Investigating the effects of bilingualism/multilingualism and musical training on Executive Functioning

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Abstract

Aims: The current study sought to provide further insight into the relationships between both bilingualism and musical training and the long speculated positive effects both domains have on the efficiency of the executive functioning (EF) system. The study examined differences in working memory (WM) and inhibitory control performance between 3 groups: bilinguals/multilinguals and monolinguals, formally trained musicians and non-musicians, bilinguals who had formal music training experience and monolinguals who had formal music training experience. The relationship between age of secondary language acquisition and stroop scores was also investigated. **Method:** A questionnaire concerning demographic, language ability, and musical ability was first administered to participants (*n* = 44), after which participants proceed to complete the Stroop Task to assess inhibitory control performance, then the Digit Span forwards and backwards tasks to assess WM. **Results:** Results did not yield significant effects across any of the EF tests between groups. No significant correlation was found between age of language acquisition and stroop scores. **Conclusion:** Though the current study failed to yield significant results, an analysis of the strengths and limitations of the current study design can be said to contribute to existing literature. Future analysis of both L2 acquisition and musical training on EF's was proposed based on previous literature that influenced study design. Future analysis of the effects of both bilingualism and music training on EF's was also proposed due to the lack of research surrounding this combination.

Contents

Literature Review

Bilingualism and Higher Cognition

Studies investigating the effects of bilingualism on general cognition have seen a significant shift in approach in the last half century, with early iterations of bilingual studies being cited as employing unstandardized measures and subjective definitions of bilingualism, and verbal-intelligence tests often being administered to non-proficient speakers of a second language in that second language (Woumans et al., 2016). Ianco-Worall (1972) first employed a more refined selection criteria when testing differences in semantic and phonetic preference amongst bilingual and unilingual children, matching variables of age, sex, school grade and social class in the two populations as well as conducting interviews with the mothers of the bilingual sample. Accounting for these variables produced significant evidence in support of Leopold's (1950) findings; that bilingual children are speculated to reach a particular stage in semantic development 2-3 years earlier than their monolingual peers.

Research investigating bilingualism found an uptake in interest following this, with bilingual individuals frequently being shown to outperform their monolingual peers in not only the expected linguistic abilities, but also executive functions (EF) of attention, working memory (WM), and cognitive control (Friesen et al., 2014; Bialystok et al., 2004). Evidence has even been found for bilingualism potentially delaying the onset of dementia symptoms in patients by 4-5 years due to the speculated benefits of strengthened synaptogenesis and enhanced working memory (WM) integrity (Sujin et al., 2019). The improved functioning in multiple domains for bilinguals in comparison to monolinguals is commonly referred to as the 'bilingual advantage'(BA) across literature, with studies showing children, adult, and older adult lifelong bilinguals and who consistently use two languages to regularly demonstrate higher levels of executive control when compared to monolinguals (Mezzacappa, 2004; Bialystok et al., 2006; Gold et al., 2013).

A systematic review conducted by van den Norrt et al., (2019) examined the efficacy of BA across 56 separate studies investigating the effects of bilingualism on cognitive control, and while showing the majority of research for having findings for a BA in cognitive control through studies involving the Simon task, Flanker tasks, Stroop tasks and switching tasks, this review also highlighted that a BA was found to be more prevalent in adult studies (56.4%) than studies involving children (42.8%), suggesting that these advantages in cognitive control may only become more evident when the brain is more fully developed in early adulthood due to EF's requiring the recruitment of prefrontal brain regions (Bunge et al., 2002). Studies have found evidence for a BA amongst child populations (Grundy & Trimmer, 2016; Mezzacappa, 2004), with age of language acquisition (AoA) considered to be a significant factor in L2 learning by researchers when considering the superior neural plasticity of children (Carlson et al., 2013), the advantage additional years of learning a secondary language provides the earlier the start, or the higher likelihood of learning that immersion in a community of native speakers provides (Hartshorne et al., 2018; Rahman et al., 2017).

There is ongoing debate as to whether a "critical period" of secondary language (L2) acquisition exists during development (Johnson & Newport, 1989), with this critical period hypothesis (CPH) suggesting that an L2 learners age and their susceptibility to L2 input is non-linear, providing explanation as to why adult L2 learners are less susceptible to input when compared to child L2 learners (Vanhove & White, 2013). The span at which this point exists during development also remains inconclusive across studies that have attempted to determine this period (Singleton & Ryan, 2004; Hartshorne et al., 2018). Gigi Luk & Bialystok (2011) found that children with AoA under 10 years scored significantly better on incongruent trials of the flanker task, however, a lack of consensus surrounding this issue serves as one of many reasons as to why a solid theoretical basis for the cognitive mechanisms that are associated with a bilingual advantage require further exploration and understanding (Valian, 2016), as is indicated by the substantial increase in the number of bilingual studies on cognitive control within varying populations over the last ten years (van den Noort, 2019).

Studies have demonstrated that when bilinguals and second language (L2) learners are listening, reading, or speaking monolingually, they are managing two (or more) language systems (Starreveld et al., 2014). This ‘parallel language activation’ involves suppressing interference from the nontarget language(s) to speak or recognize the target language(s), as research suggests that this parallel activity creates a form of lexical competition that must be resolved (Linck et al., 2008). Bilingual lexical models suggest that this prolonged period of bilingual “negotiating” or code switching in both verbal and internal manners may result in more proficient cognitive control processes (Bialystok et al., 2004; Struys et al., 2019), significantly contributing to an enhanced inhibitory control mechanism as studies have shown (van den Noort et al., 2019), as well as the increased exercise of several other underlying mechanisms in bilingual individuals that are thought to contribute to superior executive functioning. Current literature examining the effects of bilingualism on WM (Baddeley, 2003) has produced more inconsistent findings when compared to inhibitory control, with findings existing both in support and opposition as to whether a BA exists within this cognitive domain (Grundy & Timmer, 2017; Adesope et al., 2010). Diamond (2013) however, asserts that inhibitory control is a behavioral product of working memory as opposed to a separate cognitive skill, and is necessary in inhibition to hold information in the mind to determine what is important and needs to be inhibited, with subsequent research also suggesting a mediating relationship between the two skill domains (Trevisol, J., & Tomitch, L. 2017).

Music and Higher Cognition

The belief that music interventions are thought to have an influence on motor, language, cognitive, social, and academic abilities is widely accepted in the general population. Researchers have systematically investigated this domain in relation to higher cognitive functions (Schellenberg, 2011; Dumont et al., 2017), with strong neurological evidence existing for music education in activating multiple brain areas such as the prefrontal cortex (PFC), which is associated with EF (Särkämö et al., 2014). Schellenberg & Weiss (2013) explore several facets of musical proficiency such as aptitude, musical training, cognitive abilities after listening to music and while listening to music, highlighting strong associations between music aptitude and linguistic abilities as well as musical training and a wide variety of aspects such as general intelligence, school performance and cognitive tests of memory, language, and visuospatial abilities, also being asserted in seperate studies (Franklin et al., 2008; Carey et al., 2015). A systematic review conducted by Dumont et al., (2017) investigated the effects of musical training in children across five developmental domains through 46 separate studies, finding for positive effects on motor and academic domains but found studies reviewing cognitive domains to be insufficient, attributing this to the lack of qualitative research employed in previous studies and the lack of uniformity in musical interventions investigated across studies.

Existing research has been shown to strongly support the association of enhanced WM performance in musicians when compared to non-musicians, which has been found across age groups of children (Shen et al., 2019; Schellenberg, 2011), young adults (Franklin et al., 2008; Moreno et al., 2011; Hansen et al., 2013), and older adults (Amer et al., 2013). Recent studies have gone on to investigate aspects of musical learning such as enculturation, formal training and deliberate practice and their relation to cognitive mechanisms such as working memory capacity (WMC) and mental flexibility (Lee, Lu & Ko, 2007; Meinz & Hambrick, 2010), with findings suggesting the positive role of WMC in sight reading and instrument performance, also suggesting for the role of working memory (WM) in limiting the level of expert performance that can be attained by musicians. Studies have found evidence for this musician advantage across differing measures of WM, including more complex span tasks that would require additional executive control (Unsworth & Engle, 2006). Evidence for enhanced interference suppression has also been found in musicians when compared to non-musicians across age groups of children (Moreno et al., 2011; Chen et al., 2011; Shen et al., 2019), young adults (Bialystok & DePape, 2009), and older adults (Seinfeld et al., 2013). However, this speculated improvement in inhibitory control in musicians is not consistently replicated across studies (Carey et al., 2015; D'Souza et al., 2018). It must also be noted that few studies have investigated the effects of musical training on working memory, inhibitory control, and cognitive flexibility in the same study, where the effect of music training on each cognitive skill is compared (Sachs et al., 2017; Zuk et al., 2014).

Music and Language/Bilingualism

It is common view as of late in psychology that both the processes involved in music and language are viewed as overlapping mechanisms involving the coordination of multiple higher cognitive domains (Sternberg & Sternberg, 2011). Initially treated as separate psychological faculties, further evidence has been found challenging these previous conceptions, with findings supporting close relation between phonological awareness, which is necessary for reading and writing skills, musical expertise, and pitch awareness (Jäncke, 2012; Overy, 2003). Early evidence has been found supporting the relation between reading music and language abilities in children (Zinar, 1976), with subsequent research by Anvari et al., (2002) finding a significant correlation between music aptitude and reading ability in a study of 4–5-year-olds, while also finding phonological awareness to be associated with both variables. Much like the proposed CPH in L2 acquisition, Chen et al., (2021) also propose a existence of a period of superior neuroplasticity or 'sensitive period' at which the influence of musical training on EF's is most effective during development, finding that musical training before the age of 7 years led to superior performance in response inhibition, WM, and interference control when compared to musical training after the age of 7 years. Considering the basis for both the CPH and sensitive period are rooted by the assumption that EF's undergo rapid and significant development during childhood to adolescence and are thought to be extremely malleable during development (Carlson et al., 2013; Diamond, 2013), it could be inferred that these periods of development are one in the same or at least share a degree of overlap, although a lack of research surrounding a 'sensitive period' for musical training serves to impede this inference.

Bangert et al. (2006) conducted a study on musicians and non-musicians using neuroimaging procedures, with results showing that musicians exhibit stronger activation than non-musicians in Broca's and Wernicke's areas, both being regions of the brain associated with language processing. Tallal & Gaab (2006) also found through neuroimaging that several neural modules within the brain are similarly involved in speech and music. This culmination of evidence for the shared reliance on cognitive control and the speculation of shared cognitive mechanisms between music activity and language evidently lead researchers to apply these findings to L2 acquisition, with studies concerning the relationship between bilingualism and musical training finding garnering interest over the last two decades.

