A COMMUNITY-BASED, COMPARATIVE STUDY OF EXECUTIVE FUNCTIONING OF MUSICIANS AND NON-MUSICIANS

Zenaida C. Gomez, M.D.
D Darwin A. Dasig, M.D.
Perry N. Noble, M.D.
Lourdes K. Ledesma, M.D.

Section of Neurology
Makati Medical Center

INTRODUCTION

It is estimated that the proportion of people over 60 years old will increase from 10% in 2000 to 21.8% in 2050 in all regions.[1] A critical consequence of this rise will be the exponential increase in the prevalence of neurodegenerative diseases and other pathologies common in latter stages of life.[2] With this in mind, strategies to prevent cognitive decline and promote a healthy physical and psychological lifestyle are keystones for the future.

Reports of non-pharmaceutical interventions for the prevention of cognitive decline in dementia patients were use of music therapy. By listening to music, patients with Alzheimer's disease (AD) showed improvement in categorical word fluency[5], autobiographical memory[6], and the memory of lyrics[7].

Executive functions (EF) encompass a number of cognitive processes that allow for independent and self-regulated behavior.[25] These cognitive constructs include inhibition, problem solving, goal-directed behavior, and maintenance of information in working memory. Another component of EF is cognitive flexibility, the ability to adjust to novel or changing task demands which is often captured through a task-switch design.[26]

This study aims to evaluate how musical participation throughout the life span may influence cognitive functioning, specifically executive functioning.

RELATED LITERATURE

Musical participation is easily quantified in terms of number of years of training or participation, and there is data supporting differential brain organization for amateur musicians.[9,10,11] Therefore, investigation of amateur musicians and non-musicians offers an excellent model for how deliberate long-term practice and engagement in cognitively stimulating activities may alter brain development and influence cognition.[12] Parbery-Clark[8], reported that older musicians showed greater auditory working memory relative to non- musicians, and suggested that musical training might reduce the impact of age-related decline. Results from these studies suggest that music therapy might be useful for maintaining cognitive function in normal elderly adults and dementia patients.

Musical leisure activities, including playing an instrument, listening to music, and creating music, stimulate a variety of cognitive functions and may be informative regarding training induced brain plasticity that may be recruited in advanced age to compensate for age-related cognitive decline.[13-14] Successfully acquiring musical expertise requires at least a decade of training, which typically begins at an early age and includes intensive repetitive practice that may result in plastic brain reorganization. Evidence suggests that musical activity may be associated with cortical reorganization including enhanced sensorimotor functions in young instrumental musicians.[15-21] However, there are there are limited studies examining how the extent of musical experience throughout the life span may influence maintenance of cognitive functioning in advanced age.

Various extra and intra-curricular activities have been shown to improve EF skills in children. Extracurricular activities shown to enhance EF development in school-age children include martial arts, mindfulness training, and physical exercise. [27] While these findings support the potential for extracurricular activities to boost EF skills, interpretations are limited due to methodological weaknesses in these studies. Limitations include, for instance, a lack of control groups and/or the potential influence of other factors leading to improved performance, such as motivation or social engagement.

One extracurricular activity of recent interest to researchers is music, and its link to EF skills has been debated. Playing a musical instrument (especially within an ensemble setting) requires many sub-skills associated with EF such as sustained attention, goal-directed behavior and in particular the task -switching demands of cognitive flexibility. Individuals with musical training have demonstrated enhanced general cognitive, academic and language abilities when compared to those without musical training, and this connection may be mediated by EF. [28, 29] For example, higher intellectual functioning has been reported in children and adults with as compared to those without musical training through both cross-sectional and longitudinal study designs, though this connection remains debated.[30] Musicians have shown enhanced language skills compared to non-musicians across several domains, namely vocabulary knowledge, pitch processing in speech, selective attention for speech in noise, and prosody perception. [31]

Enhanced processing in adult musicians has been reported for components of EF, demonstrated through a nonverbal spatial task and both auditory and visual Stroop tasks.[32, 33] One study reported significant associations between musical training and numerous EF constructs in children [34], whereas in another study no superior performance was found on any measures of EF in musically trained children compared to those without training.[35] The discrepant findings may be due to no comparisons to a control group that was not carefully screened to have no musical experience; unknown variation in the intensity and longevity of training of the musicians; or the inconsistent implementation of standardized EF measures. Differences in socioeconomic status between musicians and non-musicians may also be the source of inconsistent findings.

