



PONTIFICIA
UNIVERSIDAD
CATÓLICA
DE CHILE

Facultad de Ciencias Sociales
Escuela de Psicología
Programa de Doctorado en Psicología

**DO YOU PLAY ANY MUSICAL INSTRUMENT?
ADULT MUSICIANS SHOW BETTER COGNITIVE PERFORMANCE IN
EXECUTIVE FUNCTIONS AND OTHER ASPECTS OF COGNITION**

Doctoral Dissertation of:

FELIPE IGNACIO PORFLITT BECERRA

Presented to the Escuela de Psicología of the Pontificia Universidad Católica de Chile
to opt for the academic degree of Doctor in Psychology

June, 2019

Santiago, Chile

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Abstract

The aim of this thesis was to study the effects of musical interpretation on executive functions and other cognitive variables.

In the first study, a comparison of cognitive performance between musicians and non-musicians was made. The results showed differences in favour of the musicians, for the variables of verbal working memory, processing speed, cognitive inhibition, fluid intelligence, divided attention and a go/no-go test.

In the second study, a distinction of the cognitive performance of musicians with different types of training was made: rhythmic, melodic and harmonic. The musicians showed differences in cognitive performance among them, where the best results were obtained by the harmonic musicians, followed by the melodic group, and finally by the rhythmic musicians, considering comparisons between groups of musicians, and with the control group (non-musicians).

The third study investigated the relationship of musical sophistication with cognitive performance. Under an updated paradigm, the measurement of musical sophistication was considered as a psychometric construct, in a ten-item questionnaire, regarding to the background in musical activities of the participants. Responding to this paradigm, the sample was built with a balanced number of participant's musicians and non-musicians. Finally, the results showed that musical sophistication significantly explained cognitive performance (26% of variance).

Resumen

El objetivo de la presente tesis fue estudiar los efectos de la interpretación musical sobre las funciones ejecutivas y otras variables cognitivas.

En el primer estudio se realizó una comparación del desempeño cognitivo entre músicos y no-músicos. Los resultados mostraron diferencias a favor de los músicos para las variables de memoria de trabajo verbal, velocidad de procesamiento, inhibición cognitiva, inteligencia fluida, atención dividida y una prueba go/no-go.

En el segundo estudio se realizó una diferenciación del desempeño cognitivo de músicos, con distintos tipos de entrenamiento: rítmicos, melódicos y armónicos. Los músicos mostraron diferencias de desempeño cognitivo entre ellos, donde los mejores resultados fueron obtenidos por los músicos armónicos, seguidos por los músicos melódicos, y en último lugar por los músicos rítmicos, considerando comparaciones entre grupos de músicos y con el grupo control (no-músicos).

El tercer estudio indagó en la relación de la sofisticación musical con el desempeño cognitivo. Bajo un paradigma actualizado, se consideró la medición de la sofisticación musical como constructo psicométrico, en un cuestionario de diez ítems que considera los antecedentes en actividades musicales de los participantes. Respondiendo al mismo paradigma, la muestra se construyó con una cantidad equilibrada de participantes músicos y no-músicos. Finalmente, los resultados mostraron que la sofisticación musical, explicó de manera significativa el desempeño cognitivo (26% de la varianza).

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Author's and committee contributions

Felipe Porflitt conceived the studies, performed the methodological designs, collected the data, participated in the analysis, and finally wrote the manuscripts and thesis.

Ricardo Rosas participated in theoretical and methodological designs, oriented the analysis and the output interpretation, and contributed in all the steps of the thesis process as advisor, also representing the Centro UC de Desarrollo de Tecnologías de Inclusión (CEDETi UC) and his team.

Academics of the committee participated in the thesis project revision and defence, giving timely feedback and general appreciations of the process. Their comments helped to do this thesis better in design, the tests used, and to do better the work in several manners.

Conflict of interest

The authors report no conflicts of interest.

Ethical standards

All procedures and instruments used in this investigation were approved by the Ethics Committee of the Pontificia Universidad Católica de Chile, responding to the international guidelines for research of minimal risk in humans, the Council for International Organizations and the World Health Organization through the Treaty of Geneva (2002) with respect to safeguarding confidentiality and physical, psychological and moral integrity of the participants.

Participants signed the voluntary agreement to participate in each measurement and data collection procedures, ensuring confidentiality and voluntary withdrawal at any time without restrictions.

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Introduction

Effects of music on different cognitive skills

Musical exercise is associated with different skills, such as the development of cognitive strategies, the acquisition of motor and auditory skills, and also the development of expression gestures (Hodges & Sebald, 2011). From the cognition point of view, stimulation given by musical activity favours the development of complex cognitive representations (Koelsch, Rohrmeier, Torrecuso, & Jentschke, 2013; Oeschlin, Descloux, et al., 2013; Oeschlin, Van De Ville, Lazeyras, Hauert, & James, 2013; Patel, 2008), various meta-cognitive strategies in professional musicians (Hallam, 2001), and a greater plasticity of the nervous system (Jäncke, 2009). There are findings that show near transfer of abilities: cognitive and motor, from musical activity. With this training, improvements in listening skills, processing and temporary orientation, and fine motor skills are observed (Miendlarzewska & Trost, 2014). When it comes to the far transfer skills, there is a discussion with contradictory evidence regarding whether or not musical practice favours these abilities, such as, for example, better academic performance (Miendlarzewska & Trost, 2014; Sala & Gobet, 2017). Why music is transferred to other skills or not is a question that the literature has still not answer accurately, and although the discussions have not resulted in much clarity on this topic, there is lot of evidence to indicate that musical training favours the development of various cognitive aspects, including transfer of near and far skills. These findings have been transversal to many cultures and musical styles, as well as to populations with different age ranges.

In the case of the child population, the evidence shows that musical training is associated with improvements in general, crystallized and fluid intelligence (e.g. Doxey & Wright, 1990; Norton et al., 2005; Schellenberg, 2011), greater brain plasticity (Hyde et al., 2009), in near transfer skills such as auditory discrimination (Forgeard, Winner, Norton, & Schlaug, 2008; Hyde et al., 2009), perception and rhythm training (e.g. Bhide, Power, & Goswami, 2013; Matthews, Thibodeau, Gunther, & Penhune, 2016) and fine motor skills (e.g. Costa-Giomi, 2006; Schlaug, 2015). There are also improvements in far transfer skills, such as phoneme discrimination (Lamb & Gregory, 1993), phonological awareness (e.g. Degé, Kubicek, & Schwarzer, 2011; Moreno et al., 2009), speech perception (Francois & Schön, 2011), academic performance (Fitzpatrick, 2006; Schellenberg, 2006; Young, Cordes, & Winner, 2014), inhibition (e.g. Bowmer, Mason, Knight, & Welch, 2018; Bugos & DeMarie, 2017; Moreno et al., 2011), verbal intelligence (Jaschke, Honing, & Scherder, 2018), planning (Bowmer et al., 2018; Jaschke et al., 2018), and also executive functioning in general (Dumont, Syurina, Feron, & Van Hooren, 2017; Jaschke et al., 2018; Moreno et al., 2011; Sachs, Kaplan, Der Sarkissian, & Habibi, 2017). In the case of executive functions in particular, Moreno et al. (2011) compared children from 4 to 6 years old with training in musical arts with a control group with training in visual arts. They used the Wechsler Intelligence Scale for preschool (WPPSI-III; Wechsler, 2002) and the evoked potentials (ERP) of a go/no-go test with electroencephalography (EEG). Their findings show that children with musical training, as opposed to the other group, transfer listening skills to verbal ability, and this is reflected in cognitive tests, and in brain activity measured with EEG. Another study of

children, from 9 to 12 years old, conducted by Degé et al. (2011), showed that time spent in the music classroom has a direct correlation with performance in executive functions. In addition, they argue that the relationship between musical training and intelligence is mediated by executive functions, and that these have an effect on intelligence that explains between 12% and 20% of the variance. A final study to exemplify the advantages of musical training in development is that of Miendlarzewska and Trost (2014). Analysing several studies, they suggest that the effects of musical training on children are not only reflected in the enhanced cognitive aspects, such as executive functions or generic intelligence, but also, in the development of sensitivity, in critical growth periods, in the plasticity of the nervous system, linguistic skills, listening skills, spatial and mathematical reasoning, various social aspects, and also in academic performance.

In the case of adults, the findings show an advantage in executive functions in musicians, compared to people who have not received this type of training. In particular, Bugos, Perlstein, McRae, Brophy, and Bedenbaugh (2007) found significant improvements for executive functioning in general, with an intervention that consisted in giving six months of piano lessons to older adults (range 60 to 85 years of age). They suggest that this is the particular case of working memory, where more robust changes are observed in participants in this age range. Franklin et al., (2008)'s study showed enhanced executive functioning, particularly in verbal working memory, in musicians with at least 9 years of training, compared to people without musical training with the same demographic characteristics. They used Raven matrices, the Rey Auditory Verbal

Learning Test (RAVLT), and the Reading and Operation Span to measure the variable. Parbery-Clark, Skoe, Lam, and Kraus (2009) found that musicians with more than 10 years of experience, obtained better results on tests related to executive functioning, compared to non-musicians. In addition, their study also showed that musicians had an improved ability to solve speech listening tasks, with background noise distractors. In adult musicians (average 28 years old), Pallesen et al. (2010) found better performance in verbal and visuo-spatial working memory. They suggest that attention is particularly favoured, with a special focus on the alert component. Their findings are also related to increased brain activity in musicians, measured with Functional Magnetic Resonance Imaging (fMRI).

Musical training has also been included in studies related to other cognitive aspects, both in children and adults. There are studies that integrate fluid intelligence, processing speed, and to a lesser extent, divided attention. In some cases, the evidence is contrasted according to age ranges. For example, for fluid intelligence, Schellenberg (2011) showed that children with musical training have advantages when compared to children without this type of training (9 to 12 years of age). On the contrary, Silvia, Thomas, Nusbaum, Beaty, and Hodges (2016) maintain that despite the fact that musical training correlates with many cognitive variables, in more complex models the correlations could be spurious, such as in a population of young adult musicians. In the case of processing speed, these differences have been analysed in children and adults, both for musicians and non-musicians. Krampe and Ericsson (1996) used the Digit Symbol Substitution Test (Wechsler, 1955) and the response speed in a digital piano, to

obtain a measure of processing speed in young and adult pianists. Their data showed only trends, based on the differences in means, but no statistical significance between the performance of musicians and non-musicians. Likewise, Zuk, Benjamin, Kenyon, and Gaab (2014) used the “coding” sub-test of WAIS-IV (Wechsler, Rosas, Pizarro, & Tenorio, 2013) as a measure of processing speed. They found that in children with musical training there was a significant difference in favour of performance, compared to children who did not receive this training, but, in adults, this difference was not seen. Thus, the evidence is not clear regarding this variable. A final relationship -divided attention and its association with musical training- has been explored to a lesser extent. According to Riva, Cazzniga, Esposito, and Bulgheroni (2013), the pre-frontal cortex, the basal ganglia and the cerebellum are areas of the nervous system that involve processes such as working memory, planning, problem solving and divided attention. According to the evidence that will be presented later, in the *neurological bases of musical training* section, music activity shares areas similar to those proposed by Riva et al. (2013), which involve divided attention among other cognitive skills.

Occupations in the art of music

In the discipline of music there are different occupations, probably as many as the sub-disciplines of psychology. Within the musical occupations are composers, producers, teachers, music therapists, orchestra or choir directors, music lovers (appreciators, fans, listeners), musical performers, among others. Recurrently, studies

related to music, cognitive psychology and neuroscience understand musical activity as musical appreciation or interpretation.