Milovanov & Tervaniemi (2011) found evidence for a significant relationship between higher musical aptitude and second language linguistic abilities, also citing regular music practice for a prolonged period as having a potential modulatory effect on linguistic organization and to alter hemispheric functioning within the brain. A recently conducted study by Liang & Taft (2020) investigated differences in phonological processing between bilinguals with English as their L2 who had both received and not received early musical training, finding that processing difficulties with English that were typical of this population were completely absent in those that had received formal music training when compared to those who had not. Schroeder at al., (2016) suggested that the cognitive enhancements of bilingualism and musical training on interference suppression could potentially be additive in nature, finding bilinguals, musicians, and bilingual musicians to significantly outperform control groups (monolinguals & non-musicians) in a visuo-spatial Simon task, with bilinguals, monolinguals, and bilingual monolinguals all exhibiting similar levels of superior performance. Similarly to studies examining these domains individually, some findings have failed to find evidence supporting the shared enhancement of certain cognitive domains between musicians and bilinguals (D'Souza et al., 2018; Bialystok & DePape, 2008), with the lack of research involving both bilinguals and musicians serving to impede the significance of current findings.

While this lack of research does need to be addressed, several other issues with previous empirical approaches when investigating the effects of musicianship and bilingualism on EF's have been identified by researchers. Valian (2016) outlines several underlying issues with previous approaches to investigating the relationship between bilingualism and EF's, suggesting that the over-reliance on simple measures of WM as opposed to high processing tasks, the degree of task impurity that exists within these frequently employed measures, is insufficient and cannot address the absence of theory surrounding the cognitive mechanisms involved in the deployment of more than one language. The implementation of more complex span tasks that assess WM in bilingual and musicians as well as controls could aid in rectifying this issue. In addition to this, measures of bilingualism and musicianship also vary greatly across studies depending on the proposed research questions (van den Noort, 2019; Jordan et al., 2022), with there being no concise or consensually agreed definition for either construct, making it difficult to determine the significance of findings in relation to one another due to the variations of definitions used across studies.

The Current Study

The substantial amount of research investigating both musical training and bilingualism has produced results both in support and opposition to the speculated learning induced cognitive enhancements in areas of executive functioning. Present contention over the inconsistency of findings reporting a BA in WM, the inconsistency of findings reporting a musician advantage in interference suppression, the limited number of studies investigating the effects of musical training on multiple EF measures within the same study, as well as the variation of measures and tasks employed between studies to measure the two domains individually, serves to suggest that additional research is required in this field. Furthermore, a lack of research exists investigating both bilingualism and musical training within the same study although there is evidence for shared cognitive mechanisms in music and language learning, as well as speculated overlap of cognitive mechanisms associated with bilingualism and musicianship, with it remaining unclear how the combination of musicianship and bilingualism effects higher cognitive processes.

Therefore, the present study aims to investigate the degree at which bilingualism and musical training are associated with enhancements in working memory and inhibitory control through the employment of the Stroop Task and the Digit Span forward and backward tasks in an Irish sample. The study also aims to examine the performance between bilinguals who have had formal music training and monolinguals who have had formal music training across these tasks. The study also aims to determine whether a relationship exists between age of L2 acquisition and enhanced inhibitory control in the bilingual sample, with these aims producing the following research questions and hypotheses:

Research Question 1: Does a significant relationship exist between age of L2 acquisition and performance in the Stroop task? Hypothesis for research question 1: In line with previous findings, there is expected to be a significant negative correlation between age of L2 acquisition and bilingual performance on the Stroop task.

Research Question 2: How will bilinguals/multilinguals perform in comparison to monolinguals in tasks of WM and Inhibitory control? Hypothesis for research question 2: As shown in previous studies, bilinguals/multilinguals are expected to outperform monolinguals on the Digit Span forwards and backwards tasks of inhibitory control. In line with previous research bilinguals/multilinguals are also expected to outperform monolinguals in the Stroop task, though Digit Span is expected to be the most significant.

Research Question 3: How will formally trained musicians perform in comparison to non-musicians in tasks of WM and Inhibitory control? Hypothesis for research question 3: As shown in previous studies, formally trained musicians are expected to outperform non-musicians on the Stroop Task for WM. In line with previous research formally trained musicians are also expected to outperform non-musicians in the Digit Span forwards and backwards tasks, though Stroop is expected to be the most significant.

Research Question 4: How will formally trained musicians who are also bilingual/multilingual perform in comparison to monolingual formally trained musicians in tasks of WM and Inhibitory control? Hypothesis for research question 4: As existing literature suggests, formally trained musicians that are also bilingual/multilingual expected to outperform monolingual formally trained musicians on both the Stroop Task and Digit Span tasks.

Methods

Participants

The research sample in the current study consisted of 44 participants. Participants were recruited by means of a non-probability convenience sampling via the researchers social media accounts (ie. Instagram & Whatsapp), as well as in person visits to other year group lectures within NCI. Participants were also recruited by means of snowball sampling as the study was shared through social media by mutual friends of the researcher. There was no incentive provided to participate, and participants were relied heavily upon in their willingness to participate. In line with ethical considerations, participants were required to give informed consent prior to participation and had confirm they were at least 18 years of age in order to participate.

Of the 44 participants included in the study 40.9% identified as male (n = 18) and 59.1% identified as female (n = 26). Participants ranged in age from 18 to 57 years (M = 25.41, SD = 8.92). Of these, 59.1% (n = 26) were categorized as monolinguals, and 40.9% (n = 18) were categorized as bilinguals/multilinguals. Sample sizes for musicians (n = 22) and non-musicians (n = 22) were equal, with 15.9% of the sample being categorized as bilingual/multilingual musicians (n = 7) and 34.1% monolingual musicians (n = 15). For additional descriptive statistics refer to Table 1. Participants were coded as bilingual if they rated their perceived proficiency in their L2 as a 4 or higher. Participants were coded as musicians if they answered yes to having experience with formal music training. Note that musicians in this sample refer participants who have experience with formal music training regardless of if they presently engage in sustained musical activity.

Measures

Access to a computer with internet connection was required in order for participants to partake in the study. It must be noted that all tasks involved in the present study were to be completed in an online setting. Access to Google Docs or another suitable cloud-based platform for creating and distributing web-based questionnaires was required in order to distribute all of the measures to participants. As both the Stroop Task and Digit span task were also completed in an online setting, access to Inquisit or another appropriate application for administering psychological tests was also required by the researcher.

Demographic, language & musical ability questionnaire

This was presented as a self-report questionnaire that was hosted through Google Forms and consisted of three sections that assessed basic demographic information, secondary language acquisition, and musical experience. This measure also hosted the information sheet that provided details pertaining to the participant's role in the study, a brief summary of what the study aims to investigate, details of participant data confidentiality and a participant's right to withdraw from the study at any point prior to submission of data (see Appendix I). Participants were required to confirm they read and understood all information presented, were willing to participate in the study and were at least 18 years before moving to the questionnaire section of the form. The first section of the questionnaire collected basic demographic data, with participants being asked to disclose their gender identity and their age (see Appendix II).

The second section of the questionnaire was concerned with collecting data for L2 acquisition with questions being loosely based off the LEAP-Q questionnaire which has been consistently used in research investigating bilingual advantage (Marian et al., 2007). Firstly participants were asked if they identified with a definition of bilingualism that emphasized the frequent use and high proficiency in an L2 (see Appendix II). If participant's answered 'no' they were directed to the music ability section of the form, and if they answered 'yes' they were redirected to subsequent questions concerning L2 acquisition. Redirected participants were asked to rate their perceived proficiency in their L2, to list all the languages they can speak in order of dominance, all the languages they speak in order of acquisition, and the age they began learning their L2 before moving to the last section of the questionnaire.

The third and final section of the questionnaire first asked participants about their experience with formal music training and their experience in playing a musical instrument (see Appendix II). If participants answered 'no' to experience with formal music training they were directed to the last page of the form and if they said 'yes' they were directed to subsequent questions pertaining to music ability. Redirected participants were asked how many years they undertook formal music training and how many instruments they had experience with. The last page of the form hosted the link for the inquisit tasks and details on how to calculate a participant ID, which participants were required to do before moving onto the next section of the study (see Appendix II).

Stroop Colour Word Task

As mentioned previously, the Stroop Task was programmed and run through Inquisit. It must be noted that the colour word Stroop with keyboard responding is the variant used in the present study. A single trial consists of a single colour name appearing on the screen in different "print" colours, for example the word green appearing on the screen with a red print colour. Participants are advised before the task to respond to the print colour with the corresponding key (ie. Red is the correct response from the above example). Four print colours; red, blue, green and black, are used in the study with the corresponding keys being "d", "f", "j" and "k" respectively. The task consisted of 84 trials that vary between congruent (both the word and print colour are the same), and incongruent trials (the word and print colour are different) which are randomly sampled throughout the task, as well as control trials. The task was estimated to take approximately 2 minutes to complete. The overall proportion of correct trials (propcorrect), as well as the proportion of correct congruent (propcorrect_congruent) and incongruent (propcorrect_incongruent) was recorded by the

Inquisit software. Total elapsed time and latency between trials was also recorded through Inquisit.

Digit Span Task

As with the Stroop task, the Digit span task was also programmed and run through Inquisit. It should be noted that the variant of the task includes both Digit span forward and Digit span backward trials (Woods et al., 2011). Before the task, participants were required to go through at least 2 practice trials until a correct response terminates the practice session and advances to the task. Participants were instructed to recall a series of digits ranging from 1-9 (that appear onscreen through method of input into a text box that is also onscreen. Digits are shown visually at a rate of 1 second and are randomly sampled without replacement in list lengths up to 9 digits and excluded successive sequences such as '123' or '654'. A warning cue following the final digit at an interval of 1 second is presented before participants were cued to repeat the digit string. If a response is correct in digit and presentation order, the participant was moved up to the next level with an incorrect response resulting in the same level being presented. Forward testing began at a sequence of 3 digits with list length increasing following a 1:2 staircase, which would increase the span by one digit following a correct response trial. Following forward testing, backwards testing began with digit sequences starting at 2 digits. In the event that a consecutive error was made the participant was moved down a level, with the list length reducing by one digit. A total of 14 forward trials and 14 backwards trials were presented in the task which was estimated to take approximately 10-15 minutes to complete. The traditional measure of two-error maximum length (TE-ML), the maximal list length successfully recalled by participants prior to missing two successive attempts of the same level was recorded for both forward and backward trials. Mean span (MS), the span that a participant is expected to get correct 50% of all times based on overall performance across 14 trials was also calculated for both forward and backward trials. Total elapsed time, the number of trials before TE_ML is reached (TE_TT), and the maximal digit span that a participant recalled correctly (ML) were also recorded for both forward and backward trials.