It is evident that musical training relates to cognitive abilities, but it remains somewhat unclear which constructs of EF, if any, may mediate this connection.

GENERAL OBJECTIVE

- To compare the executive functioning (EF) skills between musicians and non-musicians

SPECIFIC OBJECTIVES

- To correlate the relationship of executive functioning (EF) skills of musicians and the number of musical activities participated in
- To correlate the relationship of executive functioning (EF) skills of musicians and the number of years of formal musical training

METHODOLOGY

Study Design

This is a prospective cross-sectional descriptive clinical study that was conducted in different organizations (convents, church organizations, church choirs) in at least 60 musically inclined subjects. All participants are required to sign an informed consent. This study was done in accordance to the ethical principles of the Declaration of Helsinki and the National Ethics Guidelines for Health Research.

Inclusion Criteria

Included in the study are healthy, independent, musicians, 40 years old and above. High activity musicians were defined as performing artists, singers, full-time music teachers, vocal coaches, choirmaster, choir members with an average daily practice time of singing or playing musical instruments, or listens to music at least 1 hour or more each day, with or without formal musical training. Low activity musicians were defined as that who plays a musical instrument regularly, sings regularly or listens to music with no regular daily practice for less than hour each day. They were recruited from church choir members, seminaries or convents. Non-musicians are defined as that who had never played a musical instrument, not a member of any choir or who does not listen to music. Participants included in this study have a Mini-Mental State Exam (MMSE) score of more than 26, Hamilton-Depression Scale (HAM-D) score of less than 7 and with controlled existing medical conditions.

Exclusion Criteria

Participants with history of neurological diseases (like cerebrovascular accidents, epilepsy, parkinsonism etc.), uncontrolled diabetes, uncontrolled hypertension, alcohol and other drug abuses like narcotics, sedatives and hypnotics were excluded from the study.

Outcome Variables

Demographic information were collected for all patients (age, gender, educational status, socio-economic status, occupation, handedness; and for the professional musicians, the number of years of formal training, age of acquisition of musical expertise, years of actively playing the instrument/s and number of instruments played. Results of cognitive tests measuring executive function skills were performed.

Data Collection

1. Clinical Characteristics

Demographic information was collected for all patients as stated above.

2. Cognitive assessment test

The examiner administered these tests:

a. Montreal Cognitive Assessment Test (MoCA)

The Montreal Cognitive Assessment (MoCA) was designed as a rapid screening instrument for mild cognitive dysfunction. It assesses different cognitive domains: attention and concentration, executive functions, memory, language, visuo-constructional skills, conceptual thinking, calculations, and orientation. Time to administer the MoCA is approximately 10 minutes. The total possible score is 30 points; a score of 26 or above is considered normal.

b. Verbal Fluency (Phonemic and Semantic)

Verbal Fluency subtest contains three conditions that measure phonemic fluency, semantic fluency, and category switching fluency. Our output of interest compared achievement on phonemic fluency with semantic fluency. In phonemic fluency, participants were prompted with a single letter and asked to state as many words as possible, starting with that letter within 60 seconds; excluding names of people, places, or numbers. In semantic fluency, participants will be prompted with a category (e.g. animals) and were asked to name as many objects as possible, within the category of interest within 60 seconds. Normal Score is 11 words and above, less than 11 is considered abnormal.

