across all cognitive domains.

The partial corroboration of Hypothesis 1b also resonates with theories of cognitive resource allocation, where the intricate cognitive control required for musical practice could enhance certain executive functions but not all, as posited by Fink, Graif, & Neubauer, (2009). They suggest that the cognitive resources honed by specific training may not be universally applicable across all executive tasks.

Variations in the impact of music training on the Verbal Fluency Test may also be attributed to the diversity of cognitive strategies that musicians develop, tailored to the specific demands of their training, as Green (2014) suggests. These strategies may differentially affect their performance on various executive function tasks.

Musicians in particular develop different cognitive and metacognitive strategies specific to their training demands. These strategies, which include elements such as focused attention, memory techniques, and self-regulation, can differentially affect their performance on executive function tasks. Such tasks may involve inhibitory control, working memory, cognitive flexibility, and problem-solving, indicating a specialized rather than uniform effect on executive functions Green (2014).

Moreover, Hypothesis 1c is fully confirmed within the Stroop Test, where the musician group significantly outperformed the control group. The findings is associated with the research study of Zuk et.al., (2014), who observed that adult musicians excel in tasks requiring inhibitory control, a key executive function. This could be attributed to the intense mental discipline and focus that music training demands, which potentially enhances attention management and the ability to disregard irrelevant stimuli, as elaborated by Roden, Kreutz, & Bongard, (2012).

In conclusion, the findings provide a thorough analysis of how music training can bolster certain mental skills while also exhibiting variability in its effects across different verbal fluency domains (Hypothesis1b). The definitive results for Hypothesis 1c with the Stroop Test further our understanding, indicating that music training can also enhance inhibitory control. Collectively, these insights suggest that music training has the capacity to improve specific mental processes, yet the scope of its impact may vary, reflecting the intricate web of cognitive abilities and underscoring the potential for music training to contribute to targeted cognitive enhancement.

In the continuing the discussion of the findings, the present study outlines that bilingualism and multilingualism may have a beneficial effect on cognitive functions especially in verbal working memory tasks, partially confirming Hypothesis 2a

This pattern is evidenced by the remarkable performance on tasks such as the Total and Forward Digit Scores, which are significantly higher in the bilingual/multilingual groups compared to the monolingual controls. Although the backward digit span score did not reach statistical significance, the overall trend supports the hypothesis, suggesting a selective enhancement in some aspects of working memory attributable to multilingual experience.

This claim aligns with the work of Rosselli et al., (2015), where bilingual students showed improved storage and performance of sequential verbal memory tasks. In addition, Kroll et al., (2002) and Yoo & Kaushanskaya (2012) provide additional evidence that bilingualism is associated with improved verbal memory abilities specifically in storage tasks. This cognitive enhancement is not simply a byproduct of language training, but is indicative of broader cognitive benefits—supporting the theory that bilingualism can serve as a valuable tool in cognitive and educational strategies aimed at improving verbal working memory.

In addition, the study by Warmington, Kandru-Pothineni & Hitch, (2018) investigated the existence of a cognitive advantage in learning new words and in the working memory of Bilinguals. The results suggest that Bilinguals are likely to show a cognitive advantage in their working memory, supporting the view that the use of two or more languages seems to have a positive effect and enhance storage in verbal memory (Warmington et al., 2018).

Collectively, these scientific contributions make a strong case for the cognitive advantages of bilingualism/multilingualism, particularly in the capacity and functional efficiency of verbal working memory. This synthesis of empirical research highlights the important potential of language training as a means of cognitive enhancement, heralding implications for educational curricula and strategies aimed at enhancing executive functions through language acquisition.

In the investigation of bilingualism/multilingualism's effects on cognitive functions, with a particular emphasis on executive functions, the research has yielded a nuanced perspective. This study's findings provide partial confirmation for Hypothesis 2b and complete validation for Hypothesis 2c, drawing parallels with analogous trends identified in the domain of music education.

Hypothesis 2b reveals the strengths bilingual/multilingual individuals display in executive functions, integral to verbal fluency. There were notable enhancements in both Word Total and Clustering in the 'Animals' category, and Word Total for 'Letter X', showcasing a distinct bilingual advantage in terms of lexical retrieval and categorization. These improvements suggest that the cognitive processes refined during language acquisition and usage could bolster task-switching capabilities and organizational skills in verbal tasks. Nevertheless, the absence of significant gains in Switching for 'Letter X' underscores the specificity of these cognitive enhancements, indicating that bilingualism's effect on verbal fluency is not universally applied but is rather domain-specific (Bialystok et al., 2004).

This evidence supports the theory of task-specific cognitive enhancement, proposing that bilinguals acquire unique executive processing advantages through their complex linguistic experiences. The cognitive control necessitated by language switching seems to grant benefits in certain executive function tasks but not across the board, consistent with the adaptive control hypothesis as elucidated by Green (2013). Seminal works by Bialystok, Craik, and Luk, (2008), and Prior & Macwhinney (2010) further bolster this perspective, documenting the resilience of multilingual individuals' executive functions.

Further substantiation for Hypothesis 2c is found within the Stroop Test results, where individuals proficient in multiple languages significantly outperformed monolingual participants. This echoes the findings of Bialystok et al. (2004), who contended that the management of several languages reinforces the executive control system, particularly in tasks necessitating inhibitory control and attention regulation. The bilingual advantage in inhibitory control may stem from the routine suppression of interference from non-target languages, which likely sharpens the ability to disregard irrelevant stimuli (Costa et al., 2008).

In summation, the present study elucidates the specific cognitive advantages conferred by bilingualism/multilingualism, with a marked impact on verbal fluency and inhibitory control (Hypotheses 2b and 2c). The discussion emphasizes that bilingualism/multilingualism fosters certain executive functions, with the breadth of impact being distinctly domain-specific. The findings underscore the notion that the intricate cognitive balancing act inherent in bilingual/multilingual language management can result in targeted cognitive enhancements, thereby underscoring the potential of bilingualism/multilingualism in the realm of cognitive fortification.

Hypothesis 3a, which argued that musicians would not outperform bilingual/multilingual subjects on verbal working memory tasks, is partially supported by the results. Musicians showed a significant advantage in the total and backward sequences of the Digit Span Test, which may indicate a specialized effect of music training on certain aspects of working memory (Saarikivi et al., 2019).

This finding resonates with recent studies suggesting a strong correlation between musical training and improvements in working memory (D'Souza, Moradzadeh & Wiseheart, 2018). One study found that musicians showed improved working memory compared to bilinguals/multilinguals, suggesting that the structured and persistent practice inherent in musical training could lead to cognitive improvements in this area (Moradzadeh, Blumenthal & Wiseheart 2014). However, it is important to consider that some research has not consistently replicated performance improvements in musically trained experts, which introduces some uncertainty about the robustness of these benefits (Hansen, Wallentin, & Vuust, 2013).

Supporting the advantage seen in musicians, a meta-analysis concluded that musicians perform better than non-musicians on tonal and verbal working memory tasks, with moderate to large effect sizes. Additionally, an ERP study highlighted that musicians outperform non-musicians on tests of auditory, visual, and executive memory, showing improved working memory processing (Talamini et.al.,2017).

On the other hand, bilingualism has also been associated with improvements in working memory capacity. A comprehensive meta-analysis on the effects of bilingualism on working memory capacity revealed a significant small to medium effect size in favor of bilinguals compared to monolinguals. This could mean that while musicians have their strengths in working memory, bilinguals/multilinguals also have enhanced storage capabilities, possibly due to the cognitive demands of managing multiple languages (Grundy & Timmer , 2016).

Empirical studies suggest that both music training and bilingualism/multilingualism are associated with improved working memory, although the particular aspects of working memory that are enhanced may differ between the two groups. The partial confirmation of Hypothesis 3a, however, suggests that musicians may have a stronger advantage in tasks that rely more on sequential processing and memory manipulation (D'Souza, Moradzadeh & Wiseheart, 2018).

The study's exploration concerning hypotheses 3 b and 3c into the impact of music training and bilingualism/multilingualism on cognitive functions, specifically executive functions, reveals complex results. In the Verbal Fluency and Stroop Tests, musicians and bilingual/multilingual individuals did not significantly differ in Total Words, but notable divergence was observed in Clustering Animals scores, partially affirming Hypothesis 3b. No significant differences in metrics like Switching Animals and those in the 'Letter X' category confirm other aspects of Hypothesis 3b. The Stroop Test results, showing no performance variations, validate Hypothesis 3c.

These findings align possibly with research indicating shared cognitive mechanisms between musical and linguistic processes. Patel, (2011) and Slevc & Okada (2015) discuss auditory modulations and similar syntactic structures, while models by Bella, Peretz & Aronoff, (2003) and Schulkind, Posner & Rubin, (2003) draw parallels in cognitive processing. Neuroimaging studies also show comparable frontal cortex activation in both domains (Zatorre et al., 1994). This suggests that the cognitive benefits of music training and bilingualism/multilingualism may stem from overlapping areas of cognitive enhancement, particularly in executive functions.

In summary, while individual cognitive benefits are evident in both musicians and bilinguals/multilinguals, the comparative assessment indicates that the enhancements are not universally superior in either group but are influenced by shared cognitive processes. This highlights the complexity of cognitive development influenced by distinct but overlapping training experiences in music and language.

Regarding hypotheses 4, a, b, c, we hypothesized that all groups would differ in their performance on all cognitive tasks, depending on gender. The data of the present investigation did not fully confirm these hypotheses.

However, gender differences were observed in working memory tasks and executive functions. Although gender differences were observed, they were not consistently present across all measures. This partial confirmation of the hypothesis indicates a complex interaction of gender with cognitive functions, where the impact of gender varies across different tasks and contexts (Jansen, Hoja & Leonardo, 2022).

Empirical evidence, including studies by Pauls, Petermann, Lepach, (2013) indicates a statistical superiority of men in tasks assessing working memory. This is in line with the observed gender differences in the current study, and particularly in men although these differences are not consistently evident across all measures, suggesting a multifaceted interaction of gender with cognitive functions.

Opposing trends emerge in executive functions. The Stroop paradigm suggests a possible superiority in performance by females, implying gender differences in cognitive processing efficiency. However, overall, the findings support the broader understanding that individual components of executive functions may be enhanced in one gender without a clear systematic advantage, as suggested by the current literature (Mekarski et al. 1996),

In conclusion the study investigated gender differences in cognitive performance among musicians, bilinguals/multilinguals and a control group, revealing complex patterns. In working memory, males showed higher performance on the Digit Span Forward Score, particularly in musicians and bilinguals/multilinguals, but there were no significant gender differences in the Digit Span Backward Score. Females in the Music group excelled on verbal fluency tasks but not all, while task-switching abilities showed a significant effect of gender with no group interaction. The Stroop Test revealed no significant gender or interaction differences, highlighting differential gender-related trends in cognitive performance across groups and tasks.

In addressing Hypothesis 5 a,b,c, which hypothesized the effect of educational attainment on cognitive performance among musicians, bilinguals/multilinguals, and a control group on working memory and executive functions, the study presents a multifaceted picture. The hypothesis predicted that higher levels of education would be associated with improved performance on working memory and executive functions. Contrary to this expectation, the analysis revealed that educational level did not significantly affect these cognitive domains across groups.