Design

The current study can be characterized as a cross sectional research design in which no variables were directly manipulated by the researcher. All data was collected was collected at a specific point in time with participants being asked to fill out a demographic, language and music questionnaire as well as two EF measures sequentially which were all quantitative in nature. A cross sectional design was seen as appropriate due to the concern for multiple variables, the inexpensive methodology employed and the ability to prompt future applications from the study findings. For the first hypothesis, a Pearson's correlation coefficient was conducted with two continuous variables; Age of Language acquisition (AoA) and propcorrect scores. To address research questions 2-4, three dependant variables (DV's) were identified: propcorrect scores, fTE_ML, & bTE_ML. Three independent variables (IV's) were identified for research question: 2) L2 Acquisition (bilingual/multilinguals & monolinguals), 3) Formal Music Training (musicians & non-musicians), and 4) Musician L2 Acquisition (bilingual/monolingual musicians & monolingual musicians).

Procedure

Information pertaining to the study and participation was administered by the researcher in both an online setting through the researchers social media accounts (ie. Instagram, WhatsApp, & Facebook), as well as shared through mutual friends of the researcher. The researcher also recruited students in other year psychology groups after lectures with the lecturers permission, informing them briefly of the nature of the study and participation, with the lecturer providing the link to the study to these groups of participants.

As mentioned previously, participants were required to complete the study online through a Google Forms link. Upon clicking the link, participants were directed to an information sheet, which detailed a brief summary of the study details, nature of participation and the estimated time taken to complete. Details pertaining to data confidentiality, the contact information of the researcher & their supervisor were also provided in the next page of the information sheet, with participants being asked to provide informed consent by ticking the box at the bottom of the page following the reading and comprehension of this information (see Appendix I).

Upon providing consent, participants were directed fill out the demographic, language and music questionnaire which was estimated to take 5-10 minutes to complete (see Appendix II). Following the completion of the questionnaire section, participants were prompted to provide a unique participant ID in order to correlate the questionnaire data with scores from both Inquisit tasks. Six digit participant ID's were created through combining their date and month of birth and the last two digits of their phone number (see Appendix II). Following the creation of an ID, participants were directed to follow the link to complete both the stroop and digit span tasks that were hosted through inquisit, and submit their google forms data before moving onto these tasks. It must be noted that participants were required to download the free Inquisit player app in order to complete this part of the study, which was automatically prompted after following the Inquisit link. Prior to the commencement of the two tasks, participants were required to provide their ID's in order to correlate their scores with their questionnaire data.

The Stroop task was estimated to take 2-3 minutes to complete. Lastly, after completing the Stroop task, participants are advised to follow the last Inquisit link and complete the Digit Span task, which is estimated to take 15 minutes. Following the completion of these measures, the participant will be directed to a debriefing form (see

Appendix III), in which a more detailed and concise description of the study and its aims provided as well as relevant contacts should participants have queries regarding the study or their data. A reminder to submit questionnaire data if participants had not already done so was also included in the debriefing sheet.

Results

Descriptive Statistics

The current data is taken from a sample of 44 participants (n = 44), with 40.9% of the sample identifying as male (n = 18) and 59.1% identifying as female (n = 26). Preliminary analyses were performed and indicated that all continuous variables measured followed the assumptions of normality with the exception of age, which was not normally distributed. Histograms were also obtained to show the normality of data distribution (see Appendix D). Means (M), Medians (MD), Standard Deviations (SD), and Range were calculated for total age and age within groups of monolinguals, bilingual/multilinguals, musicians, non-musicians, bilingual/multilingual musicians and monolingual musicians, as shown in Table 1. English was found to be the primary language (L1) for all participants, with frequencies and percentages of languages spoken also calculated and presented in Table 2. Means (*M*), Medians (*MD*), Standard Deviations (*SD*), Minimum & Maximum values, Skewness, and Kurtosis were calculated between the aforementioned groups for both the Stroop task scores shown in Table 3, as well as forward and backward digit span scores as presented in Table 4.

Table 1:

Descriptive statistics for age between monolinguals, bilinguals/multilinguals, musicians and non-musicians

Variable	Frequency	Mean	Median	*SD*	Range
Age					
Total	44	25.41	23	8.92	18 – 57
Monolingual	26	25.88	22.5	10.46	18 – 57
Bilingual/ Multilingual	18	24.72	23	6.29	19 – 45
Non-musician	22	24.64	22.5	8.00	19 – 57
Musician	22	26.18	23	9.88	18 - 57
Bilingual/Multilingual Musicians	7	26.43	24	8.32	21 – 45
Monolingual Musicians	15	26.07	23	10.80	18 - 57

Table 2:

Frequencies and percentages of languages spoken (n = 44)

Variable	Frequency	Valid %
Number of languages spoken		
Monolingual	26	59.1
Bilingual	5	11.4
Multilingual (speaks 3 languages)	9	20.5
Multilingual (speaks 4 languages)	3	6.8
Multilingual (speaks 5 languages)	1	2.3

Table 3:

Descriptive statistics for Stroop scores between monolinguals, bilinguals/multilinguals, musicians and non-musicians

Variable	Mean	Median	*SD*	Skewness	Kurtosis	Minimum	Maximum
Stroop Task (propcorrect)							
Total	.94	.94	.05	-1.404	4.319	.76	1
Monolingual	.94	.94	.04	.201	-1.535	.89	1
Bilingual/ Multilingual	.94	.96	.06	-2.160	6.216	.76	1
Non-musician	.95	.96	.04	-.220	-1.535	.89	1
Musician	.94	.94	.05	-1.83	5.679	.76	1
Bilingual/Multilingual Musicians	.92	.94	.08	-1.893	4.194	.76	.99
Monolingual Musicians	.94	.94	.04	.139	-1.459	.89	1

Table 4:

Descriptive statistics for Digit span forward and backward scores between monolinguals, bilinguals/multilinguals, musicians and non-musicians

Variable	Mean	Median	*SD*	Skewness	Kurtosis	Minimum	Maximum
Digit Span Forward (fTE_ML)							
Total	7.57	8	1.59	.178	.775	4	12
Monolingual	7.35	7.5	1.26	.441	1.831	5	11
Bilingual/ Multilingual	7.89	8	1.97	-.244	.288	4	12
Non-musician	7.82	8	1.76	.361	.591	5	12
Musician	7.32	8	1.39	-.516	.419	4	10
Bilingual/Multilingual Musicians	7.43	8	1.99	-.655	.348	4	10
Monolingual Musicians	7.27	8	1.10	-.609	-.375	5	9
Digit Span Backward (bTE_ML)							
Total	6.91	7	1.61	.084	.078	3	11
Monolingual	6.77	7	1.82	.328	.141	3	11
Bilingual/ Multilingual	7.11	7	1.28	-.421	-.729	5	9
Non-musician	7.00	7	1.41	.111	.343	5	10
Musician	6.82	7	1.82	.139	.200	3	11
Bilingual/Multilingual Musicians	6.86	7	1.22	-.414	-1.525	5	8
Monolingual Musicians	6.80	7	2.08	.196	-.135	3	11

Inferential Statistics

A Pearson's correlation coefficient was employed to assess the relationship between age of L2 acquisition and propcorrect scores. Preliminary analysis were conducted to ensure there were no violations of the assumptions of normality, linearity and homoscedasticity. There was a non-significant, small, negative correlation between age of L2 acquisition and propcorrect scores (r = -.05, n = 18, p > .005), indicating that the two variables share approximately .22% variance. Results could not indicate that earlier acquisition of L2 was associated with higher propcorrect scores.

A one-way between groups multivariate analysis of variance was performed to investigate the differences between bilingual/multilinguals and monolinguals in Executive Functioning measures. Three dependant variables were used: Stroop scores (propcorrect), fTE_ML, and bTE_ML. The independent variable was L2 Acquisition. Preliminary assumption testing was conducted to check for normality, linearity, univariate and multivariate outliers, with no serious violations noted. No statistically significant difference was found between the two groups on the combined dependant variables, F(3, 40) = .43, p = .73, Wilks' Lamboda = .97, partial eta squared = .03. No statistical significance was found when the dependant variables were considered separately. An inspection of the mean scores indicated that bilinguals scored higher than monolinguals on all measures, with the most significant difference being fTE_ML scores. An independent samples t-test also indicated there was no significant difference between fTE_ML scores between the groups, with bilingual/multilinguals (M = 7.89, SD = 1.97), scoring slightly higher than monolinguals (M = 7.35 , SD = 1.26), t (42) = 1.12, p = .27, two tailed. The magnitude of the differences in the means (mean difference = .543, 95% CI: - .44 to 1.52) was small (Cohen's d = .34).

A one-way between groups multivariate analysis of variance was performed to investigate the differences between musicians and non-musicians in Executive Functioning measures. Three dependant variables were used: Stroop scores (propcorrect), fTE_ML, and bTE_ML. The independent variable was Formal Music Training. Preliminary assumption testing was conducted to check for normality, linearity, univariate and multivariate outliers, with no serious violations noted. No statistically significant difference was found between the two groups on the combined dependant variables, $F(3, 40) = .57$, $p = .64$, Wilks' Lamboda = .96, partial eta squared = .04. No statistical significance was found when the dependant variables were considered separately. An inspection of the mean scores indicated that non-musicians scored higher than musicians on all measures, with the most significant difference being fTE_ML scores. A subsequent independent samples t-test also revealed there was no significant difference between group scores, with non-musicians ($M = 7.82$, $SD = 1.76$), scoring higher than musicians ($M = 7.32$, $SD = 1.39$), t (42) = - 1.04, $p = .30$, two tailed. The magnitude of the differences in the means (mean difference = - .50, 95% CI: - 1.47 to .47) was small (Cohen's d = -.32).

A one-way between groups multivariate analysis of variance was performed to investigate the differences between bilingual/multilingual musicians and monolingual musicians in Executive Functioning measures. Three dependant variables were used: Stroop scores (propcorrect), fTE_ML, and bTE_ML. The independent variable was Musician L2 acquisition. Preliminary assumption testing was conducted to check for normality, linearity, univariate and multivariate outliers, with no serious violations noted. No statistically significant difference was found between the two groups on the combined dependant variables, $F(3, 18) = .53$, $p = .67$, Wilks' Lamboda = .92, partial eta squared = .08. No statistical significance was found when the dependant variables were considered separately. An inspection of mean scores indicated that bilingual/multilingual musicians scored higher than monolingual musicians on both Digit Span (fTE_ML and bTE_ML) measures.

Monolingual musicians scored higher than bilingual/multilingual musicians in the Stroop task.