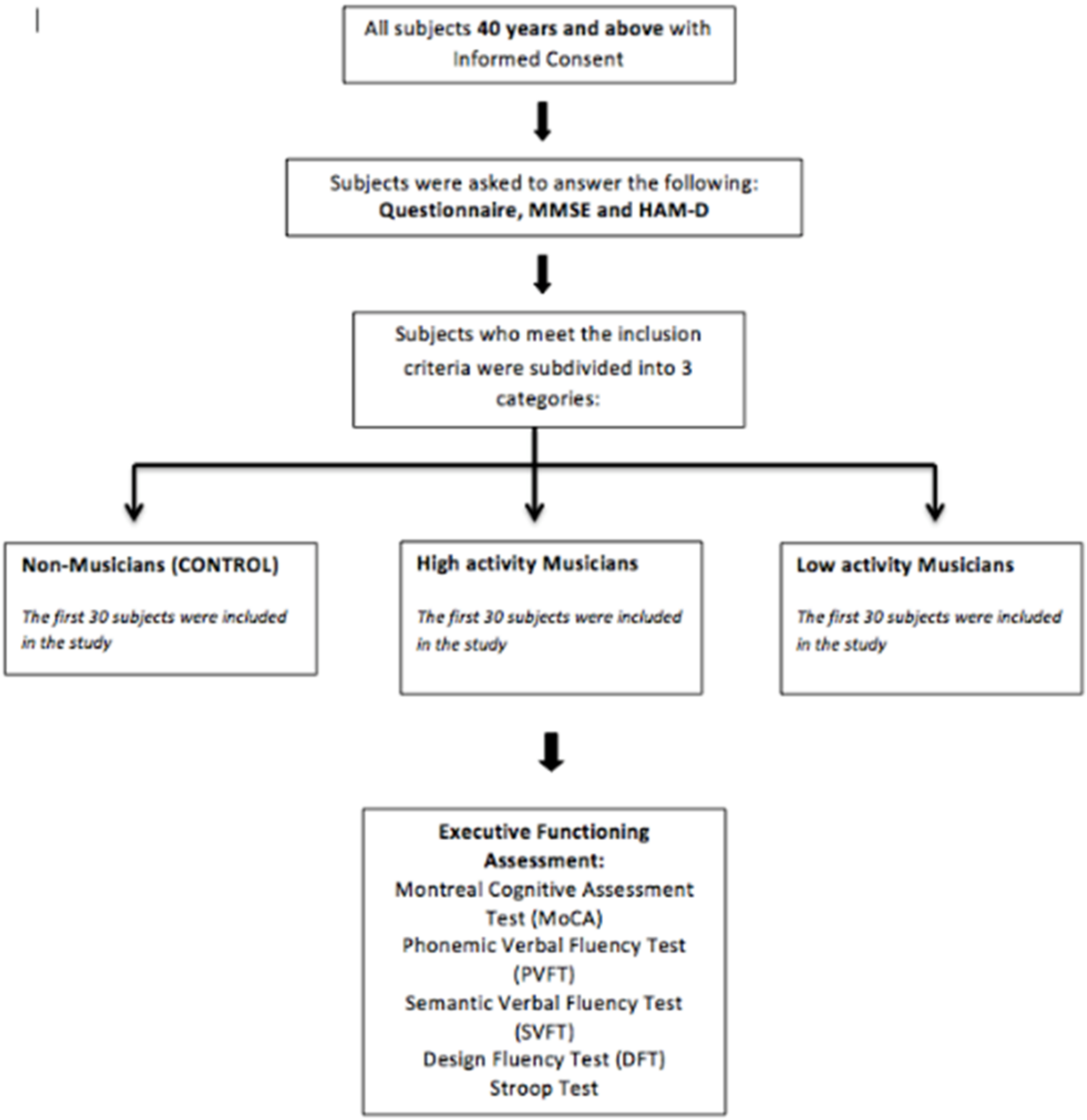
c. Design Fluency Test (DFT)

For the design fluency task, participants will be instructed to make a different design using only four straight lines such that, each line had to touch at least one other line. The task was limited to 60 seconds to draw as many different designs as they could. Normal score is 10 figures in one minute, and figures less than 8 were considered abnormal.

d. Stroop Test

The Stroop test used in this study has three conditions: one requires reading black colored names of colors (Stoop Word; SW); the second condition implies naming of the colors in which four consecutive colors are printed (Stroop Color; SC); and in the latter condition, the subject must name in each item, the color of ink used for printing a color name, which has been printed in a color different to the one written (Stroop Color-Word; SCW). This test is based on the finding that it takes longer to name colored symbols than to name words that refer to colors, and even longer to name the color of ink in which incongruent color names are written[22]. The final score for each condition is obtained by counting the number of colors correctly named or read (depending on condition) in a 45 second time interval, with higher scores indicating better performance.

Figure 1. Research Process



ANALYSIS OF DATA

Data were encoded and tallied in SPSS version 10 for windows. Descriptive statistics were generated for all variables. For nominal data frequencies and percentages were computed. For numerical data, mean ± SD were generated. Analysis of the different variables was done using the following test statistics: Chi-square test was used to compare/associate nominal (categorical) data.

RESULTS

A total of 90 subjects were included in the study equally divided into three groups. Table 1 shows the comparison of the demographic characteristics between the three groups. The results showed that there was no significant difference noted as proven by all p values >0.05. This shows that both the control group and the study group are homogenous.