Music recipients or appreciators are on one side of the discipline. Barenboim (1992) argues that “to make music you have to listen to it”. This phrase, from a pianist and orchestra conductor, qualitatively shows that appreciation and musical interpretation are not disconnected from one another, but in turn, belong to different orders. Additionally, in general terms, art always requires a receiver, although paradigms have been changing from a vertical reception or performative art, to a horizontal or participatory vision (Fajardo, 2010). The case of musical appreciation is the case of the reception of music, which, just as interpretation, has different levels of performance.

Musical interpretation is on the other side of the discipline. This sub area is understood as the ability to play music through one or more musical instruments. In some cases, interpretation involves the decoding of a written musical text to make it audible. In this way, performers can play works from the past, which were never recorded in any way other than in a score (Orlandini, 2012). Despite the historical beauty of musical notation, there are performers who read scores, and others who do not. This difference is probably due to the fact that there is music of written tradition (e.g. classical, jazz), and music of oral tradition (e.g. folk, in some cases popular). For cognitive purposes, there is no evidence that the skills of the performer are related to reading music.

In the context of the performers, there are as many differences in training as numbers of musical instruments. This is reflected, for example, in the area of music education, which practically includes specific methods for all musical instruments.

Neurological bases of musical training

Historically, musicians have shown differences in neurological processing, compared to non-musicians, through various measurement techniques (e.g. Bever & Chiarello, 1974; Emmerich, Engelmann, Rohmann, & Richter, 2010; Gaser & Schlaug, 2003; Kaganovich, Kim, Herring, Schumaker, & MacPherson, 2013; Levitin, 2006; Levitin, Grahm, & London, 2018; MacKenzie, 1986). In all cases, greater activity is shown in the neurological networks that involve musical training. From the area of neuroscience, evidence shows that musical exercise, both in appreciation and interpretation, stimulates various areas of the brain and nervous system. This activity, which was initially associated with specific areas of the brain, shows that the plasticity that music provides to the system is generated both at the cortex level and at deeper brain structures, where music training would strengthen these networks (Steinberg, Stiltz, & Rondot, 1992). Musical activity includes both ipsilateral and contralateral neuronal processing patterns, thus sharing intra and between hemispheric activity (Plack, Oxenham, Fay, & Popper, 2005).

In the case of the performers, it is seen that the areas of the nervous system associated with the sensorimotor aspects, such as the pre-motor cortex, the supplementary motor cortex, or other areas such as the auditory cortex (primary,

secondary and tertiary), the ganglia basal, corpus callosum or cerebellum experience important changes during one's lifetime, where there is more brain activity in these areas compared to non-musicians (Altenmüller, Gruhn, Parlitz, & Liebert, 2000; Hodges & Sebald, 2011). Musical interpretation involves the simultaneous use of the networks of the auditory cortex, but, discriminates the fundamental elements of music separately. The evidence shows that, in the case of expert musicians, frequencies and intensities are discriminated in the primary auditory cortex, the basic elements of music (i.e. rhythm, melody and harmony) are identified in the secondary auditory cortex, and the tertiary cortex would be in charge of the recognition of musical patterns in a composition (Altenmüller et al., 2000), in other words, a kind of "semantics of music". Within the same context, different experiments show evidence of differentiated processing for each of the elements of music. In this way, the elements or basic components of music such as rhythm, melody and harmony, would be differentiated in the secondary auditory cortex, but at the same time they would be stimulating different areas of the system.

Elements of music

From a reductionist perspective, music is "sounds and silences in order" and has different elements. Within the elemental components are rhythm, melody and harmony (Schmidt-Jones, 2014).

The first of these, rhythm, is associated with the temporal aspects of sounds. Within the study of rhythm, performers consider the expressive manipulation of the pulse (the most basic unit to measure a beat), the compasses (sub-divisions of several

pulses in weak and strong beats), and agogics (the expressive manipulation of the speed, i.e. accelerated or retarded beats). This component could be proposed as a fundamental element, since music would not exist if it were not for the distribution of sounds in beats. In the same context, there are musical instruments that can only generate rhythms (e.g. cymbals, drums, wood blocks, Peruvian boxes, drums), since they do not have the technical possibility of emitting melodies or harmony. In musical notation, there is also a relationship regarding the treatment of this element. For example, in purely rhythmic instruments, it is not necessary to specify the height of the sound, therefore, instead of presenting a staff in its notation (5 lines), just one is presented, since the important thing is the distribution in beats. An example of a rhythmic score is shown below in Figure 1.



Figure 1. Rhythmic score example

The second element, melody, is strictly a combination of sounds (exact frequencies) that have a successive order in time. These sounds never overlap each other. Unlike rhythm, the design of melodic instruments allows musical performers to drive melodies. Some instruments that respond to this element are the flute, the oboe, or the voice. Typically, this is the element that stands out and is most remembered in music. An example of this is that people tend to remember satisfactorily the melodies of songs in their original tonality (Levitin, 1994). From the point of view of musical notation, the melody responds to a horizontal axis, as shown in Figure 2. In addition,

main classification, both for instruments and musical performers, is based on the three basic elements of music, that is, rhythmic, melodic and harmonic instruments and performers. Table 1 shows examples of musical instruments, and their associations with the basic elements of music.

Table 1

Examples of musical instruments, and their associations with the basic elements of music

Rhythm	Melody	Harmony
Cymbals	Flute	Piano
Snare Drum	Trumpet	Guitar
Kettledrum	Saxophone	Organ
Agogo	French Horn	Harpsichord
Wood Block	Ocarina	Harp

Musical performers invest many years of training to achieve an expressive handling of the qualities of sound (intensity, height, timbre and duration), independent of the element of music that their instrument responds to. This allows them to play complex or historical repertoires, with high levels of difficulty. In the context of music education, the trend of musical interpretation training programs has been to evolve to increasingly complex levels of expression, being progressively more demanding with musicians in training (Orlandini, 2012). This characteristic of the training of an instrumentalist, translates into many hours of solo study (i.e. autonomous, alone), where daily study becomes fundamental. As it has been said before, there are aspects and neurological areas associated with the different elements of music. These elements, in the hours of solo study of the performers, would be stimulating different areas of the nervous system, given the musical instrument they play.

Differentiated neurological stimulation for the elements of music

Experiments related to research in neurological processing and music have historically used different measurement techniques, such as computerized tomography (CT), positron emission tomography (PET), nuclear magnetic resonance imaging (NMRI), among others. Electroencephalography (EEG) and functional magnetic resonance imaging (fMRI) have been used in the greatest number of studies. In the cases that are detailed below, processing differences are shown in experiments that have differentiated the elements of the music.

Petsche, Lindner, and Rappelsberger (1988) showed, with the use of EEG, that in the presence of rhythmic stimuli, there was a significant increase of the delta band in the posterior part of the cortex, and a decrease in the theta band of the fronto-temporal and occipital areas. In the alpha frequency, they found that when exposed to rhythmic stimuli, activity in the left parietal side of the brain increased. In addition, they found greater stimulation of the gyrus with a rumba rhythm than in the presence of other stimuli (for review of this rhythmic pattern: Lavelle, 1983). Similarly, Pretto and James (2015) showed, with the use of fMRI, that the areas activated by rhythm had an effect on the temporal upper and lower left bilateral area of the gyrus, putamen, the primary auditory cortex and several areas of the cerebellum, including lobes IV, V, VI, VII, VIII and IX, according to different experimental conditions with regular and irregular rhythms. These findings are consistent with Levitin (2006), who argues that the neurological processing of rhythm is largely due to the use of circuits of the cerebellum and the motor cortex, rather than other brain systems.

In the case of studies that have conducted experiments with melodies and neurological processing, Besson and Faïta (1995) showed, with the use of EEG, differences between musicians and non-musicians, in the late, positive and negative components in evoked potentials (ERP), in terms of electrical activity in general. These differences occur with melodic stimuli, but not with rhythmic stimuli, in consistent and inconsistent experimentation conditions. Thus, they agree with previous studies, which suggest an independence of the neuro-cognitive processing of rhythm and melody (e.g. Peretz & Kolinsky, 1993; Peretz & Morais, 1989; Zatorre, 1983), and with other studies where the melodic components required more complex neurological representations, in comparison to the rhythmic components (Sturm et al., 2015), and also, with investigations that showed people with damages in the nervous system, who presented interference in the discrimination of frequencies (i.e. musical notes) but not of rhythm or perception of time (Liégeois-Chauvel, Peretz, Babai, Laguitton, & Chauvel, 1998).

For the last element of music, harmony, Tramo (1992) study with auditory stimuli found that the activity of the cortex in the left hemisphere increases significantly in the presence of super-positions of melodies (i.e. harmony). Similarly, Sturm, Blankertz, and Curio (2017) found that there is more brain activity in the presence of harmony than melody. Specifically, they found in ERP, that the activity increased with harmonic stimuli in P3 and N2, in the Fz and Tp8 zones (EEG configuration 10/20). The study looked at 13 musicians with at least 3 years of musical experience (range of experience: 3 to 40 years), and controlled the rhythmic aspects of the stimuli, in favour to differentiating between the brain activity evoked by melody, and that evoked by

harmony. These results agree with Levitin (2006), who states that harmony provokes greater participation from the dorsolateral frontal cortex and Brodmann's areas 44 and 47, compared to melody.

In this way, there is robust evidence, with different measurement techniques, that proves there is a different processing in the nervous system according to the three basic elements of music.

Links between cognitive psychology, neuroscience and music training

As it has been reviewed in this framework, musical exercise stimulates a large part of the nervous system. These areas, in turn, have been associated with cognitive processes of different types. Executive functions, for example, are associated with the use of the pre-frontal cortex (Lezak, Howieson, Bigler, & Tranel, 2012), the dorsolateral cortex (Adólfssdóttir et al., 2014; Ruscheweyh, et al., 2013), the lateral temporal lobe and the insular cortex (Ruscheweyh, et al., 2013), the pre-motor cortex (Rushworth, Passingham, & Nobre, 2005), as well as other cortical and subcortical structures, such as Broca area, the infero-temporal cortex, area 46, the fusiform cortex and the hippocampus (Fuster, 2013). Another cognitive aspect, fluid intelligence, has been associated with the pre-frontal lateral cortex, the cortex of the anterior cingulate, and the lateral areas of the cerebellum (Gray, Chabris, & Braver, 2003). The neurological bases of processing speed have also been studied. The posterior areas of the left hemisphere, the left mid frontal gyrus, the occipital and parietal areas, as well as the temporal lobe are related to this variable in different tasks (Magistro et al., 2015). As for the final factor, divided

attention, Riva et al. (2013) propose that the neurological areas that would be associated with this type of task would be the cerebellum, the prefrontal cortex, and some subcortical structures, as previously mentioned.

It has been shown that several areas of the nervous system responsible for the resolution of this type of task are shared by those stimulated by musical training, in some cases with all the elements of music, and in others with some. This could be one of the reasons why musicians show improved neurological and cognitive performance, compared to people who have not received this type of training.

Another probable reason for this effect is that from a multi-sensory point of view, music activates senses such as hearing, sight and touch, both for people who follow basic musical stimuli (Fraisse, Oléron, & Paillard, 1958), and for auditors who are stimulated by incoming information in an auditory and visual channel (Vuoskoski, Gatti, Spence, & Clarke, 2016). The processing of music is generated by various channels in the cognitive system, it is able to evoke various emotions (Custodio & Cano-Campos, 2017; Peretz, 2001), and requires generating motor habits, bodily patterns of action and auditory images (Pelinsky, 2005). Basically, musical interpretation requires simultaneous cognitive, motor and emotional learning. In that sense, it could even be proposed that playing a musical instrument is a kind of cognitive, motor and emotional training.

There are various factors that have been reviewed in this theoretical framework. On the one hand, the neuro-cognitive advantages that musical training generates, the differences in this type of stimulation based on the elements of music, the motor aspects

that are involved, and to a lesser extent the multi-sensorial environments evoked by music. However, one aspect that I would like to cover in this thesis, and one that has been of great interest for research in this area, is to answer the question of how much musical training is necessary to develop these types of advantages and skills, and in turn, if they are solely attributable to populations of musicians. The sections below respond to the approach of exploring these ideas.