Discussion

The present study aimed to investigate the degree at which bilingualism and musical training are associated with enhancements in working memory and inhibitory control through the employment of the Stroop Task and the Digit Span forward and backward tasks within an Irish adult sample. The study also aimed to examine the performance between bilinguals who have had formal music training and monolinguals who have had formal music training across both the Stroop and Digit Span Tasks. The study also aimed to determine whether a relationship exists between age of L2 acquisition and Stroop (propcorrect) scores within the bilingual sample.

When addressing the first hypothesis, results showed that no significant correlation was found between age of L2 acquisition (AoA) and Stroop effect scores, resulting in a failure to reject the null hypothesis. In contrast to existing literature, statistical measures investigating the second hypothesis also yielded insignificant results, although a comparison of mean scores showed bilinguals/multilinguals outperformed monolinguals across all tasks. When addressing the third hypothesis, no significant difference was found between musicians and non-musicians across tasks, with an examination of mean scores showing non-musicians performed better than musicians across all tasks in stark opposition to existing literature. Lastly, statistical measures investigating the fourth hypothesis also yielded insignificant results, with bilingual/multilingual musicians scoring slightly higher than monolingual musicians on inhibitory control tasks, and lower on WM.

Contrary to previous research findings, the current study did not support evidence for a BA in Executive functions of inhibitory control and WM (Bialystock et al., 2004; Grundy & Timmer, 2016), and has been shown to support findings that suggest for the similar performance of bilinguals and monolinguals in inhibitory control (Duñabeitia et al., 2014) and working memory measures (Bonifacci et al., 2011). Additionally, current study findings could not find any evidence in support of the 'critical period hypothesis' (CPH) (Vanhove & White, 2013), with there being a number arguments asserting that a BA can only be generated under specific conditions, highlighting the flaws that exist within existing empirical research concerning a BA. Many researchers have asserted that variables other than bilingualism that exist within a sample can play a role in producing statistically significant results that are then identified by researchers as a BA when the result is potentially multivariate, with individual differences in factors such as motivation, learning strategies, and personality traits all being suggested to play roles in L2 learning (Bialystok et al., 2009). A lack of understanding and the lack of a clear theoretical basis for the cognitive mechanisms associated with bilingualism also serves to impede inferences being made from empirical findings, with Valian (2016) outlining how the degree at which other confounding positive characteristics such as SES that have been heavily associated with bilingualism (Schellenberg at al., 2011) influence results, with recent studies only beginning to control for this variable when investigating BA (D'Souza et al., 2018).

In contrast to previous research findings, the current study did not support evidence for the role of musical training in enhancing executive processes of inhibitory control and WM (Moreno et al., 2011; Hansen et al., 2013; Dumont et al., 2017), and has been shown to support findings that suggest for the similar performance of musicians and non-musicians in inhibitory control (Duñabeitia et al., 2014) and working memory (Bonifacci et al., 2011). While evidence for the relationship between early musical training and enhanced WM is strong (Lee, Lu & Ko, 2007; Meinz & Hambrick, 2010), the current study results being both non statistically significant as well as showing the non-musician sample to outperform formally trained musicians in the sample is surprising, calling into question the accuracy and validity of the employed measure used to determine formal music training. Current study results investigating WM and inhibitory control performance in bilinguals who have undergone formal music training also fails to support findings advocating their superior executive control at a similar degree to solely bilingual peers (Schroder et al., 2016), although the significantly limited research surrounding the combination of these two domains serves to limit what can be inferred from this result.

Strengths & Limitations

Several strengths were identified in the current study. Firstly, the addition of findings to a limited body of research investigating both bilingualism and musical training within the same study can be seen as a strength of the current study, regardless of significance of findings. This study also investigates the performance of bilinguals/multilinguals that have experience with formal music training on executive functioning, of which there are also very few studies of a similar nature (Schroeder et. Al., 2016; D'Souza et al., 2018). The current study also investigates the effects of musical training on working memory, and inhibitory control within the same study, with the effects of music training on each cognitive skill being compared separately, also adding to a limited body of research that exists investigating musical training and more than one executive domain within the same study (Sachs et al., 2017; Zuk et al., 2014).

The employment of a more complex span task of the Digit Span backwards could also be seen as a potential strength in the current study, as there is advocation for the use of more complex measures/ high processing tasks when investigating a BA, asserting that the over-reliance on simple span tasks could contribute to insufficient findings within preious studies (Valian, 2016). Lastly, the employment of a small battery of EF measures could be seen as a potential strength of the current study in comparison to the wide batteries of tasks that have employed across BA and musical training advantage that frequently asses only one cognitive domain of EF.

There were also a number of limitations identified in the current study following critical appraisal. Firstly, the sample size of 44 participants was small when considering the number of dependent and independent variables that were examined across each research question. This may have subdued potential findings, as Tabachnick & Fidell (2013) suggest a sample size of at least 20 in each cell is necessary to ensure robustness of data when conducting multivariate analyses, with the two levels of the IV and the 3 DV's measured making a total of six cells in the current study. Although studies investigating a BA have previously used samples that are similar in size to the current study (Linck & Weiss, 2015), the risk of undermining internal and external validity of a study due to a small sample is likely a significant reason why the majority of studies investigating both musical training and bilingualism on higher cognition use larger samples (Dumont et al., 2017; van den Noort et al., 2019).

Secondly, although self-report measures are commonly used in studies of BA (Bialystok et al., 2006; Blumenfeld & Marian, 2013), with researchers finding them to often be reliable in comparison to objective measures of language ability, it could be argued that the current study lacks reliability with its measures and operational definitions of bilingualism and musicianship, serving to be a limitation to the study findings. While there were concerns that the incorporation of additional measures of musical aptitude such as the Musical Aptitude profile, or form of auditory task to determine musicianship (Law & Zentner, 2012) and/or more reliable measures of L2 proficiency to complete prior to task engagement might have served as a deterrent to study participation, making the study overly long and potentially causing participants to withdraw mid-study, the lack of validity and reliability in the employed measures, specifically the self-reporting of music ability, likely produced samples of bilinguals and musicians that were uncharacteristic of typical populations that have been identified in previous studies, risking the generalizability of findings of the current study.

Third, there is evidence within existing literature to assume that the current study failed to control for significant confounding variables, with studies showing socioeconomic status (SES) and Intelligence to be the most significant confounding variables in bilingual literature and music literature respectively (Schellenberg, 2011; Corrigall, Schellenberg, & Misura, 2013). The current study did not account for either these variables in contrast to previous studies of a similar nature (D'Souza et al., 2018) which likely had an effect on the internal validity of population samples. Another interesting potential confounding variable that requires consideration in an Irish context is the exposure of Irish as L2 within both monolingual and bilingual samples and it's speculated influence on EF in both populations. While there is limited research examining EF's in relation to Irish L2 acquisition, (Stephens, 2013) found longitudinal evidence for the role of Irish L2 on enhanced inhibitory control in children over a 3-year period. The current studies failure to account for this variable may have also contributed to poor internal validity of sample populations. Lastly, the cross-sectional design employed in the current study meant that a cause-and-effect relationship could not be established.

Conclusion

Overall, findings can be said to contribute to existing literature and the direction of future research in several ways when considering both the strengths and weaknesses found in the current study design. Both areas of music and language are debatably the most complex instances of human behavior, with researchers still to fully understand underlying cognitive mechanisms associated with these domains and to further understand the link between the two domains as evidence suggests (Tallal & Gabb, 2006; Milovanov & Tervaniemi 2011). Future studies that include both L2 acquisition and music may be significant in investigating this association, with the present inconsistency of definitions for both domains and the variability in measures used to assess these domains separately across studies potentially impeding the ability to find further relation between the two domains. Furthermore, the present study highlights the lack of research surrounding the combined experience of L2 learning and musical training, future study in this area is also suggested considering the evidence for the shared cognitive mechanisms of music and language, and to expand upon an extremely limited body of research that presently exists investigating the relationship between L2 acquisition and musical training.

References

Adesope, 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. doi: 10.3102/0034654310368803

Amer, T., Kalender, B., Hasher, L., Trehub, S., & Wong, Y. (2013). Do Older Professional Musicians Have Cognitive Advantages?. Plos ONE, 8(8), e71630. doi: 10.1371/journal.pone.0071630

Baddeley, A. (2003). Working memory: looking back and looking forward. Nature Reviews Neuroscience, 4(10), 829-839. doi: 10.1038/nrn1201

Barac, R., Bialystok, E., Castro, D., & Sanchez, M. (2014). The cognitive development of young dual language learners: A critical review. Early Childhood Research Quarterly, 29(4), 699-714. doi: 10.1016/j.ecresq.2014.02.003

Bialystok, E., Craik, F., & Ryan, J. (2006). Executive control in a modified antisaccade task: Effects of aging and bilingualism. *Journal Of Experimental Psychology: Learning, Memory, And Cognition, 32*(6), 1341-1354. doi: 10.1037/0278-7393.32.6.1341

Bialystok, E., Craik, F., Klein, R., & Viswanathan, M. (2004). Bilingualism, Aging, and Cognitive Control: Evidence From the Simon Task.. *Psychology and Aging, 19*(2), 290–303. doi:10.1037/0882-7974.19.2.290

Bialystok, E., Hawrylewicz, K., Wiseheart, M., & Toplak, M. (2017). Interaction of bilingualism and Attention-Deficit/Hyperactivity Disorder in young adults. *Bilingualism: Language and Cognition, 20*(3), 588–601. doi:10.1017/s1366728915000887

Blumenfeld, H., & Marian, V. (2013). Cognitive control in bilinguals: Advantages in Stimulus–Stimulus inhibition. Bilingualism: Language And Cognition, 17(3), 610-629. doi: 10.1017/s1366728913000564

Duñabeitia, J., Hernández, J., Antón, E., Macizo, P., Estévez, A., Fuentes, L., & Carreiras, M. (2014). The Inhibitory Advantage in Bilingual Children Revisited. Experimental Psychology, 61(3), 234-251. doi: 10.1027/1618-3169/a000243

Carey, D., Rosen, S., Krishnan, S., Pearce, M., Shepherd, A., Aydelott, J., & Dick, F. (2015). Generality and specificity in the effects of musical expertise on perception and cognition. Cognition, 137, 81-105. doi: 10.1016/j.cognition.2014.12.005

Carlson, S. M., Zelazo, P. D., & Faja, S. (2013). Executive function. In P. D. Zelazo (Ed.), *The Oxford handbook of developmental psychology (Vol. 1): Body and mind* (pp. 706–743). Oxford University Press.