Table 1. ***Comparison of the Demographic Characteristics Between the Three Groups***

	Groups			p-value*
	Control (n=30)	**High Activity** (n=30)	**Low Activity** (n=30)	
Age (year)				
Mean ± SD	53.33 ± 7.54	53.53 ± 7.71	53.50 ± 9.55	0.99 (NS)
Sex				
Female	20 (66.7%)	15 (50.0%)	18 (60.0%)	0.42 (NS)
Male	10 (33.3%)	15 (50.0%)	12 (40.0%)	
Educational Attainment				
Tertiary	27 (90.0%)	20 (66.7%)	24 (80.0%)	0.08 (NS)
Post-graduate	3 (10.0%)	10 (33.3%)	6 (20.0%)	
Handedness				
Both	0	1 (3.3%)	0	
Left	0	3 (10.0%)	0	0.07 (NS)
Right	30 (100%)	26 (86.7%)	30 (100%)	

** p-values >0.05- Not significant; p-values ≤0.05-Significant*

Table 2 shows the comparison of the executive functioning subtest and total MOCA scores between the three groups. The results showed that there was no significant difference as proven by all p values >0.05. On the other hand, there was a significant difference noted in the total MoCA scores between the three groups as proven by the p values 0.04.

Table 2. ***Comparison of the Executive Functioning Subtest and Total MoCA Scores Between the Three Groups***

	Groups			p-value*
	Control (n=30)	**High Activity** (n=30)	**Low Activity** (n=30)	
Executive Functioning Subtest				
Mean ± SD	4.63 ± 0.56	4.83 ± 0.38	4.83 ± 0.38	0.14 (NS)
Total MOCA Score				
Mean ± SD	27.60 ± 1.45	28.43 ± 2.04	28.63 ± 1.38	*0.04 (S)*

** p-values >0.05- Not significant; p-values ≤0.05-Significant*

Table 3 shows the comparison of phonemic verbal fluency test (PVFT) for letter F, A and S, semantic verbal fluency test (SVFT) for the category animal and design fluency test (DFT) scores between the three groups. The results showed that there was a significant difference noted in the PVFT, SVFT and DFT scores between the three groups as proven by all p values <0.05.

Table 3. ***Comparison of the Phonemic, Semantic and Design Verbal Fluency Test scores Between the Three Groups***

	Groups			p-value*
	Control (n=30)	**High Activity** (n=30)	**Low Activity** (n=30)	
PVFT (F) Mean ± SD	13.06 ± 3.57	15.03 ± 4.26	12.00 ± 3.18	*0.007 (S)*
PVFT (A) Mean ± SD	11.40 ± 2.88	14.53 ± 3.95	11.67 ± 3.70	*<0.001 (S)*
PVFT (S) Mean ± SD	13.43 ± 4.74	14.67 ± 4.70	10.97 ± 3.75	*0.006 (S)*
SVFT Mean ± SD	13.97 ± 2.74	18.57 ± 5.32	13.27 ± 3.06	*<0.001 (S)*
DFT Mean ± SD	5.73 ± 2.42	7.63 ± 2.46	5.23 ± 2.47	*<0.001 (S)*

** p-values >0.05- Not significant; p-values ≤0.05-Significant*

Since there was a significant difference noted in the PVFT, SVFT and DFT scores between the three groups, a pairwise comparison was done between two groups as shown in Table 4. For F and S, there was no significant difference between the control and the high activity group (p>0.05) and between control and the low activity group (p>0.05) but a significant difference was noted between the high and the low activity group (p<0.05). For A, semantic and design fluency, a significant difference was noted when the high activity group was compared with either the control or the low activity group as shown by all p values <0.05 but no significant difference between the

Table 4. ***P Values for the Pairwise Comparison of PVFT, SVFT and DFT Between the Three Groups***

	Control vs High Activity	**Control vs Low Activity**	**High Activity vs Low Activity**
PVFT (F)	0.12 (NS)	0.80 (NS)	0.006 (S)
PVFT (A)	0.001 (S)	1.00 (NS)	0.004 (S)
PVFT (S)	0.84 (NS)	0.10 (NS)	0.005 (S)
SVFT	<0.0001 (S)	1.00 (NS)	<0.0001 (S)
DFT	0.01 (S)	1.00 (NS)	0.001 (S)

** p-values >0.05- Not significant; p-values ≤0.05-Significant*

Table 5 shows the comparison of Stroop word (SW), Stroop color (SC) and Stoop color-word (SCW) scores between the three groups. The results showed that there was a significant difference noted in the SW and SCW scores between the three groups as proven by all p values <0.05. On the other hand, there was no significant difference noted in the SC between the three groups as proven by the p values >0.05.