The findings show that while higher education is often associated with better cognitive outcomes, as suggested by Mazzonna & Peracchi (2012), this relationship is not simple or universally applicable. The lack of significant differences between Digit Span Test scores and the verbal fluency tasks highlights a more complex interaction between education and cognitive abilities than previously posited.

The study aligns with Alloway and Alloway (2010), who emphasized the critical role of working memory in academic performance. However, the lack of a significant effect of educational level on working memory in this study suggests that factors beyond educational level may play a key role in cognitive performance, particularly in working memory.

The study's findings contribute to the ongoing debate about the relationship between education and executive functions. Although educational attainment did not show a significant main effect on tasks such as Animal Switching and Total Words Beginning with “X,” the differential patterns observed suggest the complexity of cognitive stratification based on educational experiences.

Interestingly, Stroop Test results, particularly in Condition C, revealed that educational level and group affiliation had a significant impact, suggesting that the effect of education on cognitive performance may be task-specific.

Overall, the results show a nuanced validation of Hypothesis 5 a,b,c. Educational level and group relationships show a limited and variable impact on cognitive performance across all tasks and measures assessed, challenging the conventional understanding of the relationship between education and cognitive functions.

5.1 Correlations of the performance of the three groups in the cognitive tasks

Working memory (Digit span)

In exploring the cognitive performances of Musicians, Bilinguals/Multilinguals, and a Control group, the study employed Pearson correlation indices to delve into the and executive functions. This approach was pivotal in discerning the intricate correlations among these varied groups.

The findings from the Digit Span Test indicated a positive correlation in the performance of Musicians when juxtaposed with the Control group. This correlation was particularly pronounced, suggesting that as musicians exhibit enhanced cognitive abilities in this test, similar trends are observed in the control group. This phenomenon highlights a possible synergy in the cognitive functioning between these two groups, a notion supported by research indicating that both bilinguals and musicians show enhanced cognitive control and an improved ability to ignore distracting cues compared to controls (Schroeder, et al., 2016).

Similarly, the Bilinguals/Multilinguals group showed a notable positive correlation with the Control group's performance. This trend was evident across various aspects of the test, indicating that the cognitive skills honed through bilingual or multilingual experiences might align with those seen in the general population. This aligns with the idea that bilingualism and musicianship increase executive control through experience-dependent plasticity (Schroeder et.al., 2016). Additionally, research has shown that bilingualism can positively affect working memory performance, further supporting this correlation (Lukasik et.al., 2018).

Furthermore, an interesting correlation emerged between the Musicians and the Bilinguals/Multilinguals. This correlation, while variable across different components of the test, suggested a shared aspect of cognitive functioning between these two groups. The stronger correlations in certain areas of the test hinted at particular cognitive capabilities being more aligned between musicians and bilinguals/multilinguals, a concept echoed in studies investigating the relationship between musical training, bilingualism, and executive function. Moreover, research supports the idea that musicians and bilinguals tend to demonstrate better cognitive performance than their non-musician or monolingual counterparts (D'Souza, Moradzadeh & Wiseheart, 2018).

These correlations suggest a fascinating interplay in cognitive abilities across the groups studied. They point towards a possible commonality in cognitive performance, particularly in areas related to working memory, as assessed by the Digit Span Test. The enhanced cognitive performances functions observed in musicians and bilinguals/multilinguals seem to mirror trends in the broader population, indicating that these specialized skills might have broader cognitive implications.

However, it is crucial to acknowledge that correlation does not imply causation. The study's findings, while illuminating, do not establish a direct causal relationship between being a musician or bilingual/multilingual and improved cognitive performance. These correlations open avenues for further research to understand the underlying dynamics and whether these specific skills directly influence cognitive enhancement in other areas (D'Souza, Moradzadeh & Wiseheart, 2018).

Executive functions (Verbal fluency-Stroop test)

In the analysis of cognitive performance across Musicians, Bilinguals/Multilinguals, and a Control group, employing Pearson correlation indices revealed various correlations through verbal fluency and Stroop Test performances.

For the Verbal Fluency Animal Naming task, the positive correlation between 'Total Words' and 'Switching' in Musicians is supported by research indicating that musicians often exhibit enhanced cognitive functions, particularly in tasks requiring executive control, which can include aspects like switching. Similarly, for Bilinguals/Multilinguals, studies have shown that bilingualism affects cognitive abilities, including executive functions, which might explain the observed correlations in verbal fluency tasks (Winston et al., 2022).

In the Verbal Fluency Words Letter X task, the significant correlations reflect the complex impact of specialized skills like musical training and bilingualism on cognitive functions, as evidenced in various studies examining the cognitive benefits of these skills (Winston et.al.,2022).

In the Stroop Test, the significant correlations among Musicians, Bilinguals/Multilinguals, and Controls align with research showing varied results in cognitive control tasks among bilinguals, including the Stroop task, highlighting the influence of bilingualism on cognitive control. These findings suggest intricate relationships between specific cognitive skills across different groups, underscoring the complexity of cognitive processes and the potential influence of specialized skills on broader cognitive abilities (Sabourin & Vinerte, 2014).

5.2 Relations Between Education Level, Working memory and Executive functions Tasks Across Groups

To explore the relationship between education level and cognitive performance, Spearman's rho correlation indices were calculated across three distinct groups: Musicians, Bilinguals/Multilinguals, and a Control group.

In the Digit Span Test, Musicians demonstrated positive correlations between their education level and performance. This suggests that higher education may enhance memory and processing skills, consistent with studies showing a link between educational attainment and cognitive abilities. For Bilinguals/Multilinguals, a significant correlation was found only for the Forward

Score, aligning with research indicating that education can positively impact specific cognitive functions (Criscuolo et.al., 2019).

In the Verbal Fluency Animal Naming task, a positive correlation between education level and 'Total Words' was found for Musicians, reflecting studies that associate higher education with improved language and executive functioning skills. However, a negative correlation with 'Clustering' suggests that higher education may influence specific aspects of verbal fluency differently.

For the Verbal Fluency Letter X task, strong correlations between education and 'Switching' emerged, highlighting the potential influence of education on cognitive flexibility and executive control, as supported by existing literature (Winston et.al.,2022).

In the Stroop Test, significant correlations between education level and performance in various conditions were observed in all groups. These correlations underscore research findings that link educational background to specific aspects of cognitive control and processing speed (Burger et al., 2019)

Overall, these results highlight proves weakness of study in group differences of education levels among groups

5.3 HIERARCHICAL REGRESSION

In the hierarchical regression analysis investigating cognitive performance variations among Musicians, Bilinguals/Multilinguals, and a Control group, the study employed a multifaceted methodological approach. The independent variables incorporated were music training, bilingual/multilingual language proficiency, gender, and educational level, analyzed against the dependent variables of performance scores in the Digit Span test, Verbal Fluency (Animal Naming), Verbal Fluency (Letter X), and the Stroop test.

Digit Span Test Analysis

The regression model indicated that both Musicians and Bilinguals/Multilinguals significantly outperformed the Control group in the Digit Span Total Score, aligning with studies showing enhanced cognitive control in these groups (Schroeder et.al., 2016). Music training emerged as a robust predictor of higher scores in this cognitive domain, consistent with research findings on the cognitive benefits of musical training (Moradzadeh, Blumenthal & Wiseheart, 2014). Gender was a significant predictor for the Forward Score, suggesting a nuanced impact of gender on specific cognitive functions.

Verbal Fluency in Animal Naming

In the domain of Verbal Fluency (Animal Naming), both Musicians and Bilinguals/Multilinguals demonstrated superior performance compared to the Control group. The model for Total Words was significant, capturing about 31.6% of the score variance, with gender emerging as a significant factor. This supports research indicating the influence of gender on language-based cognitive tasks (Backer & Bortfeld, 2021).

Verbal Fluency in Letter X

For the Verbal Fluency (Letter X) task, Musicians and Bilinguals/Multilinguals showed enhanced performance. The regression model for Total Words was significant, accounting for 14.1% of the variance. Clustering and Switching Words did not show the same level of significance across all groups, suggesting that these aspects of verbal fluency might be influenced by different cognitive mechanisms.

Stroop Test Performance

In the Stroop test, both Musicians and Bilinguals/Multilinguals demonstrated significantly better performance across all conditions, indicating enhanced cognitive control and processing speed. This finding is in line with studies underscoring the cognitive benefits of musical training and bilingualism/multilingualism (D'Souza, Moradzadeh & Wiseheart,2018).

Conclusions

Overall, the hierarchical regression models underscored that musical training and bilingual/multilingual proficiency are significant predictors of enhanced performance across a range of cognitive tasks. The limited impact of educational level across most models suggests that inherent cognitive abilities and skills gained through music and language might play a more pivotal role in cognitive performance than formal educational background, a conclusion supported by the research (Moradzadeh, Blumenthal & Wiseheart, 2014). This comprehensive analysis provides valuable insights into the multifaceted nature of cognitive abilities and the factors influencing them.

5.4 General conclusion

This study's comprehensive analysis demonstrates that both music training and bilingualism/multilingualism significantly enhance cognitive functions, though in distinct domains and manners. In specific, music training notably improves verbal working memory and inhibition control as evidenced by high performances in the Digit Span Test and Stroop Test. These findings align with foundational research, suggesting that music training boosts sequential verbal information processing and enhances cognitive control, particularly in inhibitory tasks (Backer & Bortfeld, 2021).

Bilingualism/ multilingualism, on the other hand, show a positive effect on verbal working memory and executive functions. These linguistic skills lead to higher performance in tasks like the Total and Front Digit Scores, highlighting enhanced storage and processing of sequential verbal memory. The study also confirms that bilinguals/multilinguals outperform monolinguals in executive functions, particularly in lexical retrieval and categorization, indicating domain-specific cognitive enhancements (Giovannoli et al., 2020).

The study also explores the impact of music training and bilingualism/multilingualism on cognitive functions, particularly executive functions and working memory. While both groups show individual cognitive benefits, the comparative assessment indicates that these enhancements are influenced by shared cognitive processes and are not universally superior in either group. This suggests a complex interplay between music and language training in cognitive development.

Gender differences in cognitive performance were observed, but these were not uniformly present across all measures, indicating a complex interaction of gender with cognitive functions. This partial confirmation of gender impact varies across different tasks and contexts.

The evaluation into the effect of educational attainment on cognitive performance among musicians, bilinguals/multilinguals, and a control group presents a multifaceted picture. The study finds that educational level does not significantly affect these cognitive domains across groups, suggesting a more complex interaction between education and cognitive abilities than previously thought.

Furthermore, the study's hierarchical regression analysis reveals that musical training and bilingual/multilingual proficiency are significant predictors of enhanced performance across a range of cognitive tasks. The limited impact of educational level across most models suggests that inherent cognitive abilities and skills gained through music and language might play a more pivotal role in cognitive performance than formal educational background (Carpentier, Moreno & McIntosh, 2016).

In summary, the current research provides a thorough understanding of how music training and bilingualism/multilingualism can bolster certain mental skills and exhibit variability in its effects across different cognitive domains. The study emphasizes the potential of music training and language acquisition in cognitive enhancement strategies, highlighting their impact on working memory, executive functions, and the complex interplay with factors like gender and education.