Chen, J., Scheller, M., Wu, C., Hu, B., Peng, R., & Liu, C. et al. (2021). The relationship between early musical training and executive functions: Validation of effects of the sensitive period. Psychology Of Music, 50(1), 86-99. doi: 10.1177/0305735620978690

Corrigall, K., Schellenberg, E., & Misura, N. (2013). Music Training, Cognition, and Personality. Frontiers In Psychology, 4. doi: 10.3389/fpsyg.2013.00222

D'Souza, A., Moradzadeh, L., & Wiseheart, M. (2018). Musical training, bilingualism, and executive function: working memory and inhibitory control. *Cognitive Research: Principles and Implications, 3*(1). doi:10.1186/s41235-018-0095-6

Desjardins, J., & Fernandez, F. (2018). Performance on Auditory and Visual Tasks of Inhibition in English Monolingual and Spanish–English Bilingual Adults: Do Bilinguals Have a Cognitive Advantage?. Journal Of Speech, Language, And Hearing Research, 61(2), 410-419. doi: 10.1044/2017_jslhr-h-17-0160

Diamond, A. (2013). Executive Functions. *Annual Review Of Psychology, 64*(1), 135-168. doi: 10.1146/annurev-psych-113011-143750

Duñabeitia, J., Hernández, J., Antón, E., Macizo, P., Estévez, A., Fuentes, L., & Carreiras, M. (2014). The Inhibitory Advantage in Bilingual Children Revisited. Experimental Psychology, 61(3), 234-251. doi: 10.1027/1618-3169/a000243

Faria, C., Alves, H., & Charchat-Fichman, H. (2015). The most frequently used tests for assessing executive functions in aging. Dementia & Neuropsychologia, 9(2), 149–155. doi:10.1590/1980-57642015dn92000009

Faul, F., Erdfelder, E., Buchner, A. et al. Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. Behavior Research Methods 41, 1149–1160 (2009). https://doi.org/10.3758/BRM.41.4.1149

Franklin, M., Sledge Moore, K., Yip, C., Jonides, J., Rattray, K., & Moher, J. (2008). The effects of musical training on verbal memory. Psychology Of Music, 36(3), 353-365. doi: 10.1177/0305735607086044

Friesen, D., Latman, V., Calvo, A., & Bialystok, E. (2014). Attention during visual search: The benefit of bilingualism. International Journal Of Bilingualism, 19(6), 693-702. doi: 10.1177/1367006914534331

Gigi Luk, E., & Bialystok, E. (2011). Is there a relation between onset age of bilingualism and enhancement of cognitive control?. Bilingualism: Language and Cognition, 14, pp 588-595 doi:10.1017/ S1366728911000010

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. doi:10.1523/jneurosci.3837-12.2013

Grundy, J., & Timmer, K. (2016). Bilingualism and working memory capacity: A comprehensive meta-analysis. Second Language Research, 33(3), 325-340. doi: 10.1177/0267658316678286

Hansen, M., Wallentin, M., & Vuust, P. (2012). Working memory and musical competence of musicians and non-musicians. Psychology Of Music, 41(6), 779-793. doi: 10.1177/0305735612452186

Hartshorne, J., Tenenbaum, J., & Pinker, S. (2018). A critical period for second language acquisition: Evidence from 2/3 million English speakers. Cognition, 177, 263-277. doi: 10.1016/j.cognition.2018.04.007

Ianco-Worrall, A. D. (1972). Bilingualism and Cognitive Development. Child Development, 43(4), 1390–1400. doi:10.2307/1127524

Jäncke, Lutz (2012). The Relationship between Music and Language. Frontiers in Psychology, 3, –. doi:10.3389/fpsyg.2012.00123

Johnson, J., & Newport, E. (1989). Critical period effects in second language learning: The influence of maturational state on the acquisition of English as a second language. Cognitive Psychology, 21(1), 60-99. doi: 10.1016/0010-0285(89)90003-0

Jordan, C., Lawlor, B., & Loughrey, D. (2022). A systematic review of music interventions for the cognitive and behavioural symptoms of mild cognitive impairment (non-dementia). Journal Of Psychiatric Research, 151, 382-390. doi: 10.1016/j.jpsychires.2022.04.028

Kirova, A. M., Bays, R. B., & Lagalwar, S. (2015). Working memory and executive function decline across normal aging, mild cognitive impairment, and Alzheimer's disease. BioMed Research International. doi: 10.1155/2015/748212

Kousaie, S., & Phillips, N. (2012). Ageing and bilingualism: Absence of a "bilingual advantage" in Stroop interference in a nonimmigrant sample. Quarterly Journal Of Experimental Psychology, 65(2), 356-369. doi: 10.1080/17470218.2011.604788

Lee, Y., Lu, M., & Ko, H. (2007). Effects of skill training on working memory capacity. Learning and Instruction, 17(3), 336-344. doi:10.1016/j.learninstruc.2007.02.010

Liang, A., & Taft, M. (2020). The Relationship Between L2 Phonological Processing and Early Musical Training in Adult Bilinguals. Music &Amp; Science, 3, 205920432091928. doi: 10.1177/2059204320919285

Linck, J., Hoshino, N., Kroll, J. (2008). Cross-language lexical processes and inhibitory control. The Mental Lexicon, 3(3), 349–374. doi:10.1075/ml.3.3.06lin

MacLeod, C. M. (1991). Half a century of research on the Stroop effect: An integrative review. *Psychological Bulletin, 109*(2), 163–203. https://doi.org/10.1037/0033-2909.109.2.163

Meinz, E. J., Hambrick, D. Z. (2010). Deliberate Practice Is Necessary but Not Sufficient to Explain Individual Differences in Piano Sight-Reading Skill: The Role of Working Memory Capacity. Psychological Science, 21(7), 914–919. doi:10.1177/0956797610373933

Mezzacappa, E. (2004). Alerting, Orienting, and Executive Attention: Developmental Properties and Sociodemographic Correlates in an Epidemiological Sample of Young, Urban Children. Child Development, 75(5), 1373-1386. doi: 10.1111/j.1467-8624.2004.00746.x

Milovanov, R., Tervaniemi, M. (2011). The Interplay between Musical and Linguistic Aptitudes: A Review. Frontiers in Psychology, (2). doi:10.3389/fpsyg.2011.00321

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. doi: 10.1111/cogs.12183

Moreno, S., Bialystok, E., Barac, R., Schellenberg, E., Cepeda, N., & Chau, T. (2011). Short-Term Music Training Enhances Verbal Intelligence and Executive Function. Psychological Science, 22(11), 1425-1433. doi: 10.1177/0956797611416999

Overy, K. (2003). Dyslexia and Music : From Timing Deficits to Musical Intervention., Annals New York Academy of Sciences, 497–505. doi:10.1196/annals.1284.060

Rahman, M., Pandian, A., Karim, A., & Shahed, F. (2017). Effect of Age in Second Language Acquisition: A Critical Review from the Perspective of Critical Period Hypothesis and Ultimate Attainment. International Journal Of English Linguistics, 7(5), 1. doi: 10.5539/ijel.v7n5p1

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), e0187254. doi: 10.1371/journal.pone.0187254

Sala, G., & Gobet, F. (2017). Does Far Transfer Exist? Negative Evidence From Chess, Music, and Working Memory Training. Current Directions in Psychological Science. doi:10.1177/0963721417712760

Särkämö, T., Ripollés, P., Vepsäläinen, H., Autti, T., Silvennoinen, H., & Salli, E. et al. (2014). Structural Changes Induced by Daily Music Listening in the Recovering Brain after Middle Cerebral Artery Stroke: A Voxel-Based Morphometry Study. *Frontiers In Human Neuroscience, 8*, 1-16. doi: 10.3389/fnhum.2014.00245

Schellenberg, E. G. (2013). The Psychology of Music. Music and Cognitive Abilities. 499–550. doi:10.1016/b978-0-12-381460-9.00012-2

Sebastián-Gallés, N., Echeverría, S., & Bosch, L. (2005). The influence of initial exposure on lexical representation: Comparing early and simultaneous bilinguals. Journal of Memory and Language, 52(2), 240–255. doi:10.1016/j.jml.2004.11.001

Seinfeld, S., Figueroa, H., Ortiz-Gil, J., & Sanchez-Vives, M. (2013). Effects of music learning and piano practice on cognitive function, mood and quality of life in older adults. Frontiers In Psychology, 4. doi: 10.3389/fpsyg.2013.00810

Shen, Y., Lin, Y., Liu, S., Fang, L., & Liu, G. (2019). Sustained Effect of Music Training on the Enhancement of Executive Function in Preschool Children. Frontiers in Psychology, 10(), 1910–. doi:10.3389/fpsyg.2019.01910

Bunge, S., Dudukovic, N., Thomason, M., Vaidya, C., & Gabrieli, J. (2002). Immature Frontal Lobe Contributions to Cognitive Control in Children: Evidence from fMRI. , 33(2), 0–311. doi:10.1016/s0896-6273(01)00583-9

Singleton, D., & Ryan, L. (2004). Language Acquisition. doi: 10.21832/9781853597596

Sternberg, R. and Sternberg, K., 2011. Cognitive psychology. 6th ed. Wadsworth Publishing, pp.161, 204, 205, 208, 412, 438.

Struys, E., Woumans, E., Nour, S., Kepinska, O., & Van Den Noort, M. (2019). A domain-general monitoring account of language switching in recognition tasks: Evidence for adaptive control. Bilingualism: Language and Cognition, 22(3), 606–623. https://doi.org/10.1017/S1366728918000342

Tallal, P., & Gaab, N. (2006). Dynamic auditory processing, musical experience and language development. Trends In Neurosciences, 29(7), 382-390. doi: 10.1016/j.tins.2006.06.003

Testa, R., Bennett, P., & Ponsford, J. (2012). Factor Analysis of Nineteen Executive Function Tests in a Healthy Adult Population. Archives of Clinical Neuropsychology, 27(2), 213–224. doi:10.1093/arclin/acr112

Trevisol, J., & Tomitch, L. (2017). The relationship between bilingualism and working memory: a review. *Revista Do GELNE, 19*(1), 39-51. doi: 10.21680/1517-7874.2017v19n1id11263

Valian, V. (2016). Putting together bilingualism and executive function. Linguistic Approaches to Bilingualism, 6(5), 565–574. doi:10.1075/lab.15044.val van den Noort, M., Struys, E., Bosch, P., Jaswetz, L., Perriard, B., & Yeo, S. et al. (2019). Does the Bilingual Advantage in Cognitive Control Exist and If So, What Are Its Modulating Factors? A Systematic Review. Behavioral Sciences, 9(3), 27. doi: 10.3390/bs9030027

van den Noort, Maurice; Struys, Esli; Bosch, Peggy; Jaswetz, Lars; Perriard, Benoit; Yeo, Sujung; Barisch, Pia; Vermeire, Kathryn; Lee, Sook-Hyun; Lim, Sabina (2019). Does the Bilingual Advantage in Cognitive Control Exist and If So, What Are Its Modulating Factors? A Systematic Review. Behavioral Sciences, 9(3), doi:10.3390/bs9030027

Woods, D., Kishiyama, M., Yund, E., Herron, T., Edwards, B., & Poliva, O. et al. (2010). Improving digit span assessment of short-term verbal memory. Journal Of Clinical And Experimental Neuropsychology, 33(1), 101-111. doi: 10.1080/13803395.2010.493149

Woumans, E., Surmont, J., Struys, E., & Duyck, W. (2016). The Longitudinal Effect of Bilingual Immersion Schooling on Cognitive Control and Intelligence*. Language Learning, 66(S2), 76-91. doi: 10.1111/lang.12171

Zinar, R. (1976). Reading Language and Reading Music: Is There a Connection?. Music Educators Journal, 62(7), 70. doi:10.2307/3395034

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), Article e99868. doi:10.1371/journal. pone.0099868

Appendices

Appendix I

Information Sheet

Welcome to this research study! My name is Keith Molloy and this study is part of my final year Psychology dissertation at the National College of Ireland. I would really appreciate it if you have the time to answer a few questions on this form and complete the following tasks through the other links provided as well. This study is concerned with examining your musical experience/training, bilingualism and executive function, and is estimated to take approximately 20 minutes to complete. Please read the following information thoroughly before agreeing to take part in the study.