Table 5. ***Comparison of the Stroop Word (SW), Stroop Color (SC) and Stroop Color-Word (SCW) Scores Between the Three Groups***

	Groups			p-value*
	Control (n=30)	High Activity (n=30)	Low Activity (n=30)	
SW				
Mean ± SD	53.26 ± 4.86	61.80 ± 8.52	56.33 ± 6.10	<0.0001 (S)
SC				
Mean ± SD	41.86 ± 6.80	39.40 ± 8.99	41.16 ± 9.45	0.51 (NS)
SCW				
Mean ± SD	41.40 ± 11.12	52.60 ± 8.84	51.93 ± 13.68	<0.001 (S)

** p-values >0.05- Not significant; p-values ≤0.05-Significant*

Since there was a significant difference noted in SW and SCW score between the three groups, a pairwise comparison was done between two groups as shown in Table 6. For SW, there was no significant difference between the control and the low activity group as shown by the p values 0.24. For SCW score, there is a significant difference noted when the control group was compared with either the high or the low activity group as shown by all p values <0.05 but no significant difference between the high and the low activity group (p>0.05).

Table 6. ***P Values for the Pairwise Comparison of SW and SCW Between the Three Groups***

	Control vs High Activity	Control vs Low Activity	High Activity vs Low Activity
SW	<0.0001 (S)	0.24 (NS)	0.006 (S)
SCW	0.001 (S)	0.002 (S)	1.00 (NS)

** p-values >0.05- Not significant; p-values ≤0.05-Significant*

Table 7 shows the comparison of the musical participation between the high and the low activity groups. The results showed that there was a significant difference between the two groups with their musical participation specifically with the low activity group participating on vocals or singing and listening to music (p 0.02) and the high activity group participating with vocals, listening and playing musical instruments (p 0.01) and this is proven by p values <0.05. This table also shows the number of formal music training between high and low activity groups. The results showed that there was a significant difference between the two groups as proven by p value of 0.04 (<p 0.05) with the high activity group, having more participants with more than 5 years of formal musical training (36.7%).

Table 7. ***Musical Activity Participated In and Number of years of Formal Musical Training Between the High and the Low Activity Groups***

Musical Activity Participated In	Groups		p-value*
	High Activity (n=30)	**Low Activity** (n=30)	
Listen (L)	1 (3.3%)	0	1.00 (NS)
Vocals (V)	1 (3.3%)	0	1.00 (NS)
Vocals, Listen (V, L)	11 (36.7%)	20 (66.7%)	*0.02 (S)*
Vocals, Plays Instrument (V, P)	3 (10.0%)	5 (16.7%)	0.70 (NS)
Vocals, Plays Instrument, Listen (V, P, L)	14 (46.7%)	5 (16.7%)	*0.01 (S)*
Number of years of Formal Musical Training			
<5 years	9 (30.0%)	3 (10.0%)	
>5 years	11 (36.7%)	8 (26.7%)	0.04 (S)
None	10 (33.3%)	19 (63.3%)	

** p-values >0.05- Not significant; p-values ≤0.05-Significant*

Table 8 shows the correlation of musical activity participated in with executive functioning subtest, total MoCA, PVFT, SVFT, DFT, SW, SC, and SCW scores. The results showed that there was no significant associations noted as proven by all p values >0.05 except for SCW (p=0.05).

Table 8. ***Correlation of Musical Activity Participated In and the Test Scores of Executive Functioning subtest (EF), MoCA, Phonemic Verbal Fluency Test (PVFT), Semantic Verbal Fluency Test (SVFT), Design Fluency Test (DFT), Stroop Word Test (SW), Stroop Color Test (SC) and Stroop Color-Word Test (SCW)***