Musical sophistication measurements in populations with and without musical training

According to Müllensiefen, Gingras, Musil, and Stewart (2014), musical sophistication is a psychometric construct, which can be measured through the musical backgrounds of musician and non-musician participants, and in turn, can show differences in the cognitive system. Actually, the literature offers two tests to measure this construct: the Goldsmiths Musical Sophistication Index (GoldMSI), designed by the University of London, and the Ollen Musical Sophistication Index (OMSI) (Ollen, 2006), designed in Ohio by Joy Ollen, although it is currently online, through the Marcs Institute for Brain, Behavior & Development, in Sydney, Australia.

The first of these, the GoldMSI, considers a self-report of various activities related to music, and also has a strong component in listening skills, where participants must discriminate differences in melodies, rhythms, and tones. Unlike the GoldMSI, the OMSI generates an indicator using only the background of musical activities of its

participants, limited to a questionnaire of ten questions, leaving aside measurements of listening skills.

With high reliability, this new type of measurement generates an opportunity in the literature, since studies that relate this variable to cognitive performance are almost non-existent. As said before, the test psychometrically proposes that musical sophistication is an existing construct in both musicians and non-musicians, which is why it can be measured in the whole population. Through the course of this thesis it became interesting to explore to what extent this variable is associated with all the cognitive aspects that have been reviewed.

The variables reviewed in this work are not always presented in isolation, therefore, we investigated other factors that affect cognitive performance. In some cases, these factors are linked to musical training, and in other cases this relationship is indirect, but still has an effect.

Other variables that can affect cognitive performance

One of the factors that have a significant effect on cognitive performance is age. According to evidence from the Center on the Developing Child at Harvard University (2011), there are changes in cognitive performance throughout the performer's lifetime. The socio-economic level is also considered a relevant factor, given its associations to cognitive performance. In the case of Chile, Rosas and Santa Cruz (2013) show that depending on the type of school a student attends, cognitive capital is different. This variable requires observation for the present study, as the data was collected in Chile.

Regarding bilingualism, Bialystok and DePape (2009) and Bialystok, Craik, Green, and Gollan (2009) show evidence that monolingual musicians have similar results in cognitive performance to those of bilingual populations without musical training, and they differ significantly from people without monolingual musical training. On the other hand, laterality is also important to consider. According to the findings of Beratis, Ravabilas, Kyprianou, Papadimitriou, and Papageorgiou (2013), significant differences are shown in favour of left-handers in flexibility, inhibitory control and working memory, compared to right-handers. However, Nettle (2003) argues that these relationships were not as robust in a study that considered a similar design. A final investigation that analyses cognitive performance and laterality is that of Powell, Kemp, and García-Finaña (2012), which used. They used fMRI to measure brain activity. The authors argue that the areas of the brain related to working memory show more activity in the left-handed population.

In the case of this thesis, all the factors that could affect cognitive performance will be controlled: age, socio-economic level, bilingualism and laterality.

In order to carry out a deep investigation of all the aspects reviewed in this theoretical framework, it is proposed to write three articles, based on the questions and hypothesis presented below, relevant to each publication, with the aim of analysing the relationship between musical training and cognitive performance in adults.

Research questions and hypothesis

For Article 1: In addition to the cognitive aspects that have been investigated in the literature in populations of different age ranges: Are there other areas of cognition that are enhanced through music training in adults?

Hypothesis 1: Musicians will show better performance in executive functions and other cognitive variables in comparison to non-musicians.

For Article 2: Considering that rhythmic, melodic and harmonic musicians stimulate different areas of their brains for years through their solo study: Are there differences in cognitive performance between these groups of musicians?

Hypothesis 1.2: Musician groups will show differences between them in executive functions and other cognitive variables performance.

Hypothesis 2.2: The groups of musician will have differences in executive functions and other cognitive variables, where rhythmic, melodic and harmonic musicians, will show better cognitive performance for some variables each group, or:

Hypothesis 3.2: There will be a cognitive performance position in cognitive skills for the musician groups, where the three groups will show a cognitive performance ranking.

For Article 3: To what extent does level of musical sophistication explain cognitive performance in populations with and without musical training?

Hypothesis 1.3: Musical sophistication will have a direct relation with cognitive performance, where higher level of musical sophistication will show better cognitive performance comparing to lower level (musicians and non-musicians respectively).

The research conducted was realized by quantitative methodology, looking for respond the questions and hypothesis presented before. For the first study, an exploratory analysis was performed, in order to describe the cognitive performance position and distribution, following to a set of analysis of variance, controlling the demographic variables. For the second study, an exploratory analysis was performed looking for means and standard deviations for each group (musicians and non-musicians), in order to understand the performance position of each dependent variable. Then a set of post-hoc analysis was made, in order to show differences between musicians and with the control group, in the variables that showed significant differences between these groups. For the last study, we looked for correlations between musical sophistication and the cognitive variables. Then, in order to reduce the cognitive performance variables, a factorial analysis with the variables correlated with musical sophistication was made (just one factor). Later, a two steps regression model was executed, controlling in the first step the demographic variables, and in the second the musical sophistication results, over the cognitive performance factor.

All the results are in the following articles. I expect that these evidences will allow readers to understand the relation between play a musical instrument and cognitive performance, and they are cordially invite to read each study.

1. First Study

Behind the scene: cognitive benefits of playing a musical instrument.

**Executive functions, processing speed, fluid intelligence and
divided attention.**

Behind the scene: cognitive benefits of playing a musical instrument. Executive functions, processing speed, fluid intelligence and divided attention. *Detrás de la escena: beneficios cognitivos de tocar un instrumento musical. Funciones ejecutivas, velocidad de procesamiento, inteligencia fluida y atención dividida.*

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January, 2019

Title:

Behind the scene: cognitive benefits of playing a musical instrument. Executive functions, processing speed, fluid intelligence and divided attention. *Detrás de la escena: beneficios cognitivos de tocar un instrumento musical. Funciones ejecutivas, velocidad de procesamiento, inteligencia fluida y atención dividida.*

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Abstract

The relationships between music training and cognitive performance has been much explored over the last decades. A variety of evidence shows a different neurological and cognitive processing, in the population who have undergone instrumental music training, compared to people who have not. A review of the literature shows the many advantages in cognitive skills musicians have gained from musical training, such as benefits to their executive functions and other aspects of cognition, both in children, adults and the elderly. This study investigates in greater depth certain cognitive aspects associated with musical training in the adult population. Specifically, it explores its relationship with inhibition, working memory (verbal and visual-spatial), flexibility, processing speed, fluid intelligence and divided attention. Our results suggest that there is indeed a relationship between musical training and improvements in cognitive performance, both in executive functions and in other areas of cognition.

Keywords

Music, executive functions, divided attention, processing speed, fluid intelligence.

Introduction

There are a variety of different careers in the field of music. They include researchers, musicologists, composers, music-therapists, teachers, producers and musical performers. Performers interpret and deliver, through musical instruments, music previously designed by composers. In order to do this, they need to very precisely manage sound quality, which in turn requires as much musical ability as possible, and to be highly fluent in music. It takes a prolonged period of time (years) to train a musician, who usually begins their musical education at an early age in life; they must undergo rigorous training, including many hours of solo/autonomous study (Orlandini, 2012). This craft is as old as music itself, and despite some theories suggesting an early decline in artistic manifestations as a result of technological development (Benjamin, 1936), it continues to play an important role in history.

Musicians have been the focus of studies during the last years. An interest in this area was piqued by advances in neuroscience and cognitive psychology measurement techniques. There is evidence of improved neuro-cognitive processing in the musical population, compared to people who have not received this type of training (e.g. Bever & Chiarello, 1974; Emmerich, Engelmann, Rohmann, & Richter, 2015; Gaser & Schlaug, 2003; Kaganovich, Kim, Herring, Schumaker, & MacPherson, 2013; Levitin, 2006; Levitin, Grahm, & London, 2018; MacKenzie, 1986).

Musical interpretation facilitates the development of complex cognitive structures (Koelsch, Rohrmeier, Torrecuso, & Jentschke, 2013; Oeschlin, Descloux, et

al., 2013; Oeschlin, Van De Ville, Lazeyras, Hauert, & James, 2013; Patel, 2008). It also facilitates the exchange of top-down neural processing patterns (Plack, Oxenham, Fay, & Popper, 2005). The nervous system sectors associated with these cognitive processes are in turn linked to areas that are neurologically stimulated by musical activity. There is robust evidence from the area of neuroscience showing that certain areas produce greater activity when carrying out musical exercises than with other stimuli; these areas include the frontal and lateral cortex (Tan, Pfordresher, & Harré, 2010), cerebellum, auditory cortex, motor cortex (Levitin, 2006; Pretto & James; 2015), the occipital and parietal lobes, the gyrus, the putamen, posterior area of the cortex (Petsche et al., 1988), the Brodmann areas 44 and 47 (Levitin, 2006), and activity in the left hemisphere in general (Tramo, Cariani, Koh, Makris, & Braidà, 2005).

One of the areas that has been widely explored in the relationship between musical training and cognition are the executive functions (Bugos, Perlstein, McCrae, Brophy, & Bedenbaugh, 2007; Degé, Kubicek, & Schwarzer, 2011; Franklin, Moore, Jonides, Rattray, & Moher, 2008; Miendlarzewska & Trost, 2014; Moreno et al., 2011; Pallesen et al., 2010; Parbery-Clark, Skoe, Lam, & Kraus, 2009). Executive functions are understood as a generic control mechanism that modulates the operation of several cognitive sub-processes, regulating human cognition (Diamond, 2013; Miyake et al., 2000). Cognitive components of executive functions include inhibition, working memory, flexibility, monitoring and planning. Diamond (2013) states that inhibition, working memory and flexibility are the fundamental elements between these processes. These skills allow us to plan goals and monitor them, separating them from thoughts,

behaviours and emotions that may interfere with their achievement (Santa Cruz & Rosas, 2017). Executive functions are one of the most researched variables in the population with musical training, and results from these studies show that these types of cognitive performance in musicians are more developed compared to people without this training (e.g. Levitin, 2006; Peretz & Morais, 1989; Petschke, Lindner, & Rappelsberger, 1998; Pretto & James, 2015; Zatorre, 1983).

Regarding inhibition, findings show that musicians have advantages over people who have not received musical instruction. For example, Moreno et al. (2011) found higher scores in go/no go tests carried out by children who had received a short musical training session lasting 20 days, in comparison to other children who were trained in the visual arts (children in both groups were aged four to six). A study by Jaschke, Honing, and Scheder (2018) also found advantages for children who had received musical training (singing and playing percussions), over a control group (the average age of children in both groups was 6.4), in go/no go tests, other tests, neuropsychological planning and working memory. Slater, Ashley, Tierney, and Kraus (2018) found differences in favour of musicians, compared to non-musicians in inhibition in the adult population (aged 18 to 35), in behavioural tests that integrate visual and auditory aspects (Full scale response control quotient, sub-set of Integrated Visual and Auditory Plus Continuous Performance Test). Inhibition in these cases is favoured by musical training, both in behavioural tests, as well as in tasks associated with visual and auditory stimuli.

For cognitive flexibility, the evidence becomes contradictory. Zuk, Benjamin, Kenyon, and Gaab (2014) found advantages for flexibility in children with musical

training, compared to children who had not received any (aged 9 to 12) using Trail Making Tests (Delis, Kramer, Kaplan, & Holdnack, 2004). However, results from the study into similar aged children, measuring flexibility with the Wisconsin Card Sorting Test (WCST; Grant & Berg, 1948; Heaton, 1981) by Schellenberg (2011) did not concur. These contradictions have also been found in the adult population; results from the same study by Zuk et al. (2014) showed that there are no significant differences between adult musicians and non-musicians (18 to 35 years old) using the Trail Making Test. Conversely Hanna-Pladdy and MacKay (2011) showed that older adults (aged 60 to 83) who were musically active performed better in this type of tests, in comparison to people who did not carry out any type of musical activity during their lives.