What will the study involve?

The study will involve answering the following questionnaire and completing two computer tasks which will take approximately 10-15 minutes to complete.

The research will ask you for information about your musical education/ experience (if any) and the number of languages you speak. The aim of this research is to examine the differences between musician, bilingual, non-musician and monolingual groups through the Executive Function measures to be completed in the second part of this study.

After completion of this questionnaire you will be asked to carry out two computer tasks which must be completed on either a computer or laptop. You must not complete the study on a smartphone.

The first computer task will take approximately 3 minutes to complete and will ask you to respond to the text colour of a word when presented on screen.

The second task will take approximately 10-15 minutes to complete and will ask you to recall a sequence of digits after they are presented on screen.

Who has approved this study?

This study has been reviewed and received ethical approval from NCI Research Ethics committee. You may have a copy of this approval if you request it.

Why have you been asked to take part?

You have been asked because you are over the age of 18 and are currently residing in the island of Ireland

Do you have to take part?

No, you are under no obligation whatsoever to take part in this research. However, we hope that you will agree to take part and give us some of your time to complete this short questionnaire and complete the computer tasks. It is entirely up to you to decide whether or not you would like to take part. If you decide to do so, you will be asked to provide consent and read a copy and the information sheet. You may screenshot the information sheet and consent sheet for your own records. If you decide to take part, you are still free to withdraw at any time without giving a reason during the survey and computer tasks. However, should you submit your responses you will not be able to withdraw your information as they will be anonymised immediately upon submission. A decision to withdraw at any time during your participation, or a decision not to take part, will not affect your relationships with the researcher, the supervisor or the University.

Will your participation in the study be kept confidential?

Yes, all data that is collected from you during the course of the research will be kept confidential. You will not be providing any information that will make you personally identifiable and your data will be anonymous once you submit your responses of the survey. No names will be identified at any time. All information is collected electronically where the data will be encrypted and held securely on NCI PC or servers. Any information provided by you will not be distributed to any individual within or outside the University.

What will happen to the information which you give?

All the information you provide will be stored on an encrypted and password protected computer at NCI. Once you submit your responses no personal information about you will be identifiable. Upon completion of the research, the data will be retained on the NCI server. After ten years, all data will be destroyed. Electronic data will be reformatted or overwritten by the PI in NCI.

What will happen to the results?

The research will be written up and presented as a in a thesis for examination, presented at National and International conferences and may be published in scientific journals. A copy of the thesis will be stored in the NCI Norma Smurfit Library. A copy of the research findings can also be made available to you upon request.

What are the possible disadvantages of taking part?

It is not anticipated that there will be any negative consequences resulting from your taking part however, if these questions or tasks distress you or if you do become distressed during the study, you may terminate participation by clicking out of the study.

What if there is a problem?

Any further queries? If you need any further information pertaining to this study, you can contact me:

Name: Keith Molloy

Email: kmolloyinfo@gmail.com

Supervisor Name: Dr. Conor Nolan

If you agree to take part in the study, please tick the below box to

confirm consent to participation.

In clicking agree, you confirm that you have read and understand the information detailed above. You understand that you can withdraw from the study at any point up until the point that you click submit, and you consent to participate in the study voluntarily.

Agree ☐

Appendix II

Demographic Information

Below, please provide the accurate information about your age, gender and institute of education.

Gender Identity:

Male (including transgender male) ☐

Female (including transgender female) ☐

Other ☐

Prefer not to say ☐

Please indicate your age:

____

Language Ability

Please answer the following questions related to language ability below to the best of your knowledge.

Currently, bilingualism can be defined as the regular use of two or more languages by speakers who have a high level of proficiency in both languages. Please indicate whether you fall into this category:

Yes ☐

No ☐

**Additional questions if participant answers 'Yes' to identifying as bilingual:*

Please rate your perceived proficiency in speaking your secondary language acquired. (You should choose to rate the language you have the highest competency in excluding your primary language regardless of order of language acquisition).

1	2	3	4	5
O	O	O	O	O

Please list all the languages you know in order of dominance (from the language you speak the most of to the language you speak the least)

____

Please list all of the languages you know in order of acquisition (put your native language first)

____

Please indicate at what age you began learning your secondary language (You should choose to rate the language you have the highest competency in excluding your primary language regardless of order of language acquisition).

____

Musical Ability

Please answer the following questions related to musical ability below to the best of your knowledge.

Do you or have you ever received any form of formal musical training?

Yes ☐

No ☐

Have you or do you currently have any experience in playing a musical instrument?

Yes ☐

No ☐

**Additional questions if participant answers 'Yes' to experience with formal music training:*

At what age did you begin sustained musical activity? "Sustained musical activity" might include regular music lessons or daily musical practice that lasted for at least three consecutive years.

____

If yes, please indicate how many instruments you have experience with:

N/A ☐

1 ☐

2 ☐

3 or more ☐

Part 2 of your participation

Please enter your participant ID follow the link below to continue with your participation in this experiment. Thank you again for your participation!

In order to correlate your questionnaire responses to your scores please enter a participant ID in the box below. To create your unique participant ID, please use the date and month of your birth and the last two digits of your phone number. For example, if your birthday is the 1st Feb, and your phone number is 0851234567, your unique ID would be 010267. If your birthday is the 19th June and your phone number is 0869876543, your unique ID would be 190643. Your participant ID should be formatted as a 6 digit string of numeric characters.

IDs are only used to match your responses to this questionnaire and your scores on the computer task. No identifying information or data will be used or analysed from the unique ID.

____

Please follow the link below to continue with your participation in this experiment. Thank you again for your participation! https://mili2nd.eu/su5b

REMINDER: Please make sure you hit the submit button on this form either before or after continuing on to the next section of this research! It is advisable that you open the link above and then return to this page to submit this section of data before completing the Inquisit tasks.

Appendix III

Thank you for your participation in this study!

REMINDER:

Please ensure you have clicked submit on the questionnaire section of this study before closing these windows and completing the study!

The present study aims to investigate the differences in executive functioning tasks between musicians, bilinguals, non-musicians and monolinguals in a student population. An examination of previous literature has highlighted the present contention regarding the relationship between higher cognitive functions such as working memory, mental flexibility, inhibitory control and verbal fluency and the domains of music and bilingualism (Bialystok, Hawrylewicz, Wiseheart & Toplak, 2017; Linck, Hoshino & Kroll, 2008), with the proposed study aiming to contribute to existing research as many maintain the belief that further study in this area is required. The employed Executive Function measures of the Stroop Task and Digit Span Task are primarily employed in older populations in identifying cognitive deficits (Testa, Bennett & Ponsford, 2012), emphasizing the lack of research in which these measures are employed on young adult populations.

Will your participation in the study be kept confidential?

Yes, all data that is collected from you during the course of the research will be kept confidential. You will not be providing any information that will make you personally identifiable and your data will be anonymous once you submit your responses of the survey. No names will be identified at any time. All information is collected electronically where the data will be encrypted and held securely on NCI PC or servers. Any information provided by you will not be distributed to any individual within or outside the University.

It must be recognised that, in some circumstances, confidentiality of research data and records may be overridden by courts in the event of litigation or in the course of investigation by lawful authority. In such circumstances the college will take all reasonable steps within law to ensure that confidentiality is maintained to the greatest possible extent.

What will happen to the information which you give?

All the information you provide will be stored on an encrypted and password protected computer at NCI. Once you submit your responses no personal identifying information about you will be. On completion of the research, the data will be retained on the NCI server. After ten years, all data will be destroyed. Electronic data will be reformatted or overwritten by the PI in NCI.

What will happen to the results?

The research will be written up and presented as a in a thesis for examination, presented at National and International conferences and may be published in scientific journals. A copy of the research findings will be made available to you upon request.

What if there is a problem?