	Musical Activity Participated In					*p value
	Listen (L) (n=1)	**Vocals (V)** (n=1)	**Vocals, Listen (VL)** (n=31)	**Vocals, Plays Music (VP)** (n=8)	**VPL** (n=19)	
EF						
4/5	0	0	3 (9.7%)	1 (12.5%)	6 (31.6%)	0.33 (NS)
5/5	1 (100%)	1 (100%)	28 (90.3%)	7 (87.5%)	13 (68.4%)	
MOCA						
Mean ± SD	30 ± 0	30 ± 0	28.77 ± 1.28	28.38 ± 1.50	27.90 ± 2.33	0.34 (NS)
Median	30	30	29	28	28	
PVFT						
0	0	0	8 (25.8%)	0	3 (15.8%)	0.48 (NS)
1	1 (100%)	1 (100%)	23 (74.2%)	8 (100%)	16 (84.2%)	
SVFT						
0	0	0	0	2 (25%)	1 (5.3%)	0.08 (NS)
1	1 (100%)	1 (100%)	31 (100%)	6 (75%)	18 (94.7%)	
DFT						
0	1 (100%)	0	28 (90.3%)	7 (87.5%)	14 (73.7%)	0.10 (NS)
1	0	1 (100%)	3 (9.7%)	1 (12.5%)	5 (26.3%)	
SCW						
Mean ± SD	**80 ± 0**	**72 ± 0**	**57.42 ± 7.38**	**56.75 ± 5.01**	**60.95 ± 7.55**	**0.05 (S)**
Median	**80**	**72**	**54**	**55**	**58**	
SC						
Mean ± SD	34 ± 0	40 ± 0	39.71 ± 8.91	37.25 ± 11.71	42.84 ± 8.80	0.56 (NS)
Median	34	40	40	35	46	
SW						
Mean ± SD	40 ± 0	44 ± 0	52.52 ± 11.88	53.50 ± 9.06	52.42 ± 12.12	0.68 (NS)
Median	40	44	50	58	56	

** p-values >0.05- Not significant; p-values ≤0.05-Significant*

Table 9 shows the correlation of formal musical training with executive functioning subtest, MoCA, PVFT, SVFT, DFT, SW, SC, and SCW scores. The results showed that there was no significant associations noted as proven by all p values >0.05 except for SCW (p=0.05).

Table 9. ***Correlation of Formal Musical Training and the Test Scores of Executive Functioning subtest (EF), MoCA, Phonemic Verbal Fluency Test (PVFT), Semantic Verbal Fluency Test (SVFT), Design Fluency Test (DFT), Stroop Word Test (SW), Stroop Color Test (SC) and Stroop Color-Word Test (SCW)***

	Formal Musical Training			***p value**
	<5 (n=12)	**>5** (n=19)	**None** (n=29)	
EF				
4/5	1 (8.3%)	5 (26.3%)	4 (13.8%)	0.36 (NS)
5/5	11 (91.7%)	14 (73.7%)	25 (86.2%)	
MOCA				
Mean ± SD	27.83 ± 2.79	28.78 ± 1.27	28.55 ± 1.40	0.67 (NS)
Median	28	28	28	
PVFT				
0	2 (16.7%)	3 (15.8%)	6 (20.7%)	0.90 (NS)
1	10 (83.3%)	16 (84.2%)	23 (79.3%)	
SVFT				
0	1 (8.3%)	2 (10.5%)	0	0.22 (NS)
1	11 (91.7%)	17 (89.5%)	29 (100%)	
DFT				
0	9 (75.0%)	16 (84.2%)	25 (86.2%)	0.68 (NS)
1	3 (25.0%)	3 (15.8%)	4 (13.8%)	
SCW				
Mean ± SD	**62.50 ± 10.20**	**60.63 ± 7.72**	**56.62 ± 6.14**	**0.05 (S)**
SC				
Mean ± SD	42.50 ± 9.84	39.78 ± 9.70	39.69 ± 8.76	0.65 (NS)
SW				
Mean ± SD	53.16 ± 9.70	50.21 ± 11.98	53.24 ± 11.88	0.64 (NS)

** p-values >0.05- Not significant; p-values ≤0.05-Significant*

DISCUSSION

This study examined the executive functioning skills of healthy, musically inclined subjects and correlate them with the number of activities of musical participation and the number of years of formal musical training. The results of the study revealed significant differences between musicians and non-musicians on measures of verbal and design fluency tests and color-word interference test.

Tests of verbal fluency assess cognitive functioning and involve associative exploration and retrieval of words based on phonemic or semantic criteria (phonemic and semantic fluency, respectively), usually conducted in the setting of a time constraint (60 seconds). These measures are considered to impose comparable demands upon executive or supervisory processes because both require efficient organization of verbal retrieval and recall, as well as self-monitoring aspects of cognition (the participant must keep track of responses already given), effortful self-initiation, and inhibition of responses when appropriate. In this study, there was a noted significant difference in the performance in the verbal fluency tests among the three groups however, the results were not significant when correlated with musical participation and years of formal training.