5.5 Limitations

One of the limitations of the current study is its timing, as data collection commenced in early 2022, during the ongoing COVID-19 pandemic. This period was marked by unique psychological and social stresses, such as altered mental health states and disruptions to daily routines, which could have influenced the cognitive performances of the participants. These pandemic-related factors might have introduced confounding variables, potentially impacting the study's findings. Furthermore, while the sample size of 90 participants was adequate for initial analysis, it may not provide a robust basis for generalizing the findings to a broader population. Additionally, the relatively homogeneous nature of the sample, particularly in terms of cultural and linguistic backgrounds, limits the extent to which these results can be applied to more diverse demographic groups.

Another limitation of this study pertains to the homogeneity in the age range and educational background among the participant groups. The Musicians, Bilinguals/Multilinguals, and Control Group each displayed a relatively narrow age range, which might confine the applicability of the study’s findings to a particular demographic segment. This restricted age representation could lead to potential oversight of cognitive performance variations across broader life stages. Moreover, the educational backgrounds, while diverse across groups, may introduce additional variables impacting cognitive performance assessments. The study’s methodological framework also introduces certain limitations, particularly due to its reliance on specific cognitive assessment tools like the Verbal Fluency and Digit Span Tests. Although these instruments are widely recognized in cognitive evaluations, their ability to capture the complete range of executive functioning and working memory is not all-encompassing, thereby potentially narrowing the scope of cognitive attributes analyzed.

In this study, the data collection methods varied, with approximately 80% of assessments conducted in-person and the remainder administered through digital means, specifically via platforms such as Skype and Zoom. Additionally, systematically comparing the outcomes of digital and in-person cognitive assessments could provide insights into how different assessment modalities might influence participant performance. However, the recruitment strategy, which involved selecting musicians from conservatories and bilingual/multilingual individuals based on certified language proficiency, introduces a notable selection bias. This method tends to favor individuals with formal, structured educational backgrounds, potentially skewing the results towards those accustomed to academic environments and standardized assessment conditions. Finally, conducting studies specifically designed to assess the impact of external factors like the COVID-19 pandemic on cognitive performance would be valuable, particularly in understanding how such extraordinary circumstances affect mental functions

5.6 Future research direction and suggestions

For future research, several extensions and suggestions are proposed to address these limitations. Expanding the sample size and diversity is crucial, including participants from various cultural, linguistic, and socio-economic backgrounds to enhance the study's generalizability. Adopting a longitudinal study design would allow for examining the impact of musical training and bilingualism/multilingualism on cognitive functions over time, providing insights into long-term effects. Incorporating a wider age range and diverse educational backgrounds would offer a more comprehensive understanding of the interaction between these variables and cognitive functions. Utilizing a broader array of cognitive assessment tools could yield a more nuanced understanding of the cognitive benefits associated with music training and bilingualism/multilingualism. Future studies could also explore the cognitive effects of informal or self-guided music and language learning, contrasting them with formal training to understand the impact of different learning modalities.

Additionally, systematically comparing the outcomes of digital and in-person cognitive assessments could provide insights into how different assessment modalities might influence participant performance. Finally, conducting studies specifically designed to assess the impact of external factors like the COVID-19 pandemic on cognitive performance would be valuable, particularly in understanding how such extraordinary circumstances affect mental functions.

APPENDIX

A1. Working Memory Tasks

Digit Span Task

Οδηγίες: **Παρακαλώ επαναλάβατε μετά από εμένα.** Στο forward πρέπει να τα πει ο εξεταζόμενος με τη σειρά που τα λέει ο εξεταστής, ενώ στο backward με την αντίστροφη σειρά. Μετά από 2 αποτυχημένες προσπάθειες του εξεταζόμενου (και στο A και το B) σταματά η δοκιμασία.

	Digits Forward Trial Item/Response	Trial Score	Item Score (0,1, or 2)	Digits Backward Trial Item/Response	Trial Score	Item Score (0,1, or 2)
>	1. A. 1-7			1. A. 2-4		
	B. 6-3			B. 5-7		
	2. A. 5-8-2			2. A. 6-2-9		
	B. 6-9-4			B. 4-1-5		
	3. A. 6-4-3-9			3. A. 3-2-7-9		
	B. 7-2-8-6			B. 4-9-6-8		
	4. A. 4-2-7-3-1			4. A. 1-5-2-8-6		
	B. 7-5-8-3-6			B. 6-1-8-4-3		
	5. A. 6-1-9-4-7-3			5. A. 5-3-9-4-1-8		
	B. 3-9-2-4-8-7			B. 7-2-4-8-5-6		
	6. A. 5-9-1-7-4-2-8			6. A. 8-1-2-9-3-6-5		
	B. 4-1-7-9-3-8-6			B. 4-7-3-9-1-2-8		
	7. A. 5-8-1-9-2-6-4-7			7. A. 9-4-3-7-6-2-5-8		
	B. 3-8-2-9-5-1-7-4			B. 7-2-8-1-9-6-5-3		
	8. A. 2-7-5-8-6-2-5-8-4			Digits		
	B. 7-1-3-9-4-2-5-6-8			(M		
	Digits					
				Forward + Backward −		{Maximum = 30)

Λεκτική Ευχέρεια

Χρονικό όριο: 60 sec το καθένα

Οδηγίες: ***Θα ήθελα να μου πείτε όσο το δυνατόν περισσότερα και διαφορετικά ζώα μπορείτε μέσα σε 1 λεπτό.*** Γράφετε όλες τις λέξεις που σας λένε, ακόμη και αν είναι λάθος ή επανάληψη.

Θα ήθελα να μου πείτε όσο τον δυνατόν περισσότερες και διαφορετικές λέξεις που να αρχίζουν με το γράμμα «Χ» που να μην είναι κύρια ονόματα (δηλαδή ονόματα ανθρώπων, πόλεων, ημερών) και να μην είναι παραλλαγή της ίδιας λέξης (π.χ., τραπέζι, τραπεζάκι). Γράφετε όλες τις λέξεις που σας λένε, ακόμη και αν είναι λάθος ή επανάληψη.

Ζώα	**Χ**

Βαθμολόγηση: 1 μονάδα για κάθε σωστή απάντηση σε κάθε κατηγορία. Για οδηγίες βαθμολόγησης των υπόλοιπων μεταβλητών, βλέπε το βιβλίο: Κοσμίδου, Μ., & Βλάχου, Χ. (2009). *Ελληνικές Δοκιμασίες Λεκτικής Ευχέρειας: Χορήγηση -- Βαθμολόγηση -- Ερμηνεία*. Αθήνα: Επιστημονικές Εκδόσεις Παρισιάνου.

Σύνολο ____ Ομαδοποίηση ____ Εναλλαγές ____
Επαναλήψεις ____ Λάθη ____

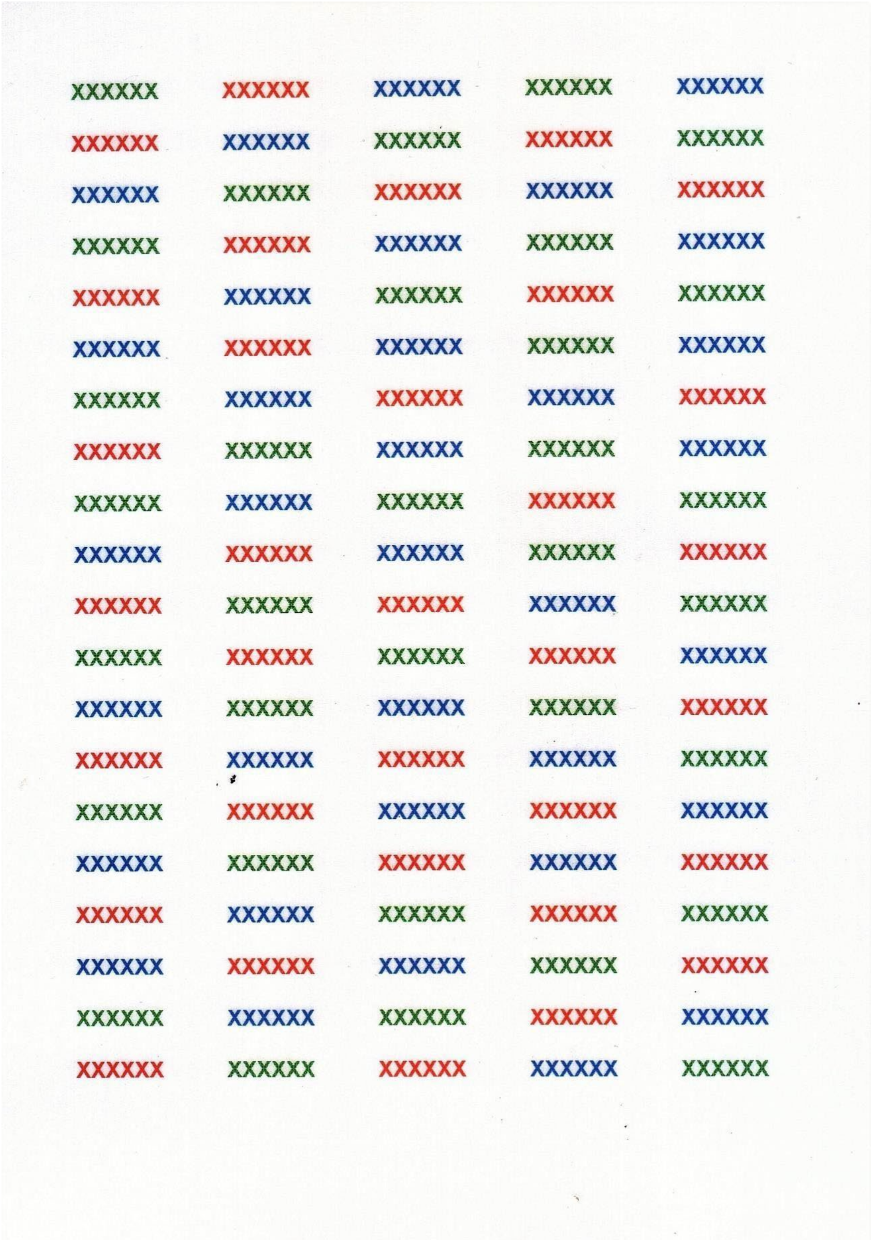
Σύνολο ____ Ομαδοποίηση ____ Εναλλαγές ____
Επαναλήψεις ____ Λάθη ____

Executive Functioning (Stroop Test)