Any further queries? If you need any further information pertaining to this study, you can contact me:

Name: Keith Molloy

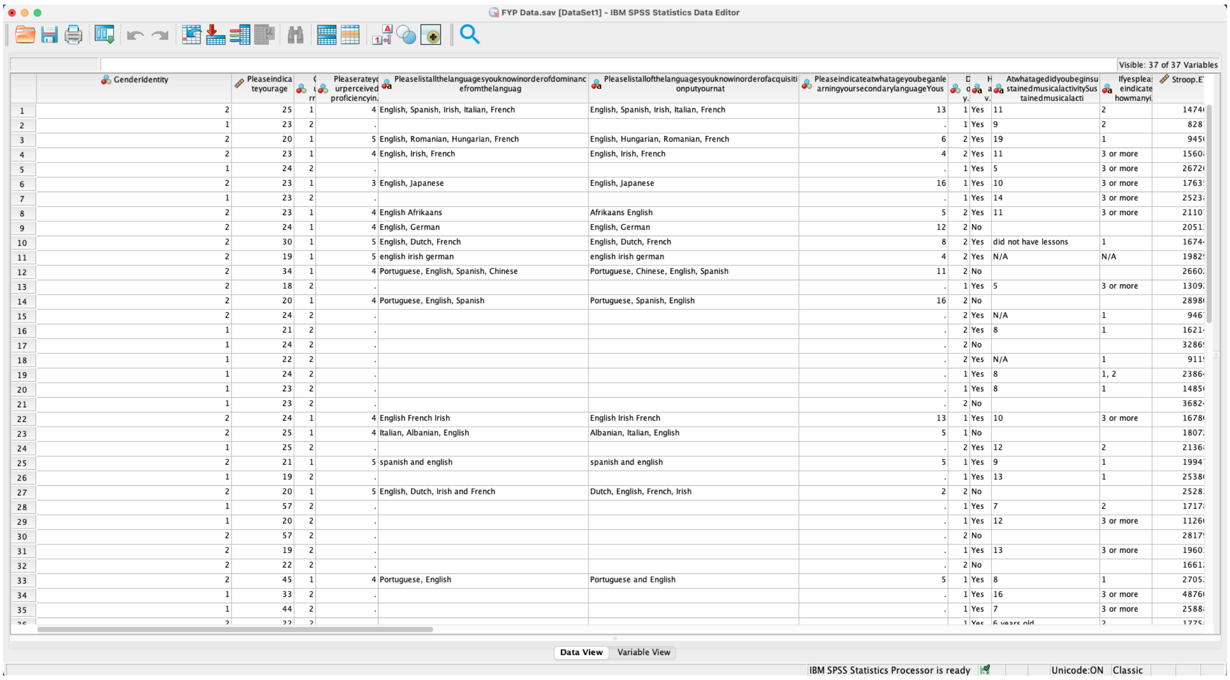
Email: kmolloyinfo@gmail.com

Supervisor Name: Dr. Conor Nolan

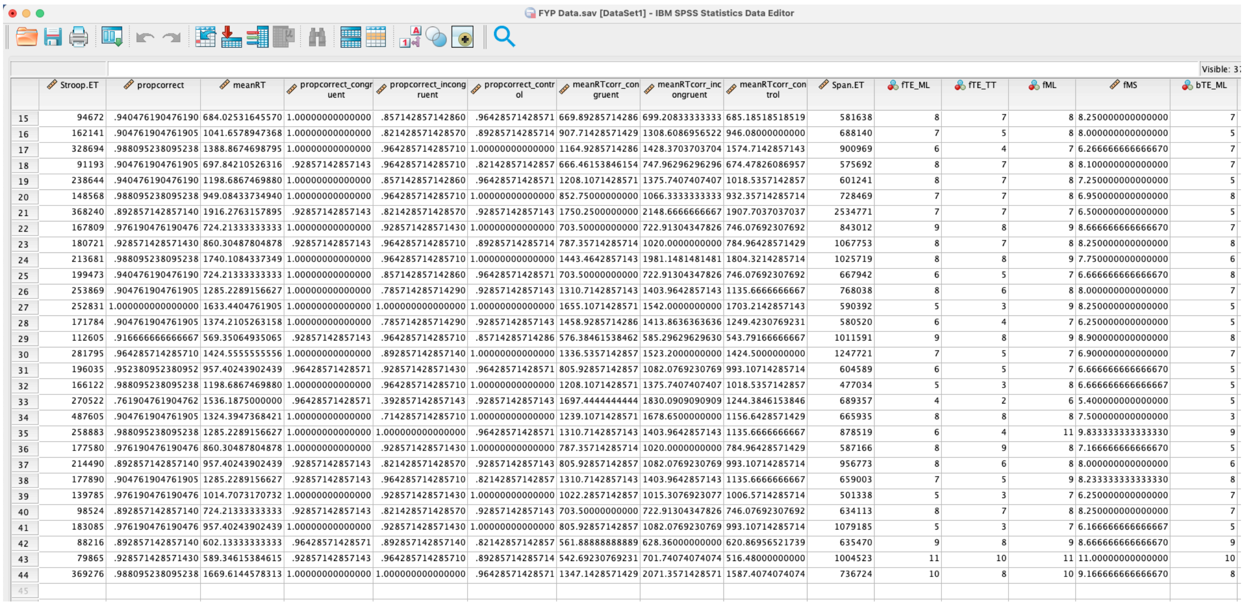
Supervisor's Email: conor.nolan@ncirl.ie

Appendix IV

Evidence of Data:



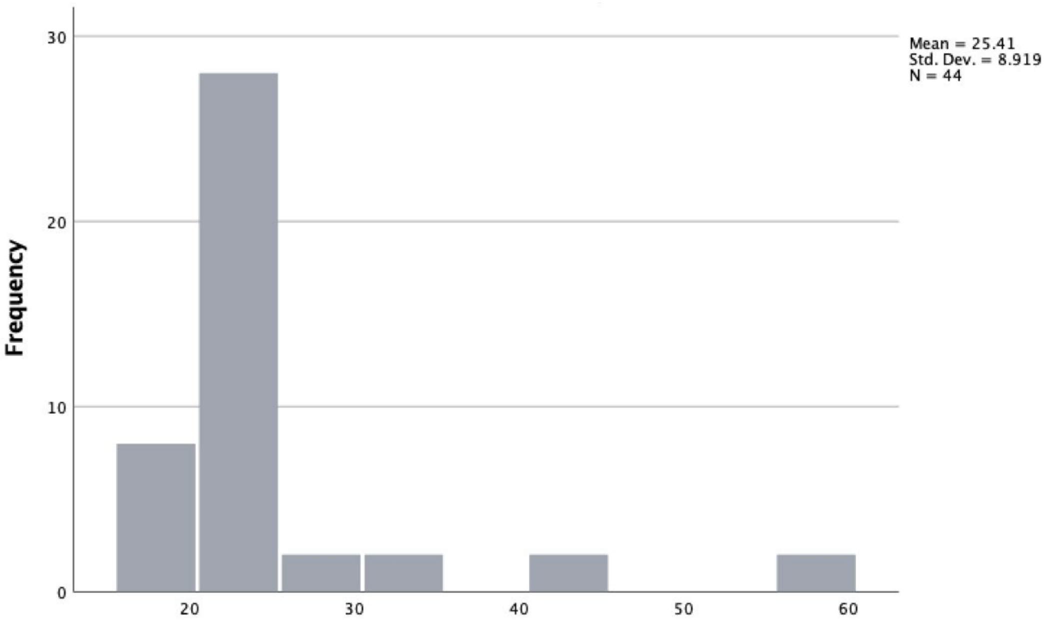
	GenderIdentity	Pleaseindicateyourage	C rr	Pleaserateyourperceivedproficiencyin.	Pleaselistallthelanguagesyouknowinorderofdominancefromthelanguag	Pleaselistallofthelanguagesyouknowinorderofacquisitiononputyournat	PleaseindicateatwhatageyoubeganlearningyoursecondarylanguageYous	D y.	H v.	Atwhatagedidyoubeginsustainedmusicalactivity Sustainedmusicalacti	Ifyespleaseindicatehowmanyi	Stroop.ET
1	2	25	1	4	English, Spanish, Irish, Italian, French	English, Spanish, Irish, Italian, French	13	1	Yes	11	2	1474
2	1	23	2	.			.	1	Yes	9	2	828
3	2	20	1	5	English, Romanian, Hungarian, French	English, Hungarian, Romanian, French	6	2	Yes	19	1	945
4	2	23	1	4	English, Irish, French	English, Irish, French	4	2	Yes	11	3 or more	1560
5	1	24	2	.			.	1	Yes	5	3 or more	2672
6	2	23	1	3	English, Japanese	English, Japanese	16	1	Yes	10	3 or more	1763
7	1	23	2	.			.	1	Yes	14	3 or more	2523
8	2	23	1	4	English Afrikaans	Afrikaans English	5	2	Yes	11	3 or more	2110
9	2	24	1	4	English, German	English, German	12	2	No			2051
10	2	30	1	5	English, Dutch, French	English, Dutch, French	8	2	Yes	did not have lessons	1	1674
11	2	19	1	5	english irish german	english irish german	4	2	Yes	N/A	N/A	1982
12	2	34	1	4	Portuguese, English, Spanish, Chinese	Portuguese, Chinese, English, Spanish	11	2	No			2660
13	2	18	2	.			.	1	Yes	5	3 or more	1309
14	2	20	1	4	Portuguese, English, Spanish	Portuguese, Spanish, English	16	2	No			2898
15	2	24	2	.			.	2	Yes	N/A	1	946
16	1	21	2	.			.	2	Yes	8	1	1621
17	1	24	2	.			.	2	No			3286
18	1	22	2	.			.	2	Yes	N/A	1	911
19	1	24	2	.			.	1	Yes	8	1, 2	2386
20	1	23	2	.			.	1	Yes	8	1	1485
21	1	23	2	.			.	2	No			3682
22	2	24	1	4	English French Irish	English Irish French	13	1	Yes	10	3 or more	1678
23	2	25	1	4	Italian, Albanian, English	Albanian, Italian, English	5	1	No			1807
24	1	25	2	.			.	2	Yes	12	2	2136
25	2	21	1	5	spanish and english	spanish and english	5	1	Yes	9	1	1994
26	1	19	2	.			.	1	Yes	13	1	2538
27	2	20	1	5	English, Dutch, Irish and French	Dutch, English, French, Irish	2	2	No			2528
28	1	57	2	.			.	1	Yes	7	2	1717
29	1	20	2	.			.	1	Yes	12	3 or more	1126
30	2	57	2	.			.	2	No			2817
31	2	19	2	.			.	1	Yes	13	3 or more	1960
32	2	22	2	.			.	2	No			1661
33	2	45	1	4	Portuguese, English	Portuguese and English	5	1	Yes	8	1	2705
34	1	33	2	.			.	1	Yes	16	3 or more	4876
35	1	44	2	.			.	1	Yes	7	3 or more	2588
36	2	22	2					1	Yes	6 years old	2	1775