Another type of fluency that has been studied is design fluency, which is measured by a patient's ability to generate a series of novel (i.e., nonrepeating), abstract designs. Impairment on the design fluency test or DFT was specific to patients with excisions involving the right frontal lobes, and further suggested that the right central region was particularly important in design fluency. The unstructured nature of the DFT, while complicating scoring, may increase sensitivity to frontal lobe mediated executive functions by increasing the initiation and organization required of the patient. In this study, there was a noted significant difference in the performance in the design fluency tests among the three groups however, when correlated with musical participation and years of formal training, the result was not significant. It is important to note though that in pairwise comparison, there was a significant difference between the DFT scores of the control and high activity group. The right brain, often considered the more subjective and creative hemisphere, focuses on the melody in music. The left hemisphere, considered the analytical part of the brain, is responsible for the understanding of musical structure and motor skills, such as playing the violin [37]. Since the DFT tests the right frontal lobe specifically, high activity participants were able to perform better.

Stroop test is a reliable measure of executive function that requires cognitive flexibility, selective attention, cognitive inhibition, and information processing speed. There was a noted significant difference between the scores of the three groups that was also evident when pairwise comparison was done. It was significant specifically when measuring color word interference or stroop color-word (SCW). This difference was also evident when correlated with years of formal musical training and musical participation. Interestingly, a previous study showed that professional musicians had significantly smaller color-word interference effects in the Stroop task [33]. This reflects an enhanced selective processing, automaticity, and inhibitory control of the study group.

The results of this study reveal that the years of engagement in musical activities is associated with better performance on tests of executive functioning, specifically cognitive flexibility. Furthermore, it is also conceivable that sustained musical activity in advanced age may maintain cognitive flexibility. Also, this study may suggest that musicians have cognitive advantages that may potentially provide cognitive reserve in advanced age. However, future investigations are needed to explore the mediating factors and neural mechanisms. There is growing evidence that lifestyle factors, including stimulating cognitive and leisure activities, may impact "cognitive reserve" and postpone the onset of Alzheimer's disease and other dementias. The reasons why musicians outperform non-musicians are unclear from our findings, although it may be considered that musical training serves as additional education. Educational attainment has been reported to retard cognitive decline in advanced age and has demonstrated differences in recruitment of networks during memory tasks providing greater compensation [37].

CONCLUSION

Executive function skills of musicians, specifically cognitive flexibility, cognitive inhibition, selective attention and information processing speed are enhanced when compared with non-musicians and this is influenced by the number of years of formal musical training and the number of musical activities participated in.

REFERENCES

1. Lutz, W., Sanderson, W., and Scherbov, S. (2008). The coming acceleration of global population ageing. *Nature* 451, 716–719. doi: 10.1038/nature06516

2. Norton, S., Matthews, F. E., and Brayne, C. (2013). A commentary on studies presenting projections of the future prevalence of dementia. *BMC Public Health* 13:1. doi: 10.1186/1471-2458-13-1

3. Societas Neurologica Japonica (2010). Guideline for dementing disorder. IgakuShoin Ltd. Tokyo.

4. Abbott RD, White LR, Ross GW, Masaki KH, Curb JD, et al. (2004) Walking and dementia in physically capable elderly men. JAMA 292: 1447–1453.

5. Thompson RG, Moulin CJA, Hayre S, Jones RW. (2005) Music enhances category fluency in healthy older adults and Alzheimer's disease patients. Exp Aging Res 31: 91–99.

6. Irish M, Cunningham CJ, Walsh JB, Coakley D, Lawlor BA, et al. (2006) Investigating the enhancing effect of music on auatobiographical memory in mild Alzheimer's disease. Dement Geriatr Cogn Disord 22: 108–120.

7. Simmons-Stern NR, Budsopn AE, Ally BA. (2010) Music as a memory enhancer in patients with Alzheimer's disease. Neuropsychologia 48: 3164–3167.

8. Parbery-Clark A, Strait DL, Anderson S, Hittner E, Kraus N. (2011) Musical experience and the aging auditory system: implications for cognitive abilities and hearing speech in noise. PLoS One, May 11 2011, volume 6, issue 5, DOI: 10.1371/journal.pone.0018082.

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

10. Koelsch, S., Fritz, T., Schulze, K., Alsop, D., & Schlaug, G. (2005). Adults and children processing music: An fMRI study. *Neuroimage, 25*(4), 1068 – 1076.

11. Tervaniemi, M., Castaneda, A., Knoll, M., & Uther, M. (2006). Sound processing in amateur musicians and nonmusicians: Event-related potential and behavioral indices. *Neuroreport, 17*(11), 1225–1228.