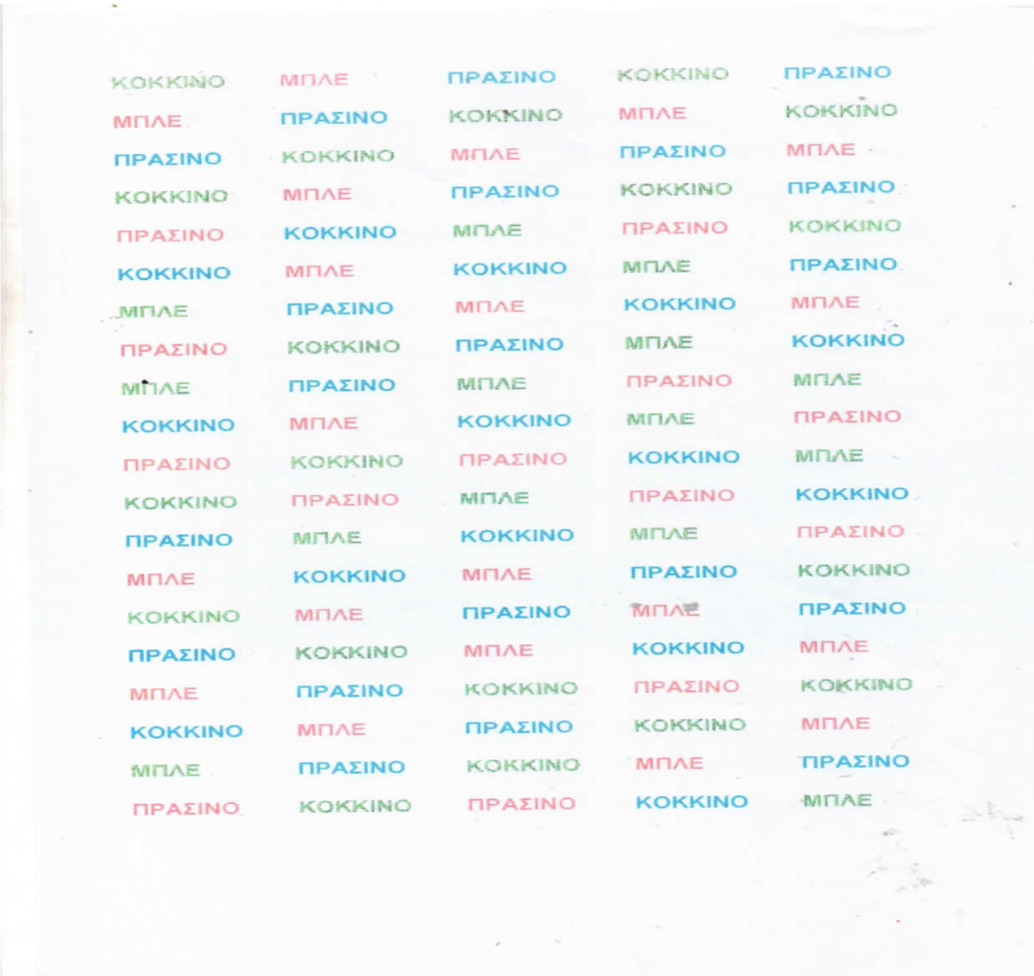
Συνθήκη Ανάγνωσης

ΚΟΚΚΙΝΟ	ΜΠΛΕ	ΠΡΑΣΙΝΟ	ΚΟΚΚΙΝΟ	ΠΡΑΣΙΝΟ
ΜΠΛΕ	ΠΡΑΣΙΝΟ	ΚΟΚΚΙΝΟ	ΜΠΛΕ	ΚΟΚΚΙΝΟ
ΠΡΑΣΙΝΟ	ΚΟΚΚΙΝΟ	ΜΠΛΕ	ΠΡΑΣΙΝΟ	ΜΠΛΕ
ΚΟΚΚΙΝΟ	ΜΠΛΕ	ΠΡΑΣΙΝΟ	ΚΟΚΚΙΝΟ	ΠΡΑΣΙΝΟ
ΠΡΑΣΙΝΟ	ΚΟΚΚΙΝΟ	ΜΠΛΕ	ΠΡΑΣΙΝΟ	ΚΟΚΚΙΝΟ
ΚΟΚΚΙΝΟ	ΜΠΛΕ	ΚΟΚΚΙΝΟ	ΜΠΛΕ	ΠΡΑΣΙΝΟ
ΜΠΛΕ	ΠΡΑΣΙΝΟ	ΜΠΛΕ	ΚΟΚΚΙΝΟ	ΜΠΛΕ
ΠΡΑΣΙΝΟ	ΚΟΚΚΙΝΟ	ΠΡΑΣΙΝΟ	ΜΠΛΕ	ΚΟΚΚΙΝΟ
ΜΠΛΕ	ΠΡΑΣΙΝΟ	ΜΠΛΕ	ΠΡΑΣΙΝΟ	ΜΠΛΕ
ΚΟΚΚΙΝΟ	ΜΠΛΕ	ΚΟΚΚΙΝΟ	ΜΠΛΕ	ΠΡΑΣΙΝΟ
ΠΡΑΣΙΝΟ	ΚΟΚΚΙΝΟ	ΠΡΑΣΙΝΟ	ΚΟΚΚΙΝΟ	ΜΠΛΕ
ΚΟΚΚΙΝΟ	ΠΡΑΣΙΝΟ	ΜΠΛΕ	ΠΡΑΣΙΝΟ	ΚΟΚΚΙΝΟ
ΠΡΑΣΙΝΟ	ΜΠΛΕ	ΚΟΚΚΙΝΟ	ΜΠΛΕ	ΠΡΑΣΙΝΟ
ΜΠΛΕ	ΚΟΚΚΙΝΟ	ΜΠΛΕ	ΠΡΑΣΙΝΟ	ΚΟΚΚΙΝΟ
ΚΟΚΚΙΝΟ	ΜΠΛΕ	ΠΡΑΣΙΝΟ	ΜΠΛΕ	ΠΡΑΣΙΝΟ
ΠΡΑΣΙΝΟ	ΚΟΚΚΙΝΟ	ΜΠΛΕ	ΚΟΚΚΙΝΟ	ΜΠΛΕ
ΜΠΛΕ	ΠΡΑΣΙΝΟ	ΚΟΚΚΙΝΟ	ΠΡΑΣΙΝΟ	ΚΟΚΚΙΝΟ
ΚΟΚΚΙΝΟ	ΜΠΛΕ	ΠΡΑΣΙΝΟ	ΚΟΚΚΙΝΟ	ΜΠΛΕ
ΜΠΛΕ	ΠΡΑΣΙΝΟ	ΚΟΚΚΙΝΟ	ΜΠΛΕ	ΠΡΑΣΙΝΟ
ΠΡΑΣΙΝΟ	ΚΟΚΚΙΝΟ	ΠΡΑΣΙΝΟ	ΚΟΚΚΙΝΟ	ΜΠΛΕ

Συνθήκη Κατονομασίας Χρωμάτων



Συνθήκη Παρεμβολών



ΚΟΚΚΙΝΟ	ΜΠΛΕ	ΠΡΑΣΙΝΟ	ΚΟΚΚΙΝΟ	ΠΡΑΣΙΝΟ
ΜΠΛΕ	ΠΡΑΣΙΝΟ	ΚΟΚΚΙΝΟ	ΜΠΛΕ	ΚΟΚΚΙΝΟ
ΠΡΑΣΙΝΟ	ΚΟΚΚΙΝΟ	ΜΠΛΕ	ΠΡΑΣΙΝΟ	ΜΠΛΕ
ΚΟΚΚΙΝΟ	ΜΠΛΕ	ΠΡΑΣΙΝΟ	ΚΟΚΚΙΝΟ	ΠΡΑΣΙΝΟ
ΠΡΑΣΙΝΟ	ΚΟΚΚΙΝΟ	ΜΠΛΕ	ΠΡΑΣΙΝΟ	ΚΟΚΚΙΝΟ
ΚΟΚΚΙΝΟ	ΜΠΛΕ	ΚΟΚΚΙΝΟ	ΜΠΛΕ	ΠΡΑΣΙΝΟ
ΜΠΛΕ	ΠΡΑΣΙΝΟ	ΜΠΛΕ	ΚΟΚΚΙΝΟ	ΜΠΛΕ
ΠΡΑΣΙΝΟ	ΚΟΚΚΙΝΟ	ΠΡΑΣΙΝΟ	ΜΠΛΕ	ΚΟΚΚΙΝΟ
ΜΠΛΕ	ΠΡΑΣΙΝΟ	ΜΠΛΕ	ΠΡΑΣΙΝΟ	ΜΠΛΕ
ΚΟΚΚΙΝΟ	ΜΠΛΕ	ΚΟΚΚΙΝΟ	ΜΠΛΕ	ΠΡΑΣΙΝΟ
ΠΡΑΣΙΝΟ	ΚΟΚΚΙΝΟ	ΠΡΑΣΙΝΟ	ΚΟΚΚΙΝΟ	ΜΠΛΕ
ΚΟΚΚΙΝΟ	ΠΡΑΣΙΝΟ	ΜΠΛΕ	ΠΡΑΣΙΝΟ	ΚΟΚΚΙΝΟ
ΠΡΑΣΙΝΟ	ΜΠΛΕ	ΚΟΚΚΙΝΟ	ΜΠΛΕ	ΠΡΑΣΙΝΟ
ΜΠΛΕ	ΚΟΚΚΙΝΟ	ΜΠΛΕ	ΠΡΑΣΙΝΟ	ΚΟΚΚΙΝΟ
ΚΟΚΚΙΝΟ	ΜΠΛΕ	ΠΡΑΣΙΝΟ	ΜΠΛΕ	ΠΡΑΣΙΝΟ
ΠΡΑΣΙΝΟ	ΚΟΚΚΙΝΟ	ΜΠΛΕ	ΚΟΚΚΙΝΟ	ΜΠΛΕ
ΜΠΛΕ	ΠΡΑΣΙΝΟ	ΚΟΚΚΙΝΟ	ΠΡΑΣΙΝΟ	ΚΟΚΚΙΝΟ
ΚΟΚΚΙΝΟ	ΜΠΛΕ	ΠΡΑΣΙΝΟ	ΚΟΚΚΙΝΟ	ΜΠΛΕ
ΜΠΛΕ	ΠΡΑΣΙΝΟ	ΚΟΚΚΙΝΟ	ΜΠΛΕ	ΠΡΑΣΙΝΟ
ΠΡΑΣΙΝΟ	ΚΟΚΚΙΝΟ	ΠΡΑΣΙΝΟ	ΚΟΚΚΙΝΟ	ΜΠΛΕ

Έντυπο Συγκατάθεσης

Η Παρούσα έρευνα διεξάγεται στο πλαίσιο της διπλωματικής μου εργασίας στο Πρόγραμμα Μεταπτυχιακών Σπουδών "Cognitive Systems’ συνεργασία του Open University of Cyprus (School of Pure and Applied Sciences) and University of Cyprus-Department of Psychology and Department of Computer Science. Αποτελεί μια διερευνητική μελέτη αξιολόγησης της Μουσικής εκπαίδευσης και Διγλωσσίας και την συνεισφοράς τους στις εκτελεστικές λειτουργίες σε υγιείς ενήλικες. Η παρούσα μελέτη θα εκπονηθεί υπό την εποπτεία της Δρ. Μαρία Σοφολόγη. Ακαδημαϊκό μέλος (ΣΕΠ)-Ακαδημαική υπότροφος-Μεταδιδακτορική ερευνήτρια (Παιδαγωγικό τμήμα-Πανεπιστήμιο Ιωαννίνων). Για την υλοποίηση των σκοπών της έρευνας θα χρειαστούμε την συνεργασία σας, που προϋποθέτει την συμμετοχή σας σε γνωστικά έργα αξιολόγησης. Η διάρκεια χορήγησης των γνωστικών έργων αναμένεται να κυμανθεί από 15 έως 30 λεπτά. Η συμμετοχή σας είναι εθελοντική και μπορείτε να διακόψετε τη διαδικασία οποιαδήποτε στιγμή. Οι πληροφορίες και τα δεδομένα που θα προκύψουν θα διατηρηθούν ανώνυμα και απόρρητα και θα χρησιμοποιηθούν αποκλειστικά και μόνο για τους σκοπούς της τρέχουσας έρευνας. Σας ευχαριστούμε πολύ για τον χρόνο που θα διαθέσετε και για την συνεργασία σας!