Differences are also seen between the musician populations and non-musicians in verbal working memory. Pallesen et al (2010), for example, designed a study with musical harmonic stimuli (major and minor chord cadences), and observed that musicians have a better working memory to carry out this type of task with than non-musicians. In turn, results from Functional Magnetic Resonance Imaging (fMRI), showed that there was greater neurological activity in musicians' cerebellum, vermis, gyrus, thalamus, caudate nucleus, putamen and insula. In addition Mainz and Hambrick (2010) found that musical expertise levels were highly related to working memory in pianists; although they did not use a control group in their study, they reached these conclusions by generating a correlation and a regression between piano experience and working memory. The study measured working memory with four sub-sets, two verbal and two visual. The first activity was operational: questions and answers to remember

(correct/incorrect); the second was reading sentences that either made sense or were nonsensical; the third was a rotation of images activity (correct or incorrect in a mirror), and the final activity required the participant to remember a figure of a space that was shown in a blue matrix. In both studies, verbal working memory was highly favoured by musical training.

In the case of visual-spatial working memory, a meta-analysis by Hetland (2000) concluded that students who receive musical instruction more effectively carry out tasks associated with spatio-temporal skills; this was true regardless of whether the type of musical training they received was improvised, structured or in the appreciation of music. Furthermore, George and Coch (2011) showed that there is an increase in tasks associated with visual-spatial memory in people with musical training. His study measured Abstract Visual Memory, and Memory for Location (TOMAL-2, Reynold & Voress, 2007). Other studies, such as the one by Slevc, Davey, Buschkuehl, and Jaeggi (2016), found improved visual-spatial skills in adult musicians compared to non-musicians (average age 20.84). The test used in this study to measure visual-spatial working memory was Visual Letter-back Task. Despite all this evidence, there are also contradictory findings, such as the results from a study by Bidelman, Hutka, and Moreno (2013), which found no improvements in aspects associated with visual-spatial tasks in musicians. Thus the literature suggests further investigation into visual-spatial working memory, in the population that has received musical training is necessary.

Other cognitive variables associated with musical training have been less explored, such as processing speed. Advantages in this variable can be seen in children

who have been trained musically compared to those who have not (Zuk et al., 2014), measured with the Wechsler Intelligence Scale for Children (WISC; Wechsler, 2003) subtest 'coding'. Fluid intelligence is another factor that is thought to be favoured by musical training. Schellenberg (2011) creates an index to measure this variable, from reasoning matrices and construction with cubes, Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999) sub-sets and executive functions, seeking evidence of the relationship between intelligence, musical training and these type of skills (attention, working memory, verbal fluency, flexibility and inhibition). Among other findings, the study observed significant differences for fluid intelligence in children (aged nine to 12) who participated in extra-curricular musical activities at school, compared to a group that did not. One last variable, divided attention, has been even less explored. Riva, Cazzniga, Esposito, and Bulgheroni (2013) showed that the areas of the nervous system that are related to monitoring, working memory, and cognitive aspects such as divided attention, are the cerebellum, the pre-frontal cortex, and certain sub-cortical structures. As previously reviewed, these sectors of the nervous system are stimulated with musical activity (e.g. Levitin, 2006; Petsche et al., 1988; Pretto & James, 2015; Tan, Pfordresher, & Harré, 2010). Despite this, the relationship between divided attention and musical training has not been explored much.

Along the same line of research, different types of associations have been found between musical training and working memory, which may depend on the level of musical ability that musicians have. However, and furthering this idea, it could be said that the improved cognitive abilities of a musician depend - rather than the musical

training itself - on the amount of time they undergo formal study of a musical instrument, their age and the frequency with which they practice, among other variables (review in detail; Ollen, 2006). This point will not be considered in this study, but it will be considered relevant and a criterion for the inclusion of the participants.

Our current evidence points towards an advanced cognitive processing in musicians, and the studies named within this paper are just one example. On this basis, this study will explore the cognitive aspects that have been widely covered in the literature - such as executive functions - and also those that have been less focused on - such as processing speed, fluid intelligence and divided attention - with the purpose of the comparing cognitive performance in adult musicians with non-musicians, and to determine whether the evidence put forward contributes to the understanding of these areas of human cognition.

We believe that this research study is a contribution to the field because not many studies investigate young adult musicians, it has certain novel measurements of executive functions, and cognitive aspects that are original for psychology and includes within its control variables certain aspects that are not typically considered co-variables.

Method

Participants

Initially, 144 people with and without musical training (108 and 36 respectively) were recruited whose mean age was 30 (SD=6.58); 35.4% were female.

The Ollen Musical Sophistication Index (OMSI; Ollen, 2006) was used to measure the musical sophistication of the participants. Scores over 500 are classified as “consistently sophisticated in music”, and cases with fewer than 500 points are classified as “unsophisticated in music”, on a scale of 1 to 1000. There were two cases of musicians who declared themselves to have a high level of musical training but who obtained fewer than 500 points. These two cases were not included in the study. The final range of scores for the group that included musically sophisticated people was 501-990. No participant in the control group obtained more than 500 points (range, 26-476).

Another inclusion criterion was that participants be monolingual. Because we used snowball sampling, we administered a questionnaire that contained questions regarding the participant's second language to re-control the variable (reading, writing, listening, speaking). One case was discarded because the participant had a high level of all four skills in a second language, and, according to Bialystok and DePape (2009) and Bialystok, Craik, Green, and Gollan (2009), this could affect the results.

Measuring only right or left-handed people was not considered an inclusion criterion, but it was controlled with a questionnaire for instruments as a dichotomous variable.

One participant was colour blind. They did not participate in colour discrimination tests (inhibition and cognitive flexibility).

The final sample comprised 141 participants: 105 musicians and 36 non-musicians. Participating musicians played a variety of instruments, and included:

singers, pianists, drummers, trumpeters, guitarists, percussionists, violinists, and bassists.

The research was approved by the Research Ethics and Security Unit of the Pontificia Universidad Católica de Chile, respecting national and international regulations for research in Social Sciences. The participants were given an informed consent on the day and did not receive any kind of incentive to participate.

Instruments

A battery test designed for the study was administered, measuring the relevant cognitive aspects for the investigation in the following order and type (table 1.1):

Table 1.1
Battery test

Dependent variable	Test	Type of test
Cognitive flexibility	Wisconsin Card Sorting Test	Form
Verbal working memory	Memory for Digit Span	Form
Cognitive inhibition	Stroop Test	Form
Go/No-go	Cats & Dogs (YellowRed)	Tablet
Visual-spatial working memory	Binding (YellowRed)	Tablet
Divided attention	Divided attention (HAL2)	Tablet
Fluid intelligence	FIX (HAL2)	Tablet
Processing speed	Cats & Dogs (YellowRed)	Tablet

Cognitive flexibility was measured with the ‘Wisconsin Card Sorting Test’ (Grant & Berg, 1948; Heaton, 1981), using an index that included the variables: perseverative responses, perseverative errors, nonperseverative errors, completed categories and learning to learn. For verbal working memory we used the Wechsler

Adults Intelligence Scale sub-test (WAIS-IV; Wechsler, Rosas, Pizarro, & Tenorio, 2013) Memory for Digit Span, with an index for its three conditions (direct, inverse and sequence). Cognitive inhibition was measured with the ‘Stroop Color and Word Test’ in 45 seconds (Golden, 2007), in its three conditions (words, colours, colours-words). Visual-spatial working memory was measured with the YellowRed ‘Binding’ sub-test, designed by the CEDETi UC (Tablet). In this test, the participant is shown a visual stimuli linking numbers with images (drawings) for a few seconds. Subsequently, on a second screen, the participant must associate the number with the corresponding image, using their finger to drag the numbers towards the linked image. Distractors are presented among the possible answers: more numbers among the alternative options, and/or fewer images than on the original screen. Go/no-go was measured with the YellowRed ‘Cats & Dogs’ subtest (Tablet), designed by the CEDETi UC, based on the Hearts & Flowers test (Wright & Diamond, 2014). The test contains three stages: congruent stimuli, opposite stimuli, and random stimuli. We only considered the condition of appearance of random stimuli for measurement, since it is the most complex stage and the one that offers the best discrimination in adults. To measure ‘divided attention’ we used the HAL2 subtest designed by CEDETi UC that bears the same name. After one practice round, participants are required to slide up or down according to even or odd numbers respectively. They must simultaneously follow red circles appearing between blue circles (distractors) that move around inside an octagon. After a few seconds, the red circles change to blue, and continue moving (same colour as the distractors). Task 1 (sliding up or down) stops when the numbers stop moving, and

the participant must immediately mark with their finger the blue circles that were previously red. An indicator responding to the performance of the both tasks at the same time is applied, and a correct answer is when task 1 and 2 are simultaneously successful. Fluid intelligence was measured with a HAL2 subtest called FIX (Tablet). In this test, participants observe 2x2 matrices with different designs, whose lower right area is incomplete. They must use their finger to mark what they consider the correct answer, out of five options on the right side of the screen. There is one correct answer and four distractors per item. Each participant's score was calculated from their answers to the test's 10 items, the total being the performance indicator. Finally, processing speed was measured by the second indicator 'Cats & Dogs'. The reaction time to the stimulus of the test's third condition was calculated, i.e. the sum of the time taken to respond to each item from when the stimuli appear, until when the participant marked on the Tablet, the last condition that considered only random answers. The response range to this variable was 408 to 871 milliseconds per item. No case was ruled out, as there were no impulsive responses, considered in this study to be less than 400 milliseconds, since the task requires simple decision-making.

Measuring control variables

The age of the participants was recorded through a questionnaire. As mentioned above, participants were asked whether they dominated a second language through a questionnaire that measured the four language skills (i.e. listening, speaking, reading, writing). A Spanish translation of the Ollen Musical Sophistication Index (*OMSI*; Ollen,

2006), was used to measure the musical sophistication of the participants (alpha Cronbach=.77). Laterality was measured by applying a Spanish version of the 'Edinburgh Handedness Inventory' (Bryden, 1977; Oldfield, 1971), through the findings shown by Nettle (2003), Powell, Kemp, and García-Finaña (2012) and Beratis, Ravabilas, Kyprianou, Papadimitriou, and Papageorgiou (2013), where the left-handed population showed performance differences in executive functions compared to right-handed people. Finally, given the characteristics of the Chilean population, the relationship with schooling and socio-economic level (Rosas & Santa Cruz, 2013), a socio-economic level index was generated, built from the educational level of the participants (four levels), and the dependence of the school they finished their schooling at (three levels).

Procedure

Data collection was carried out between the months of March to July 2018 in the cities of Santiago, Punta Arenas, Frutillar and Valparaíso, Chile, in a single session per participant. These sessions lasted approximately one and a quarter hour (75 minutes average). The rooms used for the sessions had no distractions in terms of noise or variation in lighting; the tests were always administered in the same order to ensure that all participants had the same cognitive load; the order was set to change between paper and tablet forms as few times as possible. Data were analysed using the SPSS version 24 to test the study hypotheses.

Results

To carry out the analyses, the assumptions of normality and homogeneity of the variance were verified with the Shapiro and Wilk (1965) and Levene (1960) tests respectively. The variables that presented problems in these cases were subsequently corrected with logarithmic transformation (logit), as suggested by a variety of studies for this type of sample (e.g. Feng et al., 2014; Hotelling, 1953; Robert & Casella, 2004).