12. Bangert, M., Peschel, T., Schlaug, G., Rotte, M., Drescher, D., Hinrichs, H., Altenmuller, E. (2006). Shared networks for auditory and motor processing in professional pianists: Evidence from fMRI conjunction. *Neuroimage, 30*(3), 917–926.

13. Monaghan, P., Metcalfe, N. B., & Ruxton, G. D. (1998). Does practice shape the brain? *Nature, 394* (6692), 434.

14. Zatorre, R. J., & McGill, J. (2005). Music, the food of neuroscience? *Nature, 434*(7031), 312–315.

15. Elbert, T., Pantev, C., Wienbruch, C., Rockstroh, B., & Taub, E. (1995). Increased cortical representation of the fingers of the left hand in string players. *Science, 270* (5234), 305–307.

16. Fujioka, T., Ross, B., Kakigi, R., Pantev, C., & Trainor, L. J. (2006). One year of musical training affects development of auditory cortical-evoked fields in young children. *Brain, 129*(Pt 10), 2593–2608.

17. Lotze, M., Scheler, G., Tan, H. R., Braun, C., & Birbaumer, N. (2003). The musician's brain: Functional imaging of amateurs and professionals during performance and imagery. *Neuroimage, 20*(3), 1817–1829.

18. Meister, I., Krings, T., Foltys, H., Boroojerdi, B., Muller, M., Topper, R., & Thron, A. (2005). Effects of long-term practice and task complexity in musicians and nonmusicians performing simple and complex motor tasks: Implications for cortical motor organization. *Human Brain Map- ping, 25*(3), 345–352.

19. Schmithorst, V. J., & Wilke, M. (2002). Differences in white matter architecture between musicians and non-musicians: A diffusion tensor imaging study. *Neuroscience Letters, 321*(1–2):57–60.

20. Zatorre, R. J., Belin, P., & Penhune, V. B. (2002). Structure and function of auditory cortex: Music and speech. *Trends in Cognitive Sciences, 6*(1), 37–46.

21. Zatorre, R. J., Chen, J. L., & Penhune, V. B. (2007). When the brain play music: Auditory-motor interactions in music perception and production. *Nature Reviews Neuroscience, 8*(7), 547–558.

22. Schlaug, Norton, A., Overy, K., & Winner, E. (2005). Effects of music training on the child's brain and cognitive development. *Annals of the New York Academy of Sciences, 1060,* 219–230.

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

24. Barwick, J., Valentine, E., West, R., & Wilding, J. (1989). Relations between reading and musical abilities. *British Journal of Educational Psychology, 59* (Pt 2), 253–257.

25. Lezak MD (2004) Neuropsychological Assessment. New York: Oxford University Press.

26. Blair C, Zelazo PD, Greenberg MT (2005) The measurement of executive function in early childhood. Dev Neuropsychol 28: 561-571.

27. Davis CL, Tomporowski PD, McDowell JE, Austin BP, Miller PH, et al. (2011) Exercise improves executive function and achievement and alters brain activation in overweight children: a randomized, controlled trial. Health Psychol 30: 91–98.

28. Hannon EE, Trainor LJ (2007) Music acquisition: effects of enculturation and formal training on development. Trends Cogn Sci 11: 466–472.

29. Schellenberg EG, Peretz I (2008) Music, language and cognition: unresolved issues. Trends Cogn Sci 12: 45 –46.

30. Stoesz BM, Jakobson LS, Kilgour AR, Lewycky ST (2007) Local processing advantage in musicians: Evidence from disembedding and constructional tasks. Music Percept 25: 153–165.

31. Thompson WF, Schellenberg EG, Husain G (2003) Perceiving prosody in speech. Effects of music lessons. Ann N Y Acad Sci 999: 530–532.

32. Bialystok E, Depape AM (2009) Musical expertise, bilingualism, and executive functioning. J Exp Psychol Hum Percept Perform 35: 565–574.

33. Travis F, Harung HS, 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. Conscious Cogn 20: 1256–1264.

34. Dege´ F, Kubicek C, Schwarzer G (2011) Music lessons and intelligence: a relation mediated by executive functions. Music Percept 29: 195–201.

35. Schellenberg EG (2011) Examining the association between music lessons and intelligence. Br J Psychol 102: 283–302.

36. Yoon, J. (2000, January 1). Music in the Classroom: Its Influence on Children's Brain Development, Academic Performance, and Practical Life Skills.

37. Springer, M. V., McIntosh, A. R., Winocur, G., & Grady, C. L. (2005). The relation between brain activity during memory tasks and years of education in young and older adults. *Neuropsychology, 19*(2), 181–192.