References

Abutalebi, J., Della Rosa, P. A., Green, D. W., Hernandez, M., Scifo, P., Keim, R., Cappa, S. F., & Costa, A. (2012). Bilingualism tunes the anterior cingulate cortex for conflict monitoring. *Cerebral Cortex*, 22(9), 2076-2086.

Adesope, O. O., Lavin, T., Thompson, T., & Ungerleider, C. (2010). A systematic review and meta-analysis of the cognitive correlates of bilingualism. *Review of Educational Research*, 80(2), 207–245.

Alloway, T. P., & Alloway, R. (2010). It is better than you think: *Fluid Intelligence across the lifespan.* Nature Precedings.

Altenmüller, E. (1989). Cortical DC-potentials as electrophysiological correlates of hemispheric dominance of higher cognitive functions. International Journal of Neuroscience, 47(1–2), 1–14.

Amer, T., Kalender, B., Hasher, L., Trehub, S. E., & Wong, Y. (2013). Do Older professional musicians have cognitive advantages? *PLoS One*, 8(7),71630.

Amunts, K., Schmidt-Passos, F., Schleicher, A., & Zilles, K. (1997). Postnatal development of interhemispheric asymmetry in the cytoarchitecture of human area 4. *Anatomy and Embryology*, 196(5), 393–402.

Anderson, P. (2002). Assessment and Development of Executive Function (EF) During Childhood. *Child Neuropsychology,* 8(2), 71–82.

Anderson, P. (2010). Towards a developmental model of executive function. *In Executive functions and the frontal lobes* (pp. 37–56). Psychology Press.

Aron, A. R., Robbins, T. W., & Poldrack, R. A. (2004). Inhibition and the right inferior frontal cortex. *Trends in Cognitive Sciences*, 8(4), 170–177.

Aronin, L., & Hufeisen, B. (2009). The Exploration of Multilingualism: Development of Research on L3, Multilingualism and Multiple Language

Acquisition. AILA *Applied Linguistics Series* 6. Amsterdam/Philadelphia: Benjamins

Backer, K. C., & Bortfeld, H. (2021). Characterizing bilingual effects on cognition: The search for meaningful individual differences. *Brain Sciences,* 11(1), 81.

Baddeley, A. (1993). Working memory and conscious awareness. In A. F. Collins, S. E. Gathercole, M. A. Conway, & P. E. Morris (Eds.), *Theories of memory* (pp. 11–28).

Baddeley, A. (1996.).The Central Executive. *Exploring Working Memory*, 243–245.

Baddeley, A. D., &; Hitch, G. (1974). Working memory. *Psychology of Learning and Motivation*, 47–89.

Baddeley, A. (1992). Working memory. *Science*, 255(5044), 556–559.

Baddeley, A. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences*, 4(11), 417–423.

Baddeley, A. (2003). Working memory: Looking back and looking forward. *Nature Reviews Neuroscience*, 4(10), 829–839.

Baddeley, A. (2012). Working memory: Theories, models, and controversies. *Annual Review of Psychology*, 63(1), 1–29.

Baddeley, A. D., Allen, R. J., & Hitch, G. J. (2011). Binding in visual working memory: The role of the episodic buffer. *Neuropsychologia,* 49(6), 1393–1400.

Baddeley, A., Gathercole, S., & Papagno, C. (1998). The phonological loop as a language learning device. Psychological Review, 105(1), 158–173.

Baddeley, A. D., & Logie, R. H. (1999). Working memory: The multiple-component model. In A. Miyake & P. Shah (Eds.), *Models of working memory*: Mechanisms of active maintenance and executive control (pp. 28–61). Cambridge University.

Baler, R. D., & Volkow, N. D. (2006, December). Drug addiction: the neurobiology of disrupted self-control. *Trends in Molecular Medicine*, 12(12), 559–566.

Barbey, A. K., Koenigs, M., & Grafman, J. (2013). Dorsolateral prefrontal contributions to human working memory. *Cortex,* 49(5), 1195–1205.

Barkley, R. A. (1997, January). Behavioral inhibition sustained attention, and executive functions: Constructing a unifying theory of ADHD. *Psychological Bulletin,* 121(1), 65–94.

Bella, S. D., Peretz, I., & Aronoff, N. (2003). Time course of Melody Recognition: A gating paradigm study. *Perception & Psychophysics, 65*(7), 1019–1028.

Benz, S., Sellaro, R., Hommel, B., & Colzato, L. S. (2016). Music makes the World Go Round: The impact of musical training on non-musical cognitive functions—a review. *Frontiers in Psychology, 6.*

Bergman-Nutley, S., & Klingberg, T. (2014). Effect of working memory training on working memory, arithmetic and following instructions. Psychological Research, 78(6), 869–877.

Best, J. R., & Miller, P. H. (2010). A developmental perspective on executive function. Child Development, 81(6), 1641–1660.

Bialystok, E. (2001). Bilingualism in development: Language, literacy, and cognition. New York, NY: Cambridge University Press.

Bialystok, E. (2009). Bilingualism: The good, the bad, and the indifferent. Bilingualism: Language and Cognition, 12(1), 3–11.

Bialystok, E., Barac, R. (2012). Emerging bilingualism: Dissociating advantages for metalinguistic awareness and executive control. *Cognition* 122: 67–73.

Bialystok, E., Craik, F., & Freedman, M. (2007). Bilingualism as a protection against the onset of symptoms of dementia. *Neuropsychologia, 45*(2), 459-464.

Bialystok, E., Craik, F., & Luk, G. (2008). Cognitive control and lexical access in younger and older bilinguals. Journal of Experimental Psychology: *Learning, Memory, and Cognition,* 34(4), 859–873.

Bialystok, E., Craik, F. I. M., & Luk, G. (2012). Bilingualism: Consequences for mind and brain. Trends in Cognitive Sciences, 16(4), 240–250.

Bialystok, E., Craik, F. I. M., Klein, R., & Viswanathan, M. (2004). Bilingualism, Aging, and Cognitive Control: Evidence From the Simon Task. *Psychology and Aging, 19*(2), 290–303.

Bialystok, E., & DePape, A.-M. (2009). Musical expertise, bilingualism, and executive functioning. Journal of Experimental Psychology: *Human Perception and Performance,* 35(2), 565–574.

Bialystok, E., & Feng, X. (2009). Language proficiency and executive control in proactive interference: Evidence from monolingual and bilingual children and adults. *Brain and Language*, 109(2–3), 93–100.

Bialystok, E., & Martin, M. (2004). Attention and inhibition in bilingual children: evidence from the dimensional change card sort task. *Developmental Science, 7*(3), 325-339.

Bialystok, E., Martin, M. M., & Viswanathan, M. (2005). Bilingualism across the lifespan: The rise and fall of inhibitory control. *International Journal of Bilingualism,* 9(1), 103–119.

Bialystok, E., & Viswanathan, M. (2009). Components of executive control with advantages for bilingual children in two cultures. *Cognition*, 112(3), 494–500.

Bloomfield, L. (1933). *Language.* New York: Holt.

Blumenfeld, R. S., & Ranganath, C. (2006). The dorsolateral prefrontal cortex promotes long-term memory formation through its role in working memory organization. The Journal of Neuroscience, 26(3), 916–925.

Bonifacci, P., Giombini, L., Bellocchi, S., & Contento, S. (2011). Speed of processing, anticipation, inhibition and working memory in bilinguals. Developmental Science, 14(2), 256–269.

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review*, 108(3), 624–652.

Brandler, S., & Rammsayer, T. H. (2003). Differences in mental abilities between musicians and non-musicians. Psychology of Music, 31(2), 123–138.

Braver, T. S., Reynolds, J. R., & Donaldson, D. I. (2003). Neural mechanisms of transient and sustained cognitive control during task switching. *Neuron, 39*(4), 713–726.

Brown, T. E., & Landgraf, J. M. (2010). Improvements in Executive Function Correlate with Enhanced Performance and Functioning and Health-Related Quality of Life: Evidence from 2 Large, Double-Blind, Randomized, Placebo-Controlled Trials in ADHD. *Postgraduate Medicine,* 122(5), 42–51.

Buckner, R. L., Andrews-Hanna, J. R., & Schacter, D. L. (2008). the brain's default network. *Annals of the New York Academy of Sciences*, 1124(1), 1–38.

Bugos, J. A., Perlstein, W. M., McCrae, C. S., Brophy, T. S., & Bedenbaugh, P. H. (2007). Individualized piano instruction enhances executive functioning and working memory in older adults. *Aging & Mental Health*, 11(4), 464–471.

Bunge, S. A., & Crone, E. A. (2009). Neural correlates of the development of cognitive control. Neuroimaging in Developmental Clinical Neuroscience, 22–37.

Burger, L., Fay, S., Angel, L., Borella, E., Noiret, N., Plusquellec, P., & Taconnat, L. (2019). Benefit of practice of the Stroop test in young and older adults: Pattern of gain and impact of educational level. *Experimental Aging Research*, 46(1), 52–67.

Burgess, P. W., & Simons, J. S. (2005). Theories of frontal lobe executive function: Clinical applications. *The Effectiveness of Rehabilitation for Cognitive Deficits*, 211–232.

Burgess, P., Alderman, N., Evans, J., Emslie, H., & Wilson, B. A. (1998). The ecological validity of tests of executive function. *Journal of the International Neuropsychological Society*, 4(6), 547–558.

Burunat, I., Alluri, V., Toiviainen, P., Numminen, J., & Brattico, E. (2014). Dynamics of brain activity underlying working memory for music in a naturalistic condition. *Cortex*, 57, 254–269.

Carey, D., Rosen, S., Krishnan, S., Pearce, M. T., Shepherd, A., Aydelott, J., & Dick, F. (2015). Generality and specificity in the effects of musical expertise on perception and cognition. *Cognition,* 137, 81–105.

Carpentier, S., Moreno, S., & McIntosh, A. R. (2016). Short-term music training enhances complex, distributed neural communication during music and linguistic tasks. Journal of Neuroscience Research.

Chan, A. S., Ho, Y.-C., & Cheung, M.-C. (1998). Music training improves verbal memory. Nature, 396(6707), 128–128.

Chanda, M. L., & Levitin, D. J. (2013). The neurochemistry of music. *Trends in Cognitive Sciences,* 17(4), 179–193.

Charronnat, B., Bigand, E., & Madurell, F. (2005). The influence of voice leading on harmonic priming. Music Perception, 22(4), 613–627.

Chen, J. L., Rae, C., & Watkins, K. E. (2017). Effects of music training on inhibitory control and associated neural networks in school-aged children: A longitudinal study. *Developmental Cognitive Neuroscience*, 26, 40-49.

Chen, J., Zhou, Y., & Chen, J. (2020). The relationship between musical training and inhibitory control: An ERPs study. *Acta Psychologica Sinica*, 52(12), 1365-1376.

Cohen, M. A., Evans, K. K., Horowitz, T. S., & Wolfe, J. M. (2011). Auditory and visual memory in musicians and no musicians. Psychonomic Bulletin Review, 18(3), 586–591.

Collette, F., Hogge, M., Salmon, E., & Van der Linden, M. (2006). Exploration of the neural substrates of executive functioning by functional neuroimaging. *Neuroscience*, 139(1), 209–221.

Colombo, P. J., Habibi, A., & Alain, C. (2020). Editorial: Music training, neural plasticity, and executive function. Frontiers in Integrative Neuroscience, 14.