A table was generated with the descriptive statistics of the dependent variables, presented in Table 2.1 to outline performance positions between musicians and non-musicians.

Table 2.1
Dependent variables descriptive data

Dependent variable	Musicians	Non-musicians
Verbal working memory	3.60 (0.35)	3.11 (0.26)
Cognitive inhibition	0.76 (1.00)	0.12 (0.83)
Cognitive Flexibility	0.53 (0.27)	0.44 (0.30)
Go/No-go	0.53 (0.26)	0.42 (0.28)
Visual-spatial working memory	0.52 (0.29)	0.44 (0.28)
Divided attention	8.19 (1.12)	7.52 (1.63)
Fluid intelligence	0.54 (0.26)	0.41 (0.28)
Processing speed	24.45 (1.65)	25.85 (2.25)

Mean (Standard deviation).

Processing speed expressed in seconds.

The results obtained of all variables in the comparison between musicians and non-musicians are shown in Table 3.1.

Table 3.1

Comparison of performance between musicians and non-musicians. Ancova controlling age, socio-economic level and laterality.

Dependent variable	<i>df</i>	<i>F</i>	<i>p</i>	η_p^2	π	Reliability
Verbal working memory	3	14.24	.000***	.345	.99	.97
Processing speed	4	10.03	.000***	.271	.99	.83
Cognitive inhibition	4	5.35	.000***	.167	.99	.71
Fluid intelligence	4	3.56	.005**	.116	.91	.80
Divided attention	4	2.63	.026**	.089	.80	.69
Go/No-go	4	2.39	.072*	.050	.59	.83
Viso-spatial working memory	4	1.98	.120	.042	.50	.81
Cognitive flexibility	3	1.36	.250	.031	.42	.91

*Significant at $\alpha < .10$, ** significant at $\alpha < .05$, *** significant at $\alpha < .001$

Control for age, socio-economic level and laterality was included for all variables. For the case of verbal working memory and cognitive flexibility, a control for age was not included in the equation, since the tests previously controlled for this variable. Reliability was calculated with Cronbach's alpha.

There are significant differences in performance for verbal working memory, processing speed, cognitive inhibition, fluid intelligence, divided attention and in the go/no-go test. All these differences were generated in favour of the group of musicians. In the case of processing speed, the variable is interpreted inversely; the lower the score, the better the processing speed (Table 2.1).

Although there are statistical significance in several variables, the effect sizes that would be explained by musical training seemed particularly attractive for verbal working memory and processing speed. In the case of the first one, the effect size is large, and in the second case it is medium (Cohen, 1988).

Discussion

The results of this research study show conclusively that musicians' cognitive development is superior to non-musicians, in certain important cognitive skills.

In the case of verbal working memory, the results showed significant differences in favour of the musicians, and a large effect size (Cohen, 1988). This evidence is consistent with the findings by Pallesen et al. (2010) in the adult population, and suggests that verbal working memory, with musical stimuli, is associated with verbal working memory in other contexts, in this case measured with the Memory for Digit Span subtest. Regarding the level of expertise proposed by Meinz and Hambrick (2010), the evidence also concurs that musicians who have had many years of musical training have a more developed verbal working memory, considering that one of the inclusion criteria of this study was that the musicians participating had a consistent musical sophistication. Furthermore, our study opens the spectrum within the discipline of music, since our sample was not only composed of pianists, as occurred in the study conducted by Meinz and Hambrick (2010).

Our data shows that adult musicians performed better in processing speed. The findings of a study by Zuk et al. (2014) showed differences in favour of children with musical training, compared to children who had not received this training, but adult musicians were not favoured when measured for this variable (WISC sub-test). In our case, this variable was measured as the response to a stimulus in the Cats & Dogs test, and the medium effect size (Cohen, 1988), in favour of the musicians, shows that these differences are significant. These findings suggest that not all types of processing speed

measurements show that population with musical training have advanced skills. However, when participants are given an immediate surprise stimulus, adult musicians tend to respond faster, by a few milliseconds, than non-musicians.

In inhibition, significant differences were also observed in favour of musicians, both for cognitive inhibition and go/no-go, with a small effect size in both variables (Cohen, 1988). This evidence is consistent with those of Moreno et al. (2011), Jaschke et al. (2018), and Slater, Azem, Nicol, Swedenborg, and Kraus (2017), even when considering that the studies were carried out with different measurement techniques, and that in the particular case of Jaschke et al. (2018) performance was measured longitudinally. The study by Moreno et al. (2011), showed with the go/no-go paradigm, that these differences are more visible in children ($F=6.42$, $p <.05$, $\eta_p^2=.12$). In this study, the difference is seen in adults but with a lower confidence interval and effect size ($F=2.39$, $p=.07$, $\eta_p^2=.05$). Here is where investigating the relationship between performance in go/no-go tests and musical training becomes interesting, since it changes over time.

For the fluid intelligence variable, significant differences were also found in favour of the musicians compared to the control group, with a small effect size (Cohen, 1988). These results show evidence in adults, and concur with the findings of a study by Schellenberg (2011) in children, since in both cases (children and adults), musicians perform better than people who have never received musical training. In turn, they can also be related to evidence found by Oeschlin, Van de Ville, et al. (2013) and Oeschlin,

Descoux, et al. (2013), where it is estimated that fluid intelligence is predicted by the volume of the hippocampus, and that this is favoured by instrumental musical training.

Regarding divided attention, this evidence gives empirical support, from cognitive psychology, to the relationship between certain areas in the nervous system that are associated with these cognitive aspects (Riva et al., 2013). The results suggest that there is an association between musical training and divided attention, since there are significant differences of performance in favour of the group of musicians compared to the control group, with a small effect size (Cohen, 1988). It would be of interest to investigate this relationship further in the future as its explanation could lie in musical training, where musicians are required to use motor coordination when simultaneously reading music while playing music (not investigated in this study). The findings of our research thus concur with the neurological associations proposed by Riva et al. (2013) for divided attention.

In the case of visual-spatial working memory, no differences were found between musicians and non-musicians. These results concur with those obtained by Bidelman et al. (2013) who also did not find significant differences for this type of measurement in musicians. In turn, they contradict Hetland's (2000) meta-analysis conclusions, which did find a statistically significant increase in the musician population compared to non-musicians in visual-spatial tasks. They are also contradictory to the results from a study by George and Coch (2011), which showed a correlation between years of musical training and an increase of these skills, or those from Slevc et al. (2016), which showed that musicians performed near to significant better than non-musicians in this variable

using Visual Letter-back Task. More research is undoubtedly required to shed further light on the relationship between visual-spatial skills and musical training.

In the last variable, cognitive flexibility, there were no significant differences between musicians and non-musicians in our study. This evidence is contradictory to the findings from a study carried out by Hanna-Pladdy and MacKay (2011) in older adults, and Zuk et al. (2014) in children, where cognitive flexibility was measured with the Trail Making Test. However, it does agree with the evidence from a study conducted by Schellenberg (2011), where no significant differences were found in children when applying the same measurement (Wisconsin Card Sorting Test). Confirming whether there is a clear relationship between musical training and performance in cognitive flexibility, is difficult with this type of evidence, although this contradiction might be explained because the Wisconsin Card Sorting Test does not include a task associated to movement, and the Trail Making Test contains an integrated motor and cognitive task, which could have greater similarity to the exercise of playing a musical instrument.

Conclusion

Making music involves cognitive and motor skills. This research study explores the possible benefits of playing a musical instrument for certain aspects of cognition. To a lesser extent, it covered two motor aspects through a go/no-go test, with regard to performance and processing speed.

The findings of this research study showed differences in cognitive performance for verbal working memory, processing speed, cognitive inhibition, go/no-go test, fluid

intelligence and divided attention, in favour of musicians, compared to people who have never received this training. Other studies observed the same differences in children who had received musical training, compared to children who had not. In our study, these differences were also evidenced in a population of adult musicians.

As mentioned above, according to the results obtained for the go/no-go test, further investigating the trajectories of musicians and their relationship with these measurements would be of interest, since the relationship was more robust in children and more attenuated in adults.

Limitations

Our research contributes to understanding musical training in young adults, in the variables investigated in the literature, and others that have been less explored. This study, in turn, is not part of a on-going discussion in the literature, as to whether the outstanding cognitive performance in musicians has a causal role in musical training, or whether it is the cognitive characteristics of a specific population that are attracted to careers within the musical field (Demorest & Morrison, 2000; Wheeler & Wheeler, 1951). Future research should focus on this through longitudinal studies in different populations (children, adults and older adults), and in tests that address the cognitive and motor skills inherent to musical performance, since, despite there being little evidence, it is possible that the advantages gained from studying music are extended well beyond the purely cognitive.

References

- Benjamin, W. (1936). *The Work of Art in the Age of Mechanical Reproduction*. In H. Arendt (Ed.) *Illuminations* (p. 3). New York: Schocken Books.
- Beratis, I. N., Ravabilas, A. D., Kyprianou, M., Papadimitriou, G. N., & Papageorgiou, C. (2013). Investigation of the link between higher order cognitive functions and handedness. *Journal of Clinical and Experimental Neuropsychology*, *35*(4), 393-403. doi: 10.1080/13803395.2013.778231
- Bever, T.G., & Chiarello, R.J. (1974). Cerebral dominance in musicians and nonmusicians. *Science*, *185*, 537-539. doi: 10.1126/science.185.4150.537
- Bialystok, E., Craik, F., Green, D., & Gollan, T. (2009). Bilingual minds. *Psychological Science in the Public Interest*, *10*(3), 89-129. doi: 10.1177/1529100610387084
- Bialystok, E., & DePape, A. (2009). Musical expertise, bilingualism, and executive functioning. *Journal of Experimental Psychology: Human Perception and Performance*, *35*(2), 565-574.
- Bidelman, G., Hutka, S., & Moreno, S. (2013). Tone language speakers and musicians share enhanced perceptual and cognitive abilities for musical pitch: evidence from bidirectionality between the domains of language and music. *PLoS One*, *8*, e60676.
- Bryden, M. P. (1977). Measuring handedness with questionnaires. *Neuropsychologia*, *15*(4), 617-624.
- Bugos, J., Perlstein, W., McCrae, C., Brophy, T., & Bedenbaugh, P. (2007). Individualized piano instruction enhances executive functioning and working memory in older adults. *Aging & Mental Health* *11*(4), 464-471. doi: 10.1080/13607860601086504
- Center on the Developing Child at Harvard University (2011). Building the Brain's "Air Traffic Control" System: How Early Experiences Shape the Development of Executive Functions: Working Paper (No. 11), Boston. Reviewed from www.developingchild.harvard.edu
- Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Erlbaum.
- Degé, F., Kubicek, C., & Schwarzer, G. (2011). Music lessons and intelligence: a relation mediated by executive functions. *Music Perception*, *29*(2), 195-201.