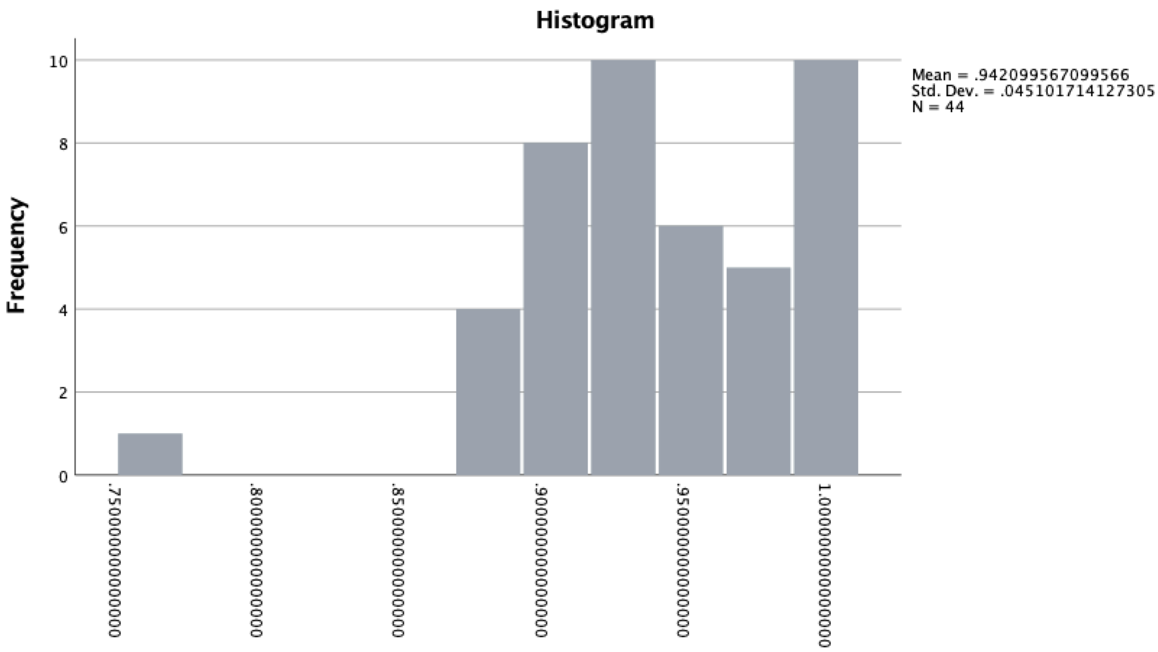
	Stroop.ET	propcorrect	meanRT	propcorrect_congruent	propcorrect_incongruent	propcorrect_control	meanRTcorr_congruent	meanRTcorr_incongruent	meanRTcorr_control	Span.ET	fTE_ML	fTE_TT	fML	fMS	bTE_ML
15	94672	.940476190476190	684.02531645570	1.00000000000000	.857142857142860	.96428571428571	669.89285714286	699.20833333333	685.18518518519	581638	8	7	8	8.250000000000000	7
16	162141	.904761904761905	1041.6578947368	1.00000000000000	.821428571428570	.89285714285714	907.71428571429	1308.6086956522	946.08000000000	688140	7	5	8	8.000000000000000	5
17	328694	.988095238095238	1388.8674698795	1.00000000000000	.964285714285710	1.00000000000000	1164.9285714286	1428.3703703704	1574.7142857143	900969	6	4	7	6.266666666666670	7
18	91193	.904761904761905	697.84210526316	.92857142857143	.964285714285710	.82142857142857	666.46153846154	747.96296296296	674.47826086957	575692	8	7	8	8.100000000000000	7
19	238644	.940476190476190	1198.6867469880	1.00000000000000	.857142857142860	.96428571428571	1208.1071428571	1375.7407407407	1018.5357142857	601241	8	7	8	7.250000000000000	5
20	148568	.988095238095238	949.08433734940	1.00000000000000	.964285714285710	1.00000000000000	852.75000000000	1066.3333333333	932.35714285714	728469	7	7	8	6.950000000000000	8
21	368240	.892857142857140	1916.2763157895	.92857142857143	.821428571428570	.92857142857143	1750.2500000000	2148.6666666667	1907.7037037037	2534771	7	7	7	6.500000000000000	5
22	167809	.976190476190476	724.21333333333	1.00000000000000	.928571428571430	1.00000000000000	703.50000000000	722.91304347826	746.07692307692	843012	9	8	9	8.666666666666670	7
23	180721	.928571428571430	860.30487804878	.92857142857143	.964285714285710	.89285714285714	787.35714285714	1020.0000000000	784.96428571429	1067753	8	7	8	8.250000000000000	8
24	213681	.988095238095238	1740.1084337349	1.00000000000000	.964285714285710	1.00000000000000	1443.4642857143	1981.1481481481	1804.3214285714	1025719	8	8	9	7.750000000000000	6
25	199473	.940476190476190	724.21333333333	1.00000000000000	.857142857142860	.96428571428571	703.50000000000	722.91304347826	746.07692307692	667942	6	5	7	6.666666666666670	8
26	253869	.904761904761905	1285.2289156627	1.00000000000000	.785714285714290	.92857142857143	1310.7142857143	1403.9642857143	1135.6666666667	768038	8	6	8	8.000000000000000	7
27	252831	1.000000000000000	1633.4404761905	1.00000000000000	1.000000000000000	1.00000000000000	1655.1071428571	1542.0000000000	1703.2142857143	590392	5	3	9	8.250000000000000	5
28	171784	.904761904761905	1374.2105263158	1.00000000000000	.785714285714290	.92857142857143	1458.9285714286	1413.8636363636	1249.4230769231	580520	6	4	7	6.250000000000000	5
29	112605	.916666666666667	569.35064935065	.92857142857143	.964285714285710	.85714285714286	576.38461538462	585.29629629630	543.79166666667	1011591	9	8	9	8.900000000000000	8
30	281795	.964285714285710	1424.5555555556	1.00000000000000	.892857142857140	1.00000000000000	1336.5357142857	1523.2000000000	1424.5000000000	1247721	7	5	7	6.900000000000000	7
31	196035	.952380952380952	957.40243902439	.96428571428571	.928571428571430	.96428571428571	805.92857142857	1082.0769230769	993.10714285714	604589	6	5	7	6.666666666666670	5
32	166122	.988095238095238	1198.6867469880	1.00000000000000	.964285714285710	1.00000000000000	1208.1071428571	1375.7407407407	1018.5357142857	477034	5	3	8	6.666666666666667	5
33	270522	.761904761904762	1536.1875000000	.96428571428571	.392857142857143	.92857142857143	1697.4444444444	1830.0909090909	1244.3846153846	689357	4	2	6	5.400000000000000	5
34	487605	.904761904761905	1324.3947368421	1.00000000000000	.714285714285710	1.00000000000000	1239.1071428571	1678.6500000000	1156.6428571429	665935	8	8	8	7.500000000000000	3
35	258883	.988095238095238	1285.2289156627	1.00000000000000	1.000000000000000	.96428571428571	1310.7142857143	1403.9642857143	1135.6666666667	878519	6	4	11	9.833333333333330	9
36	177580	.976190476190476	860.30487804878	1.00000000000000	.928571428571430	1.00000000000000	787.35714285714	1020.0000000000	784.96428571429	587166	8	9	8	7.166666666666670	5
37	214490	.892857142857140	957.40243902439	.92857142857143	.821428571428570	.92857142857143	805.92857142857	1082.0769230769	993.10714285714	956773	8	6	8	8.000000000000000	6
38	177890	.904761904761905	1285.2289156627	.92857142857143	.964285714285710	.82142857142857	1310.7142857143	1403.9642857143	1135.6666666667	659003	7	5	9	8.233333333333330	8
39	139785	.976190476190476	1014.7073170732	1.00000000000000	.928571428571430	1.00000000000000	1022.2857142857	1015.3076923077	1006.5714285714	501338	5	3	7	6.250000000000000	7
40	98524	.892857142857140	724.21333333333	.92857142857143	.821428571428570	.92857142857143	703.50000000000	722.91304347826	746.07692307692	634113	8	7	8	8.250000000000000	7
41	183085	.976190476190476	957.40243902439	1.00000000000000	.928571428571430	1.00000000000000	805.92857142857	1082.0769230769	993.10714285714	1079185	5	3	7	6.166666666666667	5
42	88216	.892857142857140	602.13333333333	.96428571428571	.892857142857140	.82142857142857	561.88888888889	628.36000000000	620.86956521739	635470	9	8	9	8.666666666666670	9
43	79865	.928571428571430	589.34615384615	.92857142857143	.964285714285710	.89285714285714	542.69230769231	701.74074074074	516.48000000000	1004523	11	10	11	11.0000000000000	10
44	369276	.988095238095238	1669.6144578313	1.00000000000000	1.000000000000000	.96428571428571	1347.1428571429	2071.3571428571	1587.4074074074	736724	10	8	10	9.166666666666670	8
45															

Appendix V

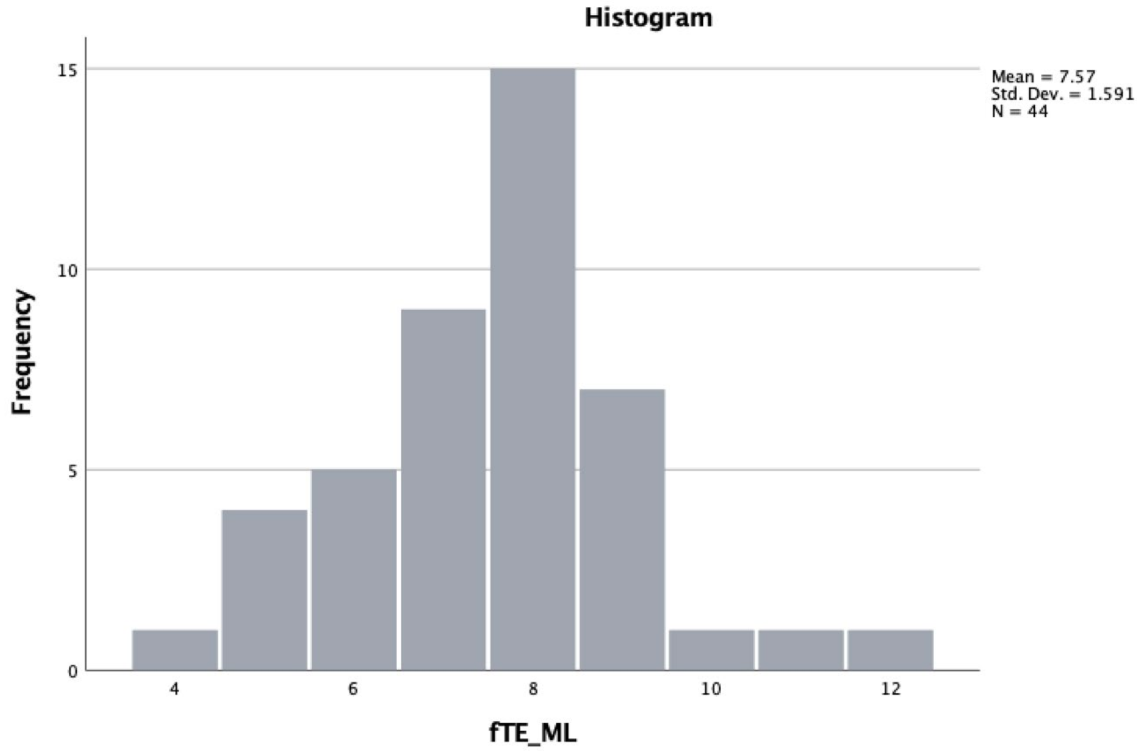
Histogram for Age



Histogram for propcorrect scores



Histogram for fTE_ML scores



Histogram for bTE_ML scores