Conway, A. R. A., Cowan, N., Bunting, M. F., Therriault, D. J., & Minkoff, S. R. B. (2002). A latent variable analysis of working memory capacity, short-term memory capacity, processing speed, and General Fluid Intelligence. Intelligence, 30(2), 163–183.

Cooper, R. P., & Shallice, T. (2006). Hierarchical schemas and goals in the control of sequential behavior. *Psychological Review,* 113(4), 887–916.

Costa, A., Hernández, M., Costa-Faidella, J., & Sebastián-Gallés, N. (2009). On the bilingual advantage in conflict processing: Now you see it, now you don't. *Cognition*, 113(2), 135–149.

Costa, A., Hernández, M., & Sebastián-Gallés, N. (2008). Bilingualism AIDS conflict resolution: Evidence from the ant task. *Cognition*, 106(1), 59–86.

Costa, A., Roelstraete, B., & Hartsuiker, R. J. (2006). The lexical bias effect in bilingual speech production: evidence for feedback between lexical and sublexical levels across languages. *Psychonomic Bulletin & Review, 13*(6), 972-977.

Costa-Giomi, E. (1999). The effects of three years of piano instruction on children's cognitive development. *Journal of Research in Music Education*, 47(3), 198–212.

Cowan, N., Elliott, E. M., Scott Saults, J., Morey, C. C., Mattox, S., Hismjatullina, A., & Conway, A. R. A. (2005). On the capacity of attention: Its estimation and its role in working memory and cognitive aptitudes. Cognitive Psychology, 51(1), 42–100.

Cockcroft K., Wigdorowitz, M., & Liversage, L. (2017). A multilingual advantage in the components of working memory. Bilingualism: *Language and Cognition*, 22(1), 15–29

Coderre, E. L., Van Heuven, W. J. B., & Conklin, K. (2013). The timing and magnitude of Stroop interference and facilitation in monolinguals and bilinguals. Bilingualism: *Language and Cognition*, 16(2), 420-441.

Collette, F., Hogge, M., Salmon, E., & Van der Linden, M. (2006). Exploration of the neural substrates of executive functioning by functional neuroimaging. *Neuroscience*, 139(1), 209–221.

Criscuolo, A., Bonetti, L., Särkämö, T., Kliuchko, M., & Brattico, E. (2019). On the association between musical training, intelligence and executive functions in adulthood. Frontiers in Psychology, 10.

Cuppini, C., Magosso., & Ursino, M. (2012). Learning the lexical aspects of a second language at different proficiencies: A neural computational study. Bilingualism: *Language and Cognition*, 16(2), 266–287.

Ho, Y.-C., Cheung, M.-C., & Chan, A. S. (2003). Music training improves verbal but not visual memory: Cross-sectional and longitudinal explorations in children. *Neuropsychology*, 17(3), 439–450.

De Angelis, G. (2007). Third or Additional Language Acquisition. Clevedon: *Multilingual Matters*.

De Frias, C. M., Dixon, R. A., & Strauss, E. (2006). Structure of four executive functioning tests in healthy older adults. *Neuropsychology,* 20(2), 206–214.

Degé, F., Kubicek, C., & Schwarzer, G. (2011). Music lessons and intelligence: A relation mediated by executive functions. Music Perception, 29(2), 195–201.

Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, 64(1), 135–168.

Dijkstra, T., & Van Heuven, W. J. B. (1998). The BIA model and bilingual word recognition. In J. Grainger & A. M. Jacobs (Eds.), Localist connectionist approaches to human cognition (pp. 189–225). Lawrence Erlbaum Associates Publishers.

Ding, Y., Tang, Y., Chen, A., & Zang, Y. (2018). A behavioral study on tonal working memory in musicians and non-musicians. *PLoS ONE, 13(8),* e0201763.

Dos Santos-Luiz, C., Mónico, L. S., Almeida, L. S., & Coimbra, D. (2016). Exploring the long-term associations between adolescents' music training and academic achievement. *Musicae Scientiae, 20*(4), 512–527.

D'Souza, A. A., Moradzadeh, L., & Wiseheart, M. (2018). Musical training, bilingualism, and executive function: Working memory and inhibitory control. Cognitive Research: Principles and Implications, 3(1).

Du, Y., & Zatorre, R. J. (2017). Musical training sharpens and bonds ears and tongue to hear speech better. Proceedings of the National Academy of Sciences, 114(51), 13579–13584.

Engle, R. W. (2002). Working memory capacity as executive attention. Current Directions in Psychological Science, 11(1), 19–23.

Engle, R. W. (2010). Role of working-memory capacity in Cognitive Control. *Current Anthropology*, *51*(S1).

Engle, R. W., Tuholski, S. W. T. W., Laughlin, J. E., & Conway, A. R. A. C. R. A. (1999). Working memory, short-term memory, and general fluid intelligence: a latent-variable approach. *Exp. Psychol Gen*, 309–331

Engel de Abreu, P. M. J., Conway, A. R. A., & Gathercole, S. E. (2010). Working memory and Fluid Intelligence in young children. Intelligence, 38(6), 552–561.

Engel de Abreu, P. (2011). Working memory in multilingual children: Is there a bilingual effect? *Memory, 19(*5), 529-537.

Engel de Abreu, P. M., Gathercole, S. E., & Martin, R. (2011). Disentangling the relationship between working memory and language: The roles of short-term storage and cognitive control. *Learning and Individual Differences*, 21(5), 569–574.

Ericsson, K. A., Krampe, R. T., & Tesch-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review, 100*(3), 363–406.

Fasano, M. C., et al. (2019). Short-Term Orchestral Music Training Modulates Hyperactivity and Inhibitory Control in School-Age Children: A Longitudinal Behavioural Study. *Frontiers in Psychology*, 10:750.

Fink, A., Graif, B., & Neubauer, A. C. (2009). Brain correlates underlying creative thinking: EEG alpha activity in professional vs. novice dancers. *NeuroImage, 46*(3), 854–862.

Franklin, M. S., Moore, K. S., Yip, C.-Y., Jonides, J., Rattray, K., & Moher, J. (2008). The effects of musical training on verbal memory. Psychology of Music, 36(3), 353–365.

Furneaux, S., & Land, M. F. (1999). The effects of skill on the eye–hand span during musical sight–reading. Proceedings of the Royal Society of London. Series B: Biological Sciences, 266(1436), 2435–2440.

Friedman NP, Miyake A, Young SE, DeFries JC, Corley RP, et al. (2008) Individual differences in executive functions are almost entirely genetic in origin. J Exp Psychol Gen 137: 201–225.

Friedman, N. P., & Miyake, A. (2017). Unity and diversity of executive functions: Individual differences as a window on cognitive structure. *Cortex*, 86, 186–204.

Fuster, J. M. (2001). The prefrontal cortex—an update. Neuron, 30(2), 319–333.

Gade, M., & Schlemmer, K. (2021). Music modulates cognitive flexibility? an investigation of the benefits of musical training on markers of cognitive flexibility*. Brain Sciences, 11*(4), 451.

Garbin, G., Sanjuan, A., Forn, C., Bustamante, J. C., Rodriguez-Pujadas, A., Belloch, V., … Ávila, C. (2010). Bridging language and attention: Brain Basis of the impact of bilingualism on Cognitive Control. NeuroImage, 53(4), 1272–1278.

Gaser, C., & Schlaug, G. (2003). Brain structures differ between musicians and non-musicians. The Journal of Neuroscience, 23(27), 9240–9245.

Gathercole, S. E., & Masoura, E. V. (2005). Contrasting contributions of phonological short-term memory and long-term knowledge to vocabulary learning in a foreign language. *Memory, 13*(3–4), 422–429.

Cenoz, J., & Genesee, F. (1998). Beyond bilingualism: Multilingualism and multilingual education. Clevedon, England: Multilingual Matters.

George, E. M., & Coch, D. (2011). Music training and working memory: An ERP study. *Neuropsychologia, 49*(5), 1083–1094.

Gilbert, S. J., & Burgess, P. W. (2008). Executive function*. Current Biology*, 18(3).

Giovannoli, J., Martin-Rhee, M. M., Bialystok, E., & Tannock, R. (2020). The Impact of Bilingualism on Executive Functions in Children and Adolescents: A Systematic Review Based on the PRISMA Method. *Frontiers in Psychology, 11*, 574789.

Goetz, C. G. (2003). Athetosis. Encyclopedia of the Neurological Sciences, 288.

Gold, B. T., Kim, C., Johnson, N. F., Kryscio, R. J., & Smith, C. D. (2013). Lifelong bilingualism maintains neural efficiency for cognitive control in aging. *Journal of Neuroscience,* 33(2), 387-396.

Goolsby, T. W. (1994). Profiles of processing: Eye Movements during sightreading. Music Perception, 12(1), 97–123.

Green, D. W. (1998). Mental control of the bilingual lexico-semantic system. Bilingualism: *Language and Cognition*, 1(2), 67–81.

Green, D. W., & Abutalebi, J. (2013). Language control in bilinguals: The adaptive control hypothesis. *Journal of Cognitive Psychology*, 25(5), 515–530.

Green, L. (2014). Hear, listen, play!: How to free your students' aural, improvisation and performance skills. New York, NY: Oxford University Press.

Grissom, N. M., & Reyes, T. M. (2019). Correction: Let's call the whole thing off: Evaluating gender and sex differences in executive function. Neuropsychopharmacology, 44(7), 1344–1344.

Grosjean, F. (2010). Bilingual: Life and reality. Harvard University Press.

Grundy, J. G., & Timmer, K. (2016). Bilingualism and working memory capacity: A comprehensive meta-analysis. Second Language Research, 33(3), 325–340.

Hakuta, K. (1986). Mirror of language: *The debate on bilingualism.* New York: Basic Books.

Hallam, S. (2010). The power of music: Its impact on the intellectual, social, and personal development of children and young people. International Journal of Music Education, 28(3).

Hansen, P., Climie, E. A., & Oxoby, R. J. (2020). The demands of performance generating systems on executive functions: *Effects and Mediating Processes. Frontiers in Psychology*, 11.

Hansen, M., Wallentin, M., & Vuust, P. (2013). Working memory and musical competence of musicians and non-musicians. *Psychology of Music, 41*(6), 779–793.

Hanna-Pladdy, B., & Gajewski, B. (2012). Recent and past musical activity predicts cognitive aging variability: Direct comparison with General Lifestyle Activities. *Frontiers in Human Neuroscience, 6*.

Hanna-Pladdy, B., & MacKay, A. (2011). The relation between instrumental musical activity and cognitive aging. *Neuropsychology, 25*(3), 378–386.

Haugen, E. (1953). The Norwegian Language in America, a Study in Bilingual Behavior, Volume 2.

Hennessy, S. L., Sachs, M. E., Ilari, B., & Habibi, A. (2019). Effects of music training on inhibitory control and associated neural networks in school-aged children: *A longitudinal study*. Frontiers in Neuroscience, 13.

Hetland, L. (2000). Learning to make music enhances spatial reasoning. Journal of Aesthetic Education, 34(3/4), 179.

Hommel, B., Colzato, L. S. (2015). Learning from history: The need for a synthetic approach to human cognition. *Frontiers in Psychology*, 6.

Hsieh, S (1994). Shifting intentional set: Exploring the dynamic control of tasks. Attention and Performance XV.