- Delis, D.C., Kramer, J.H., Kaplan, E. & Holdnack, J. (2004). Reliability and validity of the Delis-Kaplan Executive Function System: An Update. *Journal of the International Neuropsychological Society*, 10, 301-303.
- Demorest, S., & Morrison, S. (2000). Does Music Make You Smarter? *Music Educators Journal*, 87(2), 11-17. doi: 10.2307/3399646
- Diamond, A. (2013). Executive functions. *Annual review of psychology*, 64, 135. doi: 10.1146/annurev-psych-113011-143750
- Emmerich, E., Engelmann, M., Rohmann, M., & Richter, F. (2015). Hearing Impairment in Professional Musicians and Industrial Workers – Profession-Specific Auditory Stimuli Used to Evoke Event-Related Brain Potentials and to Show Different Auditory Perception and Processing. *Update On Hearing Loss*, chapter 7. University of Brasilia. doi: 10.5772/59528
- Feng, C., Wang, H., Lu, N, Chen, T., He, H., Tu, X. (2014). Log-transformation and its implications for data analysis. *Shangai Archives of Psychiatry*, 26(2). 105-109. doi: 10.3969/j.issn.1002-0829.2014.02.009
- Franklin, M., Moore., Yip., Jonides, J., Rattray, K. y Moher, J. (2008). The effects of musical training on verbal memory. *Psychology of Music*, 36, 353-365. doi: 10.1177/0305735607086044
- Gaser, C., & Schlaug, G. (2003). Brain Structures Differ between Musicians and Non-Musicians. *The Journal of Neuroscience*, 23(27). 9249-9245. doi: 10.1523/JNEUROSCI.23-27-09240.2003
- George, E., & Coch, D. (2011). Music training and working memory: an ERP study. *Neuropsychologia*, 49, 353-365.
- Golden, C. J. (2007). *Stroop test de colores y palabras, manual* (5º ed.). Madrid: TEA Ediciones.
- Grant, D., & Berg, E. (1948). A behavioral analysis of degree of reinforcement and ease of shifting to new responses in a Weigel-type card-sorting problem. *Journal of Experimental Psychology*, 38, 404-411.
- Hanna-Pladdy, B., & MacKay, A. (2011). The relation between instrumental musical activity and cognitive aging. *Neuropsychology*, 25(3), 378–86. doi: 10.1037/a0021895
- Heaton, R. (1981). *Wisconsin Card Sorting Test Manual*. Odessa, FL: Psychological Assesment Resource Inc.

- Hetland, L. (2000). Learning to make music enhances spatial reasoning. *J. Aesth. Educ.*, *34*, 179-238
- Hotelling, H. (1953). New light on the correlation coefficient and its transformations. *Journal of the Royal Statistical Society, Series B*, *15*(2), 193-225.
- Jaschke, A., Honing, H., & Scheder, E. (2018). Longitudinal Analysis of Music Education on Executive Functions in Primary School Children. *Frontiers in Neuroscience*, *12*(103). doi: 10.3389/fnins.2018.00103
- Kaganovich, N., Kim, J., Herring, C., Schumaker, J., & MacPherson, M. (2013). Musicians show general enhancement of complex sound encoding and better inhibition of irrelevant auditory changes in music: an ERP study. *European Journal of Neuroscience*, *37*, 1295-1307.
- Koelsch, S., Rohrmeier, M., Torrecuso, R., & Jentschke, S. (2013). Processing of hierarchical syntactic structure in music. *Proceedings of the National Academy of Sciences*, *110*(38), 15443–8. doi: 10.1073/pnas.1300272110
- Levene, H. (1960). *Robust tests for equality of variances*. Stanford University Press.
- Levitin, D. (2006). *This is your Brain on Music: The Science of a Human Obsession*. Dutton/Penguin.
- Levitin, D., Grahm, J., & London, J. (2018). The Psychology of Music: Rhythm and Movement. *Annual Review of Psychology*, *69*(13), 13-25. doi:10.1146/annurev-psych-122216-011740
- Liégeois-Chauvel, C., Peretz, I., Babai, M., Laguitton, V., & Chauvel, P. (1998). Contribution of different cortical areas in the temporal lobes to music processing. *Brain*, *121*, 1853-1867.
- MacKenzie, C. (1986). Motor skills in music performance: Comments on Sidnell. *Psychomusicology*, *6*, 25-28.
- 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), 914–9. doi: 10.1177/0956797610373933
- Miendlarzewska, E., & Trost, W. (2014). How musical training affects cognitive development: rhythm, reward and other modulating variables. *Frontiers in Neuroscience*, *7*(279). doi:10.3389/fnins.2013.00279
- Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T.

- D. (2000). The unity and diversity of executive functions and their contributions to complex “frontal lobe” tasks: A latent variable analysis. *Cognitive Psychology*, 41(1), 49-100. doi:10.1006/cogp.1999.0734
- Moreno, S., Bialystok, E., Barac, R., Schellenberg, E. G., Cepeda, N. J., & Chau, T. (2011). Short-term music training enhances verbal intelligence and executive function. *Psychological Science*, 22, 1425-1433. doi:10.1177/0956797611416999
- Nettle, D. (2003). Hand laterality and cognitive ability: A multiple regression approach. *Brain and Cognition*, 52(3), 390-398. doi:10.1016/S0278-2626(03)00187-8
- Oeschlin, M. S., Descloux, C., Croquelois, A., Chanal, J., Van de Ville, D., Lazeyras, F., & James C. (2013). Hippocampal volumen predicts fluid intelligence in musically trained people. *Hippocampus*, 23, 552-558. doi:10.1002/hipo22120
- Oechslin, M. S., Van De Ville, D., Lazeyras, F., Hauert, C.-A., & James, C. E. (2013). Degree of musical expertise modulates higher order brain functioning. *Cerebral Cortex*, 23(9), 2213– 24. doi:10.1093/cercor/bhs206
- Oldfield, R. C. (1971). The assesment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia*, 9, 97-113.
- Ollen, J. (2006). A criterion-related validity test of selected indicators of musical sophistication using expert ratings. (Electronic Thesis or Dissertation). Retrieved from <https://etd.ohiolink.edu/>
- Orlandini, L. (2012). La interpretación musical. *Revista Música Chilena*, 218, 77-81.
- Pallesen, K. J., Brattico, E., Bailey, C. J., Korvenoja, A., Koivisto, J., Gjedde, A., & Carlson, S. (2010). Cognitive control in auditory working memory is enhanced in musicians. *PloS one*, 5(6), e11120. doi:10.1371/journal.pone.0011120
- Parbery-Clark, A., Skoe, E., Lam, C., y Kraus, N. (2009). Musician enhancement for speech-in-noise. *Ear and Hearing*, 30, 653-661. doi:10.1097/AUD.0b013e3181b412e9
- Patel, A. (2008). *Music, Language and the Brain*. Oxford University Press.
- Peretz, I. & Morais, J. (1989). Music and Modularity. *Contemporary Music Review*, 4(1). 279-293. doi:10.1080/07494468900640361
- Petschke, H., Lindner, K., & Rappelsberger, P. (1988). The EEG: An adequate method to concretize brain process elicited by music. *Music Perception*, 6. 133-160.

- Plack, C.J., Oxenham, A.J., Fay, R.R., & Popper, A.N. (2005). *Pitch: Neural Coding and Perception*. New York: Springer.
- Powell, J. L., Kemp, G. J., & García-Finaña, M. (2012). Association between language and spatial laterality and cognitive ability: an fMRI study. *NeuroImage*, 59(2), 1818-1829. doi:10.1016/j.neuroimage.2011.08.040
- Pretto, M., & James, C. (2015). Principles of Parsimony: fMRI Correlates of Beat-Based Versus Duration-Based Sensorimotor Synchronization. *Psychomusicology*, 25(4), 380-391. doi:10.1037/pmu0000122
- Reynolds, C., & Voress, J. (2007). *Test of memory and language*. (2nd Ed.). Austin: PRO-ED Inc.
- Riva, D., Cazzniga, F., Esposito, S., & Bulgheroni, S. (2013). Executive functions and cerebellar development in children. *Applied Neuropsychology Child*, 2(2). doi:10.1080/21622965.2013.791092
- Robert, C. & Casella, G. (2004). *Monte Carlo Statistical Methods*. New York: Springer.
- Rosas, R. & Santa Cruz, C. (2013). *Dime en qué colegio estudiaste y te diré qué CI tienes: Radiografía al desigual acceso al capital cognitivo en Chile*. Ediciones Universidad Católica de Chile.
- Santa Cruz, C., & Rosas, R., (2017). Mapping of Executive Functions / Cartografía de las Funciones Ejecutivas. *Estudios de Psicología*, 38, 284-310. doi:10.1080/02109395.2017.1311459
- Schellenberg, E. G. (2011). Examining the association between music lessons and intelligence. *British Journal of Psychology*, 102(3), 283. doi:10.1111/j.2044-8295.2010.02000.x
- Shapiro, S., & Wilk, M. (1965). An analysis of variance test for normality (Complete Samples). *Biometrika*, 52(3-4), 591-611. doi:10.1093/biomet/52.3-4.591
- Slater, J., Ashley, R., Tierney, A., & Kraus, N. (2018). Got Rhythm? Better Inhibitory Control Is Linked with More Consistent Drumming and Enhanced Neural Tracking of the Musical Beat in Adult Percussionists and Nonpercussionists. *Journal of Cognitive Neuroscience*, 30(1), 14-24.
- Slevc, L. R., Davey, N., Buschkuhl, M., & Jaeggi, S. (2016). Tuning the Mind: Exploring the connections between musical ability and Executive Functions. *Cognition*, 152(1), 199-211. doi:10.1016/j.cognition.2016.03.017
- Tan, S. L., Pfordresher, P., & Harré, R. (2010). *Psychology of music: From sound to*

- significance*. New York, NY: Psychology Press.
- Tramo, M. J., Cariani, P. A., Koh, C. K., Makris, N., & Braidá, L. D. (2005). Neurophysiology and Neuroanatomy of Pitch Perception: Auditory Cortex. *Annals of the New York Academy of Sciences* 1060. 148-174.
- Wechsler, D. (1999). *Wechsler Abbreviated Scale of Intelligence*. San Antonio, TX: Psychological Corporation.
- Wechsler D (2003) *Wechsler Intelligence Scale for Children. WISC-IV*. (Fourth Edition) San Antonio, TX: Pro-Ed, Inc.
- Wechsler, D., Rosas, R., Pizarro, M., & Tenorio, M. (2013). *WAIS-IV: Manual de administración y corrección*. NCS Pearson. P. 221.
- Wheeler, L., & Wheeler, V. (1951). The intelligence of music students. *Journal of Educational Psychology*, 42(4), 223-230. doi:10.1037/h0055291
- Wright, A., & Diamond, A. (2014). An effect of inhibitory load in children while keeping working memory load constant. *Frontiers in Psychology*, (5)213. doi:10.3389/fpsyg.2014.00213
- Zatorre, R. (1983). Category-boundary effects and speeded sorting with a harmonic musical-interval continuum: Evidence for dual processing. *Journal of Experimental Psychology: Human Perception and Performance*, 9, 739-752. doi:10.1037/0096-1523.9.5.739
- 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), e99868.

2. Second Study

**Core music elements: rhythmic, melodic and harmonic musicians
show differences in cognitive performance.**

**Core music elements: rhythmic, melodic and harmonic musicians
show differences in cognitive performance.**

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Title:

Core music elements: rhythmic, melodic and harmonic musicians show differences in cognitive performance.

Abstract

This study explores the cognitive scopes of a population that has been in the spotlight for some decades: musicians. Although there is no single definition for music training, it has been shown that this type of activity, prolonged over time, generates favourable changes at a neurological and cognitive level. This research does not seek to define musical training, but rather to propose a framework of separation between musicians. These differences are based on the basic elements of music (i.e. rhythm, melody and harmony), which activate the nervous system differently in expert adult musical performers. A battery of tests was applied that includes tasks of executive functions, such as verbal and visuo-spatial working memory, cognitive inhibition, a go/no-go test, and cognitive flexibility, as well as tests that measure other cognitive aspects, such as fluid intelligence, divided attention and processing speed. Four groups were established to compare cognitive performance: rhythmic, melodic and harmonic musicians, and a control group (non-musicians). The results show performance differences between the groups of musicians, as well as between musicians and non-musicians.

Keywords

Cognition, musical training, executive functions, rhythm, melody, harmony.