Hund-Georgiadis, M., & von Cramon, D. Y. (1999). Motor-learning-related changes in piano players and non-musicians revealed by functional magnetic-resonance signals. Experimental Brain Research, 125(4), 417–425.

Izbicki, P. (2020). The Behavioral and Neurophysiological Effects of Music Training on Cognitive and Motor Inhibition in Aging Adults.

Jansen, P., Hoja, S., &Jost, L. (2022). Are there gender differences in executive functions in musicians and non-musicians? *Journal of Individual Differences, 43*(1), 20–27.

Jaeggi, S. M., Buschkuehl, M., Jonides, J., & Perrig, W. J. (2008). Improving fluid intelligence with training on working memory. Proceedings of the National Academy of Sciences of the United States of America, 105(19), 6829-6833

Jentzsch, I., Mkrtchian, A., & Kansal, N. (2014). Improved effectiveness of performance monitoring in amateur instrumental musicians. Neuropsychologia, 52, 117–124.

Jurado, M. B., & Rosselli, M. (2007). The elusive nature of executive functions: A review of our current understanding. *Neuropsychology Review,* 17(3), 213–233.

Jylkkä, J., Soveri, A., Laine, M., & Lehtonen, M. (2019). Assessing bilingual language switching behavior with ecological momentary assessment. Bilingualism: ,, 23(2), 309–322.

Kane, M. J., & Engle, R. W. (2003). Working memory capacity and the control of attention: The contributions of goal neglect, response competition, and task set to Stroop interference. Journal of Experimental Psychology: *General*, 132(1), 47–70.

Kemp, C. (2009). Defining multilingualism. In the Exploration of Multilingualism: Development of research on L3, multilingualism and multiple language acquisition (pp. 11-26). John Benjamins Publishing.

Kousaie, S., & Phillips, N. A. (2012). Aging and bilingualism: Absence of a “bilingual advantage” in Stroop interference in a nonimmigrant sample. *Quarterly Journal of Experimental Psychology*, 65(2), 356–369.

Kosmidis, M., Vlahou, C., Panagiotaki, P., & Kiosseoglou, G. (2004). The verbal fluency task in the Greek population: Normative data, and clustering and switching strategies. *Journal Of The International Neuropsychological Society, 10*(2), 164-172.

Krizman, J., Marian, V., Shook, A., Skoe, E., & Kraus, N. (2012). Subcortical encoding of sound is enhanced in bilinguals and relates to executive function advantages. *Proceedings of the National Academy of Sciences*, 109(20), 7877–7881.

Krizman, J., Skoe, E., Marian, V., & Kraus, N. (2014). Bilingualism increases neural response consistency and attentional control: Evidence for sensory and cognitive coupling. *Brain and Language,* 128, 34-40.

Krizman, J., Skoe, E., & Kraus, N. (2012). Sex differences in auditory subcortical function. *Clinical Neurophysiology*, 123(3), 590–597.

Kroll, J. F., Michael, E., Tokowicz, N., & Dufour, R. (2002). The development of lexical fluency in a second language. *Second Language Research, 18*(2), 137–171.

Larsen-Freeman, D. (2007). Reflecting on the Cognitive-Social Debate in Second Language Acquisition. *Modern Language Journal*, 91, 773-787

Lee, Y., Lu, M., & Ko, H. (2007). Effects of skill training on working memory capacity. *Learning and Instruction*, 17 (3), 336–344.

Lezak, Muriel Deutsch, (1983). Neuropsychological assessment (2nd ed.). New York: Oxford University Press. *Journal of Psychoeducational Assessment*, 4(1), 91–92.

Lezak, M. D., Howieson, D. B., & Loring, D. W. (2004). Neuropsychological Assessment (4th ed.). *New York*: Oxford University Press.

Limberger, B. K., & Buchweitz, A. (2014). Os efeitos do bilinguismo e do multilinguismo NAS Funções Executivas. Fórum Linguístico, 11(3), 261

Linnavalli, T., Putkinen, V., Lipsanen, J., Huotilainen, M., & Tervaniemi, M. (2018). Music playschool enhances children's linguistic skills. *Scientific Reports,* 8(1).

Luiz, C., Gil, D., de Camargo, N., & Miguel, J. (2021). Auditory abilities in individuals with and without formal musical training. Journal of Hearing Science, 11(3), 27–31.

Luk, G., Bialystok, E., Craik, F. I., & Grady, C. L. (2011). Lifelong bilingualism maintains white matter integrity in older adults. *The Journal of Neuroscience*, 31(46), 16808–16813.

Lukasik, K. M., Lehtonen, M., Soveri, A., Waris, O., Jylkkä, J., & Laine, M. (2018). Bilingualism and working memory performance: *Evidence from a large-scale online study*. *PLOS ONE, 13*(11).

Luo, L., Craik, F. I., Moreno, S., & Bialystok, E. (2013). Bilingualism interacts with domain in a working memory task: Evidence from aging. *Psychology and Aging,* 28(1), 28–34.

Luria, A. R. (1966). Disturbances of higher cortical functions with lesions of the temporal region. *Higher Cortical Functions in Man,* 94–122.

Luria, A. R. (1973). The frontal lobes and the regulation of behavior. In K. H. Pribram & A. R. Luria, *Psychophysiology of the frontal lobes*. Academic Press.

Luria, A. R. (1974). The working brain: An introduction to neuropsychology. New York: Basic Books.

Luria, A. R. (1980). Objects of neuropsychological investigation of higher cortical functions in the presence of local brain lesions. *Higher Cortical Functions in Man*, 387–397.

Luria, A.R., Pribram, K. H., & Homskaya, E. D. (1964). An experimental analysis of the behavioral disturbance produced by a left frontal arachnoidal endothelioma (meningioma). *Neuropsychologia,* 2(4), 257–280.

MacCallum, R. C., Zhang, S., Preacher, K. J., & Rucker, D. D. (2002). On the practice of dichotomization of quantitative variables. *Psychological Methods*, 7(1), 19–40.

MacDonald, R. A. (2013). Music, health, and well-being: A Review. International Journal of Qualitative Studies on Health and Well-Being, 8(1), 20635.

Maguire, E. A., Gadian, D. G., Johnsrude, I. S., Good, C. D., Ashburner, J., Frackowiak, R. S., & Frith, C. D. (2000). Navigation-related structural change in the hippocampi of taxi drivers. *Proceedings of the National Academy of Sciences, 97*(8), 4398–4403.

Majerus, S., Poncelet, M., Greffe, C., & Van der Linden, M. (2006). Relations between vocabulary development and verbal short-term memory: The relative importance of short-term memory for serial order and Item Information. Journal of Experimental Child Psychology, 93(2), 95–119.

Mazzonna, F., & Peracchi, F. (2012). Ageing, cognitive abilities, and retirement. *European Economic Review, 56*(4), 691-710.

Mechelli, A., Crinion, J. T., Noppeney, U., O'Doherty, J., Ashburner, J., Frackowiak, R. S., & Price, C. J. (2004). Structural plasticity in the bilingual brain. Nature, 431(7010), 757–757.

Mekarski, J. E., Cutmore, T. R., & Suboski, W. (1996). Gender differences during processing of the Stroop task. *Perceptual and Motor Skills, 83*(2), 563–568.

Meuter, R. F. I., & Allport, A. (1999). Bilingual language switching in naming: Asymmetrical costs of language selection. Journal of Memory and Language, 40(1), 25–40.

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience,* 24(1), 167–202.

Milovanov, R., Pietilä, P., Tervaniemi, M., & Esquef, P. A. A. (2010). Foreign language pronunciation skills and musical aptitude: A study of Finnish adults with higher education. *Learning and Individual Differences,* 20(1), 56–60.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex “frontal lobe” tasks: A latent variable analysis. *Cognitive Psychology, 41*(1), 49–100.

Mor, B., Yitzhaki-Amsalem, S., & Prior, A. (2014). The joint effect of bilingualism and ADHD on executive functions. *Journal of Attention Disorders*, 19(6), 527–541.

Moradzadeh, L., Blumenthal, G., & Wiseheart, M. (2014). Musical training, bilingualism, and executive function: A closer look at task switching and dual-task performance. *Cognitive Science*, 39(5), 992–1020.

Moreno S, Bialystok E, Barac R, Schellenberg EG, Cepeda NJ, (2011). Short-term music training enhances verbal intelligence and executive function. *Psychol Sci 22*: 1425–1433.

Moreno, S., & Bidelman, G. M. (2014). Examining neural plasticity and cognitive benefit through the unique lens of musical training. *Hearing Research*, 308, 84–97.

Moreno, S., & Farzan, F. (2015). Music training and inhibitory control: A multidimensional model. *Annals of the New York Academy of Sciences*, 1337(1), 147–152.

Morrison, F. J., Ponitz, C. C., & McClelland, M. M. (2010). Self-regulation and academic achievement in the transition to school. In S. D. Calkins & M. A. Bell (Eds.), Child development at the intersection of emotion and cognition (pp. 203–224).

Norman, D. A., & Shallice, T. (1986). Attention to action. *Consciousness and Self-Regulation*, 1–18.

Oechslin, M. S., Van De Ville, D., Lazeyras, F., Hauert, C.-A., & James, C. E. (2013). A degree of musical expertise modulates higher-order brain functioning. Cerebral Cortex, 23(9), 2213–2224.

Okada, B., & Slevc, L. R. (2018). Musical Training: *Contributions to Executive Function.*

Okhrei, A., Kutsenko, T., & Makarchuk, M. (2017). Performance of working memory of musicians and non-musicians in tests with letters, digits, and geometrical shapes. *Biologija,* 62(4).

Paap, K. R., & Greenberg, Z. I. (2013). There is no coherent evidence for a bilingual advantage in executive processing. *Cognitive Psychology, 66*(2), 232–258.

Paap, K. R., Johnson, H. A., & Sawi, O. (2015). Bilingual advantages in executive functioning either do not exist or are restricted to very specific and undetermined circumstances*.* *Cortex*, 69, 265–278.

Pallesen, K. J., Brattico, E., Bailey, C. J., Korvenoja, A., Koivisto, J., Gjedde, A., & Carlson, S. (2010). Cognitive control in auditory working memory is enhanced in musicians. *PLoS ONE*, 5(6).

Parbery-Clark, A., Skoe, E., Lam, C., & Kraus, N. (2009). Musician enhancement for speech-in-noise. *Ear & Hearing*, 30(6), 653–661.

Passarotto, E., Kopp, B., Lee, A., & Altenmüller, E. (2023). Musical expertise and executive functions in experienced musicians. *Brain Sciences*, 13(6), 908.

Passingham, R. E., & Toni, I. (2001). Contrasting the dorsal and ventral visual systems: Guidance of movement versus decision making. *NeuroImage,* 14(1).

Patel, A. D. (2011). Why would musical training benefit the neural encoding of speech? the opera hypothesis. *Frontiers in Psychology, 2.*

Pauls, F., Petermann, F., & Lepach, A. C. (2013). Gender differences in episodic memory and visual working memory including the effects of age. *Memory, 21*(7), 857–874.

Peterson, D. A., & Thaut, M. H. (2007). Music increases frontal EEG coherence during verbal learning. *Neuroscience Letters*, 412(3), 217–221.

Pribram K. H. (1973). The primate frontal cortex – the executive of the brain. *Psychophysiology of the Frontal Lobes,* 293–314.