Introduction

Playing a musical instrument requires various cognitive and motor skills (MacKenzie, 1986). These skills have been associated with a different neurological processing in populations with musical training, compared to those who have not received musical training (e.g. Bever & Chiarello, 1974; Emmerich, Engelmann, Rohmann, & Richter, 2015). Also, diverse evidence shows that musicians perform better than non-musicians in executive functions¹ (e.g. Bugos, 2004; Franklin, Moore, Jonides, Rattray, & Moher, 2008; Moreno et al., 2011; Pallesen et al., 2010; Parbery-Clark, Skoe, Lam, & Kraus, 2009), processing speed (Zuk, Benjamin, Kenyon, & Gaab, 2014), and fluid intelligence (Schellenberg, 2011). This evidence has generated a particular interest in cognitive psychology and neuroscience to measure this type of population, at different ages during their lifetime, in order to understand in greater depth how music affects neuro-cognitive processing.

However, the study of music does not imply the same training for all musical instruments. In fact, there are different methods for each instrument (e.g. Kodaly, Orff, Willems, Roland, Suzuki, among many others), and also, as technology advances, instruments that require new motor and cognitive skills are being created. In this way, it becomes impossible to believe, qualitatively, that musical training is the same for all musicians.

¹ They are also called cognitive control or executive control (Miyake et al., 2000; Diamond, 2013).

The literature in the areas of cognitive psychology and neuroscience has shown an implicit tendency to separate populations with musical training into various categories. For example, categories have been proposed according to the degree of expertise (Kaganovich, Kim, Herring, Schumaker, & MacPherson, 2013), the number of hours invested in the lifetime (Ericsson, Krampe, & Tesch-Römer, 1993), measuring the extra-programmatic musical activity of children at school (Degé, Kubicek, & Schwarzer, 2011; Moreno & Farzan, 2015; Schellenberg, 2011), as well as studying the effects of playing a musical instrument in a general manner (Omahen, 2009; Ramachandra, Meighan, & Gradzki, 2012; Zuk et al., 2014). Other studies have generated sub-groups for the construction of their auditory stimuli, but without separating the musicians. This is generally seen in research studies that include rhythmic and melodic stimuli within the designs (e.g. Jaschke, Honing, & Scheder, 2018; Slater, Nicol, Swedenborg, & Kraus, 2017; Slevc, Davey, Buschkuehl, & Jaeggi, 2016). In general, these categories correspond to the nature of each investigation, and not to the specific characteristics of the musical activity. In this study, we want to state that regardless of the level of expertise, musicians have more basic differences, given the characteristics of the instruments they play.

To understand this point from another angle, we must consider that each musical instrument is associated with an element of music, or rather, it is more associated with one element of music than another. The basic elements of music are rhythm, melody and harmony (Schmidt-Jones, 2014). In this musical context, there are instruments that can only respond to one element, such as drums to rhythm. Within their technical

possibilities, these instruments cannot play melodies or harmonies, since they are not designed for that purpose. This is because rhythmic instruments do not produce defined heights (i.e. musical notes, tones, chromas). This element (rhythm) could be considered as the most basic compared to the other two. On the other hand, there are instruments that respond to the melody element, such as flutes or oboes. These instruments can generate specific tones, such as an “A” note, which in Western music is typically set at 440 hertz (Beyer, 1999). Melodic instruments are capable of making one sound at a time. These instruments can generate rhythms, but typically do not have this objective in the ensemble, since there are more appropriate instruments for this. Finally, the most complex case -in this order- is that of harmonic instruments, such as pianos or organs. With these instruments, several musical notes can be played simultaneously. Harmonic instruments are used for this purpose, but secondarily, they can generate melodies or rhythms. However, just like the melodic instruments, they are designed for another purpose.

The following table (1.2) shows examples of musical instruments, and their associations with the three elements of music:

Table 1.2
Musical instrument classification examples by music element

Rhythm	Melody	Harmony
Cymbal	Flute	Piano
Snare	Trumpet	Guitar
Timbale	Saxophone	Organ
Agogo	French Horn	Harpsichord
Jam Block	Ocarina	Harp

From the field of neuroscience, there is robust evidence that shows a differentiated activity in the nervous system for the basic elements of music.

In the case of rhythm, its processing is associated in greater proportion to the IV, V, VI, VII, VIII and IX areas of cerebellum, and the motor cortex (Levitin, 2006; Pretto & James, 2015), as well as to greater activity in the putamen, primary auditory cortex, activity in the delta band in the posterior part of the cortex, a decrease in the theta band of the fronto-temporal and occipital areas, greater activity than other auditory stimuli in the left parietal side of the brain, in addition to a high stimulation of the gyrus in its upper temporal and inferior left bilateral areas (Petsche, Lindner, & Rappelsberger, 1988).

Melody is associated with an activation of different areas of the nervous system, compared to rhythm. Within the areas associated with melody are the primary auditory cortex, the areas of the frontal and lateral cortex (Tan, Pfordrescher, & Harré, 2010), and Brodmann's area 44 and 47 (Levitin, 2006). In turn, processing differences are shown with melodic stimuli, between musicians and non-musicians, in the late, positive and negative components with potential evoked in electroencephalography (ERP/EEG). These differences are not seen with rhythmic stimuli (Besson & Faïta, 1995). Other studies propose independence in the processing of rhythm and melody (e.g. Peretz & Morais, 1989; Peretz & Kolinsky, 1993; Sturm et al., 2015; Zatorre, 1983). In the same way, this evidence is consistent in people who have suffered damages in their nervous system, where it is shown that some individuals have interference in the discrimination

of tones, but not in the perception of rhythm or time (Liégois-Chauvel, Peretz, Babai, Laguitton, & Chauvel, 1998).

In the case of the last element, harmony, Tramo (1992) suggests that the areas stimulated by this element are mostly associated with the activity of the cortex in the left hemisphere, and that this activity in the brain is significantly greater when melodies are layered (i.e. harmony). Consistent with this, the activity in P3 and N2 (ERP/EEG) in the Fz and Tp8 areas (EEG set: 10/20) is greater with harmonic stimuli, versus melodic stimuli, while controlling the rhythmic elements of the stimuli (Sturm, Blankertz, & Curio, 2017).

These evidences are the central bases of the present study, since, according to the element of music associated to their musical instrument, musicians stimulate their nervous system in different ways, during all the hours of solo study (i.e. autonomous, without other musicians) throughout their lifetime.

As it was previously mentioned, several findings show a stronger cognitive performance in the population that has received musical training, in comparison to people who have not received this type of training. According to studies on executive functions, there are performance advantages in musicians versus non-musicians in children, young adult and older adults. In the case of inhibition, the evidence shows these advantages in musicians versus non-musicians with behavioural and go/no-go tests (e.g. Kaganovich et al., 2013; Moreno & Farzan, 2015; Slater et al., 2017). For verbal working memory, these favourable differences were found with tests that consider different auditory stimuli, and in turn, show that these skills are related to greater brain

activity in musicians versus non-musicians, measured with fMRI² (e.g. Meinz & Hambrick, 2010; Pallesen et al., 2010). For cognitive flexibility, the population with musical training has shown advantages in Trail Making Tests, both for adults and children (e.g. Hanna-Pladdy & MacKay, 2011; Zuk et al., 2014). Visuo-spatial working memory has shown contradictory evidence. According to the findings of Hetland (2000), George and Coch (2011), and Slevc et al. (2016), musical training strengthens some aspects that escape the auditory or verbal field. These studies also show evidence of different advantages in musicians versus non-musicians in the visual aspects. However, according to Bidelman, Hutka, and Moreno (2013), this cognitive ability is not particularly enhanced by music training, and the data does not show differences in performance, in comparison to people without musical training.

The literature considers other cognitive aspects, and their relationship with music training. Fluid intelligence, for example, has been explored as a mediator of musical activity and executive functions. It has been found that children who had musical activity in their development (9 to 12 years) present significant advantages in this variable, compared to children who did not have this type of training (Schellenberg, 2011). On the other hand, Zuk et al. (2014) found an advanced processing speed in children who had received music lessons, compared to children who did not have this type of learning. One last aspect, divided attention, has not been explored. Riva, Cazzniga, Esposito, & Bulgheroni (2013) state that the areas that show greater activity in the resolution of tasks of divided attention and other cognitive aspects are the

² Functional Magnetic Resonance Imaging

cerebellum, the pre-frontal cortex and some deeper brain structures. These areas are similar to those that stimulate musical activity according to Levitin (2006), Tan et al. (2010), and Pretto and James (2015) among other authors, but few studies suggest including attention variables in their designs.

For the purposes of this study, executive functions are a generic control mechanism, which modulates the operation of several cognitive sub-processes, regulating human cognition (Diamond, 2013; Miyake, et al., 2000). Within these cognitive skills, three functions are proposed that would have a greater relevance in development according to Diamond (2013): inhibition, working memory and flexibility. She defines them in the following way. Cognitive inhibition allows one to consciously direct attention, course of thought, behaviour and emotions, cancelling their internal predispositions as well as external predispositions from the environment. Working memory is understood as the ability to operate with a number of determined mental representations, both in a visual and an auditory ways. Cognitive flexibility allows us to change problem-solving strategies in the face of new situations, letting go of previously conceived ideas. For the other aspects of cognition, we understand fluid intelligence as the ability to perceive relationships, independent of previous specific practice or instruction, regarding these same new relationships. At the same time, this variable is associated with problem-solving strategies, independent of previous knowledge (Cattell, 1963). Processing speed is the ability to perform simple cognitive tasks, in a repetitive, fast and fluid manner. This skill acts as an important predictor of performance in various cognitive tasks (McGrew, 2005). The last factor, divided attention, is understood as the

ability to perform more than one task simultaneously (Hahn et al. 2008). It also requires dividing or changing attention quickly (Parasuraman, 1998) and considers that incoming stimuli can come from more than one sensory dimension (Braun, 1998).

The stimulations in the nervous system caused by rhythm, melody and harmony, and the evidence of improved cognitive processing in the population with musical training, offer the opportunity to analyse the cognitive performance of musicians in a deeper way. Based on this, the main objective of this research is to determine if there are performance differences in executive function, fluid intelligence, processing speed and divided attention tests, in expert adult musicians, considering performers that play rhythmic, melodic, and harmonic instruments, while contrasting them with a control group of non-musicians.

The state-of-the-art shows differences to divide auditory stimuli in investigations, where rhythmic, melodic and sometimes even harmonic stimuli are included. In spite of this, dividing the independent variables according to these components is uncommon. From the literature review, only one study by Slater et al. (2017) shows a division between vocalists and percussionists, where percussionists show better cognitive inhibition ($p=0.031$). However, current literature does not offer the total separation of the independent variables in the three elements of music.

The present study took advantage of this bibliographical weakness, for the construction of a transversal study, balancing the groups according to the elements of music, and controlling according to some demographic variables that should be considered.

Method

Participants

A list of musician candidates was created through directors of schools linked to musical performance in Chile, in the cities of Santiago, Valparaíso, Punta Arenas and Frutillar. The directors contacted the participants and provided a short overview of the study. Then, direct contact was made to explain the measurements in detail to each participant, and later the evaluation was scheduled. Given the specific characteristics of the sample, after data collection, each participant was asked about other musicians who could be evaluated (snowball sampling). Finally, a control group was generated, which closely matched the demographic data of the groups of musicians to balance the sample.

The sample was initially made up of 144 participants with an average age of 30 years old ($SD=6.58$), of which 35.4% were women. Three cases were discarded: a bilingual person, and two participants who declared themselves musicians, but who did not comply with the minimum of musical sophistication required for the study (<500 , OMSI³). In addition, one participant declared himself colour blind. In his case, the tests that based their results on colour discrimination (inhibition and cognitive flexibility) were not applied. The final sample was $N=141$ participants for almost all of the tests. The group of rhythmic musicians was formed mainly by orchestra percussionists, drummers and Latin percussionists. The group of melodic musicians was formed mainly

³ Ollen Music Sophistication Index (Ollen, 2006).

by singers, trumpeters, violinists and flutists. The group of harmonic musicians was formed by pianists and guitarists.