Prior, A., & Gollan, T. H. (2011). Good language-switchers are good task-switchers: Evidence from Spanish–English and Mandarin–English bilinguals. Journal of the International Neuropsychological Society, 17(4), 682–691.

Prior A., & Macwhinney, B. (2009). A bilingual advantage in task switching. Bilingualism: *Language and Cognition, 13*(2), 253–262.

Racette, A., & Peretz, I. (2007). Learning lyrics: To sing or not to sing? Memory & Cognition, 35(2), 242–253.

Rickard, N. S., & Chin, T. (2017). Defining the musical identity of “non-musicians.” Handbook of Musical Identities, 288–303.

Roden, I., Kreutz, G., & Bongard, S. (2012). Effects of a school-based instrumental music program on verbal and visual memory in primary school children. *A longitudinal study*. *Frontiers in Psychology*, 3, 572.

Rodriguez-Gomez, D. A., & Talero-Gutiérrez, C. (2022). Effects of music training in Executive Function Performance in children: *A systematic review*. Frontiers in Psychology, 13.

Román-Caballero, R., Arnedo, M., Triviño, M., & Lupiáñez, J. (2018). Musical practice as an enhancer of cognitive function in healthy aging - A systematic review and meta-analysis. *PLOS ONE*, 13(11).

Roselli, M., Ardila, A., Lalwani, L. N., & Velez-Uribe, I. (2015). The effect of language proficiency on executive functions in balanced and unbalanced Spanish–English bilinguals. Bilingualism: *Language and Cognition, 19*(3), 489–503.

Sabourin, L., & Vinerte, S. (2014). The bilingual advantage in the Stroop task: Simultaneous vs. early bilinguals. Bilingualism: *Language and Cognition*, 18(2), 350–355.

Sachs, M., Kaplan, J., Der Sarkissian, A., & Habibi, A. (2017). Increased engagement of the cognitive control network associated with music training in children during an fMRI Stroop task. *PLOS ONE*, 12(10).

Saarikivi, K. A., Huotilainen, M., Tervaniemi, M., & Putkinen, V. (2019). Selectively enhanced development of working memory in musically trained children and adolescents. *Frontiers in Integrative Neuroscience*, 13.

Salway, A. F., & Logie, R. H. (1995). Visuospatial working memory, movement control and executive demands. *British Journal of Psychology*, 86(2), 253–269.

Sarkamo, T. (2018). Music for the ageing brain: Cognitive, emotional, social, and neural benefits of musical leisure activities in stroke and dementia. *Dementia* (London), 17(6), 670-685.

Schellenberg, E. G. (2006). Long-term positive associations between music lessons and IQ. *Journal of Educational Psychology*, 98(2), 457–468.

Schellenberg, E. G. (2011). Examining the association between music lessons and intelligence. *British Journal of Psychology, 102*(3), 283–302.

Schellenberg, E. G., & W. Weiss, M. (2013). Music and cognitive abilities. The *Psychology of Music,* 499–550.

Schroeder, S. R., Marian, V., Shook, A., & Bartolotti, J. (2016). Bilingualism and musicianship enhance cognitive control. *Neural Plasticity*, 2016, 1–11.

Schulkind, M. D., Posner, R. J., & Rubin, D. C. (2003). Musical features that facilitate melody identification: How do you know it's "your" song when they finally play it? *Music Perception, 21*(2), 217–249.

Seinfeld, S., Figueroa, H., Ortiz-Gil, J., & Sanchez-Vives, M. V. (2013). Effects of music learning and piano practice on cognitive function, mood and quality of life in older adults. *Frontiers in Psychology, 4.*

Shallice, T. (1988). From neuropsychology to mental structure. Cambridge University Press.

Shallice, T. (2002). Fractionation of the supervisory system. *Principles of Frontal Lobe Function*, 261–277

Shallice, T. S., & Burgess, P. B. (1996). The domain of supervisory processes and temporal organization of behavior. *Philosophical Transactions of the Royal Society of London.* Series B: *Biological Sciences*, 351(1346), 1405–1412.

Skoe, E., & Kraus, N. (2012). A little goes a long way: How the adult brain is shaped by musical training in childhood. *The Journal of Neuroscience, 32*(34), 11507–11510.

Slevc, L. R., Davey, N. S., Buschkuehl, M., & Jaeggi, S. M. (2016). Tuning the mind: Exploring the connections between musical ability and executive functions. *Cognition, 152*, 199–211.

Slevc, L. R., & Okada, B. M. (2014). Processing structure in language and music: A case for shared reliance on cognitive control. *Psychonomic Bulletin & Review, 22*(3), 637–652.

Sloboda, J. (2004). Exploring the Musical Mind Cognition, Emotion, Ability, Function.

Stuss, D. T. (2011). Functions of the frontal lobes: Relation to executive functions. Journal of the International Neuropsychological Society, 17(05), 759–765.

Stuss, D. T., & Levine, B. (2002). Adult clinical neuropsychology: Lessons from studies of the frontal lobes. *Annual Review of Psychology, 53*(1), 401–433.

Slevc, L. R., & Miyake, A. (2006). Individual differences in second-language proficiency. *Psychological Science, 17*(8), 675–681.

Smithson, L., & Nicoladis, E. (2013). Verbal memory resources predict iconic gesture use among monolinguals and bilinguals. Bilingualism: Language and Cognition, 16(4), 934–944.

Soveri, A., Rodriguez-Fornells, A., & Laine, M. (2011). Is there a relationship between language switching and executive functions in bilingualism? introducing a within-group analysis approach. *Frontiers in Psychology*, 2.

Strait, D., & Kraus, N. (2011). Playing music for a smarter ear: Cognitive, Perceptual and neurobiological evidence. *Music Perception*, 29(2), 133–146

Strait, D. L., Kraus, N., Parbery-Clark, A., & Ashley, R. (2010). Musical experience shapes top-down auditory mechanisms: evidence from masking and auditory attention performance. Hearing Research, 261(1-2), 22–29.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18(*6), 643–662.

Stuss DT, Alexander MP (2000) Executive functions and the frontal lobes: A conceptual review. *Psychol Res 63*: 289–298.

Suárez-Pereira, I., & Carrión, Á. M. (2015). Updating stored memory requires adult hippocampal neurogenesis. Scientific Reports, 5(1). doi:10.1038/srep13993.

Talamini, F., Altoè, G., Carretti, B., & Grassi, M. (2017). Musicians have better memory than non-musicians: A meta-analysis. *PLOS ONE, 12*(10).

Tao, L., Marzecová, A., Taft, M., Asanowicz, D., & Wodniecka, Z. (2011). The efficiency of attentional networks in early and late bilinguals: the role of age of acquisition. *Frontiers in Psychology*, 2, 123.

Taylor, A. C., & Dewhurst, S. A. (2017). Investigating the Influence of Music Training on Verbal Memory, 45(6).

Thaut, M. H., McIntosh, G. C., & Hoemberg, V. (2015). Neurobiological foundations of neurologic music therapy: Rhythmic entrainment and the motor system. *Frontiers in Psychology, 5*.

Thaut, M. H., Peterson, D. A., McIntosh, G. C., & Hoemberg, V. (2014). Music Mnemonics aid verbal memory and induce learning-related brain plasticity in multiple sclerosis. *Frontiers in Human Neuroscience*, 8.

Travis, F., Harung, H. S., & Lagrosen, Y. (2011). Moral development, executive functioning, peak experiences and brain patterns in professional and amateur classical musicians: interpreted in light of a Unified Theory of Performance. *Consciousness and Cognition*, 20(4), 1256-1264

Treffers-Daller, J., Ongun, Z., Hofweber, J., & Korenar, M. (2020). Explaining individual differences in executive functions performance in multilinguals: The impact of code-switching and alternating between multicultural identity styles. *Frontiers in Psychology,11.*

Trimble, M. R. (1986). The Frontal Lobes. By Donald T. Stuss and Frank D. Benson. New York: *Raven Press. British Journal of Psychiatry, 149*(3), 393–394.

Unsworth, N., & Engle, R. W. (2007). The nature of individual differences in working memory capacity: Active maintenance in primary memory and controlled search from secondary memory. Psychological Review, 114(1), 104–132.

Ursino, M., Magosso, E., & Cuppini, C. (2010). Sensory fusion. *Perception-Action Cycle*, 23–62.

Valdés, G., & Figueroa, R. A. (1994). Bilingualism and testing: A special case of bias. Ablex Publishing

Wallentin, M., Nielsen, A. H., Friis-Olivarius, M., Vuust, C., & Vuust, P. (2010). The musical ear test, is a new reliable test for measuring musical competence. *Learning and Individual Differences, 20*(3), 188–196.

Wan, C. Y., & Schlaug, G. (2010). Music making as a tool for promoting brain plasticity across the life span. *The Neuroscientist, 16*(5), 566–577.

Warmington, M.A., Kandru-Pothineni, S., & Hitch, G. J. (2018). Novel-word learning, executive control and working memory: A bilingual advantage. Bilingualism: *Language and Cognition, 22*(04), 763–782.

Wechsler, D. (1955). *Wechsler Adult Intelligence Scale – Manual.* New York, NY: Psychological Corporation.

Welsh, M. C., & Pennington, B. F. (1988). Assessing Frontal Lobe Functioning in Children: Views from Developmental Psychology. *Developmental Neuropsychology,* 4, 199-230.

Winston, J. L., Jazwinski, B. M., Corey, D. M., & Colombo, P. J. (2022). Music training, and the ability of musicians to harmonize, are associated with enhanced planning and problem-solving. *Frontiers in Psychology*, 12.

Wiseheart, M., Viswanathan, M., & Bialystok, E. (2014). Flexibility in task switching by monolinguals and bilinguals. Bilingualism: Language and Cognition, 19(1), 141–146.

Wodniecka, Z., Craik, F. I. M., Luo, L., & Bialystok, E. (2010). Does bilingualism help memory? competing effects of verbal ability and executive control. *International Journal of Bilingual Education and Bilingualism, 13*(5), 575–595.

Yang, H., & Yang, S. (2015). Are all interferences bad? bilingual advantages in working memory are modulated by varying demands for controlled processing. Bilingualism: *Language and Cognition*, 20(1), 184–196.

Yoo, J., & Kaushanskaya, M. (2012). Phonological memory in bilinguals and monolinguals. *Memory & Cognition, 40*(8), 1314–1330.

Yurgil, K. A., Velasquez, T. D., Winston, J. L., & Reichman, N. B. (2020). Music Training, Working Memory, and Neural Oscillations: A Review. Frontiers in Psychology, 11, 211.

Zatorre, R., Evans, A., & Meyer, E. (1994). Neural mechanisms underlying melodic perception and memory for pitch. *The Journal of Neuroscience, 14*(4), 1908–1919.

Zelazo, P. D., & Müller, U. (2002). Executive function in typical and atypical development. In U. Goswami (Ed.), Blackwell Handbook of childhood cognitive development (pp. 445–469).

Zhang, J. D., Susino, M., McPherson, G. E., & Schubert, E. (2018). The definition of a musician in Music Psychology: A Literature Review and the six-year rule. *Psychology of Music,* 48(3), 389–409.

Zuk, J., Benjamin, C., Kenyon, A., & Gaab, N. (2014). Behavioral and neural correlates of executive functioning in musicians and Non-Musicians. *PLoS ONE*, 9(6).