Instruments

After signing the informed consent form, the following battery of tests was applied (Table 2.2), responding to the needs of the investigation. Some tests were administered in sheet form and others on a tablet (Samsung Galaxy Tab A, 10.1-inch screen). The average measurement time for each participant was 75 minutes. The battery was administered in the following order:

Table 2.2
Battery test

Dependent variable	Test	Test type
Cognitive Flexibility	Wisconsin Card Sorting Test	Form
Verbal Working Memory	Digit Span (WAIS-IV)	Form
Cognitive Inhibition	Stroop Test	Form
Go/No-Go	Cats&Dogs (YellowRed)	Tablet
Visuo-Spatial Working Memory	Binding (YellowRed)	Tablet
Divided Attention	Divided Attention (HAL2)	Tablet
Fluid Intelligence	FIX (HAL2)	Tablet

Tests description

Cognitive flexibility was measured with the Wisconsin Sorting Card Test (Grant & Berg, 1948; Heaton, 1981). An index was constructed from the variables of perseverative responses, perseverative errors, non-perseverative errors, completed categories and learning to learn. Verbal working memory was measured with Digit Span, a sub-test of the Wechsler Intelligence Scale (WAIS-IV; Wechsler, Rosas, Pizarro, & Tenorio, 2013). The three conditions of the test were analysed to generate an indicator

for each participant. Cognitive inhibition was measured with the Stroop Test. According to the characteristics of the sample, it was decided to measure the number of words/colours in 45 seconds for the three conditions of the test. Subsequently, the formula proposed in the application manual was used to calculate the indicator for each participant (Golden, 2007). The go/no-go was measured with the YellowRed subtest of the Cats & Dogs test, a test designed by the UC Development Centre for Inclusion Technologies (CEDETi UC), based on the Hearts & Flowers test (Wright & Diamond, 2014). The most complex level of responses consisting of 33 items (random answers) was used. Visuo-spatial working memory was measured with the Binding Test sub test of the YellowRed Battery, designed by CEDETi UC. This test consists of participants watching visual stimuli for a few seconds where a number is associated with an image. Subsequently (second time), the participant must drag with their finger the number that was originally associated with each image, presented in a different order. Divided attention was measured with the HAL2 sub test bearing the same name (CEDETi UC). The test consists of completing two tasks simultaneously, where the participant has to slide upward on the left of the screen if the number that appears is even, and downwards if the number is odd. At the same time, they must follow the trajectory of circles moving on the right side of the screen, which at the beginning are red but then they change to the same colour as the distractors (blue). When the circles stop moving, both tasks cease, and the participants must mark with their finger the circles that were initially red. Fluid intelligence was measured with FIX, a sub test of HAL2 (CEDETi UC). This test consists of 10 items, where the participant must indicate which piece completes a design

of four elements (matrix), which is always missing the lower right corner. There is a correct answer and four distractors per item. Processing speed was considered based on the millisecond answer of the go/no-go test (Cats & Dogs), from the appearance of the stimulus until the participant responds (1 to 1033 milliseconds). The indicator of each participant was generated from the sum of the 33 responses of the last condition of the test.

In addition, at the end of each evaluation, a questionnaire was administered that provided the following information about the control variables, which according to the literature review, should be considered for this type of population. Age (Center on the Developing Child at Harvard University, 2011), socio-economic level (Rosas & Santa Cruz, 2013), bilingualism (Bialystok, Craik, Green, & Gollan, 2009; Bialystok & DePape, 2009; Moreno, Wodniecka, Tays, Alain, & Bialystok, 2014), and laterality were controlled (Nettle, 2003; Beratis, Ravabilas, Kyprianou, Papadimitriou, & Papageorgiou, 2013). Table 3.2 details the type of test that was used to measure the control variables.

Table 3.2
Control variables

Control Variable	Test
Education Received*	Level of Education School Type
Music Sophistication	Ollen Music Sophistication Index (Translated)
Laterality	Edinburgh Handedness Inventory (Spanish)
Bilingualism	Questionnaire
Age	Questionnaire
*2 level index	

Age was measured through a simple questionnaire. The socio-economic level was built based on the characteristics of the Chilean population, considering two levels. For the first measurement, the type of school the participants attended was considered (governmental, private subsidized, private), taking into account that some participants had not yet finished higher education. In a second instance, the educational level was considered (high school, technical institute, university, postgraduate). The index was generated with both indicators. Although the sample was previously selected as monolingual, to measure bilingualism the participants were asked about their performance in the four basic language skills (speaking, listening, writing, reading) of a second language, controlling for a second time, giving the characteristics of the snowball sampling. As mentioned before, only one participant considered himself to be proficient in all the basic skills of a second language, and therefore she/he was removed from the study. Laterality was measured with a Spanish version of the Edinburgh Handedness Inventory (Oldfield, 1971), a test designed to measure laterality through surveys and not through behavioural tests.

Procedure

Each participant was measured individually, in a room without noise or light distractors. They were asked not to use cell phones during the tests. Each evaluation lasted an average of one hour and fifteen minutes. To maximize data collection, no pause times were considered between each of the tests. As previously mentioned, after taking the tests, participants were asked if they knew someone who could join the study.

Some participants reached out and others did not. The snowball sampling showed a good result at the end of the process.

Results

Descriptive statistics by group

The following table (4.2) was generated to explore the performance of each group by dependent variable.

Table 4.2
Descriptive statistics data

Dependent variable	Rhythm	Melody	Harmony	Control
Cognitive Inhibition	0.71 (.80)	0.75 (1.02)	0.82 (1.17)	0.12 (.83)
Go/No-Go	0.55 (.27)	0.54 (.28)	0.50 (.23)	0.42 (.28)
Verbal Working Memory	3.46 (.34)	3.66 (.38)	3.68 (.29)	3.11 (.26)
Visuo-Spatial W. Memory	0.51 (.27)	0.49 (.32)	0.59 (.27)	0.44 (.28)
Cognitive Flexibility	0.49 (.29)	0.56 (.28)	0.52 (.25)	0.44 (.30)
Fluid Intelligence	0.50 (.26)	0.53 (.29)	0.59 (.25)	0.41 (.28)
Divided Attention	8.29 (1.06)	8.00 (1.21)	8.29 (1.10)	7.51 (1.63)
Processing Speed	24.37(1.47)	24.40(1.67)	24.58(1.81)	25.85(2.25)

Mean (Standard Deviation)

Analysis of variance for dependent variables

Subsequently, several variance analyses were generated, including the control variables that had to be controlled showing in table 5.2.

Table 5.2
Between groups Ancovas

Dependent variable	df	F	<i>p</i>	η_p^2	π	<i>Reliability</i>
Verbal Working Memory	3	18.08	.000**	.374	.99	.97
Processing Speed	4	28.25	.000**	.274	.99	.83
Cognitive Inhibition	4	4.89	.000**	.154	.98	.71
Fluid intelligence	4	2.65	.025*	.090	.80	.80
Divided Attention	4	2.56	.030*	.087	.78	.69
Go/No-Go	4	1.52	.186	.053	.52	.83
Visuo-Spatial W. Memory	4	1.49	.196	.052	.51	.81
Cognitive Flexibility	3	1.30	.273	.037	.40	.91

*significant at $\alpha < .05$, **significant at $\alpha < .001$

For the verbal working memory and cognitive flexibility variables, age was not controlled, because the tests show the results with that variable previously controlled. Reliability was calculated by Cronbach's alpha.

Post-hoc analysis

Then the differences between groups were analysed, in the variables where significant differences of the ANCOVAS were found, controlling with the correction of Bonferroni (1935), looking for specific differences among the musicians, as the main hypothesis of the study suggests. The following tables and figures show the results.

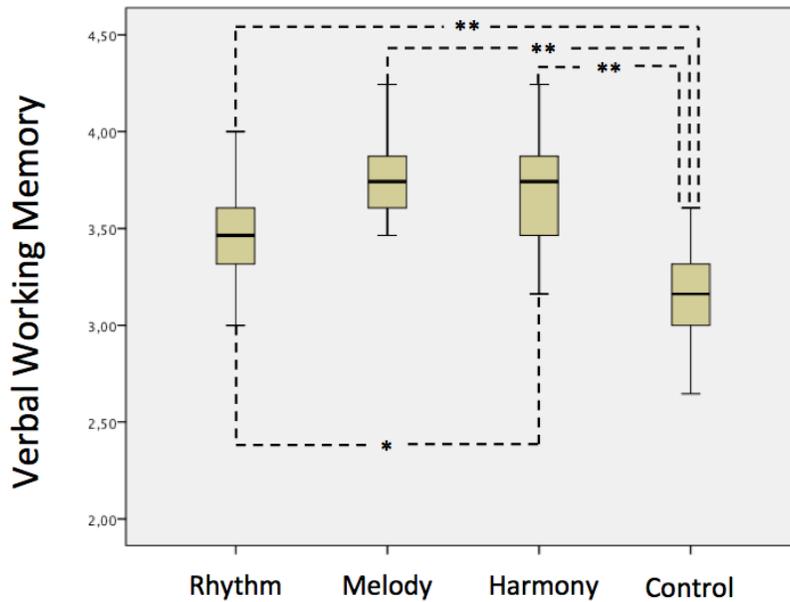
Verbal working memory

Table 6.2

Post-hoc analysis for Verbal Working Memory

Group	Comparison	Mean dif.	Stn. Error	<i>p</i>
Rhythm	Melody	-.198	.076	.060
	Harmony	-.220	.077	.028*
	Control	.354	.077	.000**
Melody	Harmony	-.022	.076	1.00
	Control	.552	.076	.000**
Harmony	Control	.574	.077	.000**

*Significant at $\alpha < .05$, ** significant at $\alpha < .001$



*Significant at $\alpha < .05$, **significant at $\alpha < .001$

Figure 1.2. Differences between groups for Verbal Working Memory

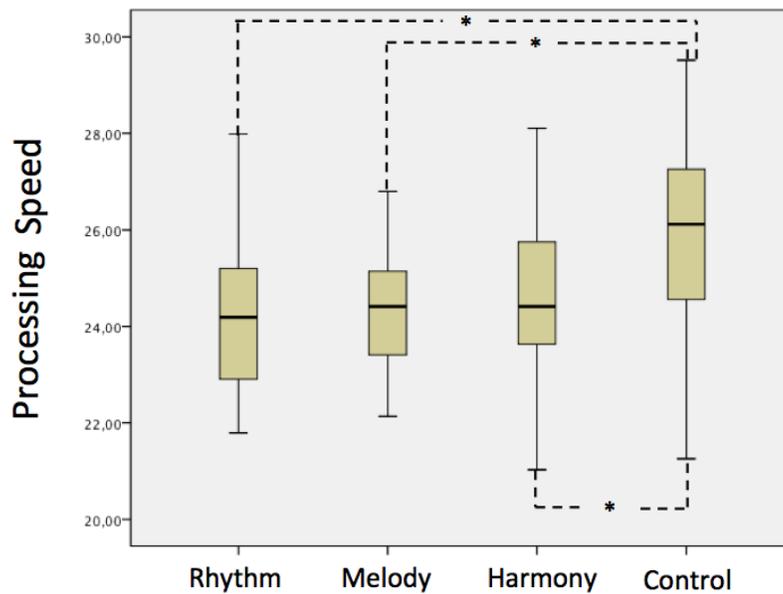
Processing Speed

Table 7.2

Post-hoc analysis for Processing Speed

Group	Comparison	Mean dif.	Stn. Error	<i>p</i>
Rhythm	Melody	-2.25	21.612	1.00
	Harmony	-14.26	21.763	1.00
	Control	-79.91	21.763	.002*
Melody	Harmony	-12.01	21.612	1.00
	Control	-77.67	21.612	.003*
Harmony	Control	-65.66	21.763	.018*

*Significant at $\alpha < .05$



*Significant at $\alpha < .05$

Figure 2.2. Differences between groups for Processing Speed

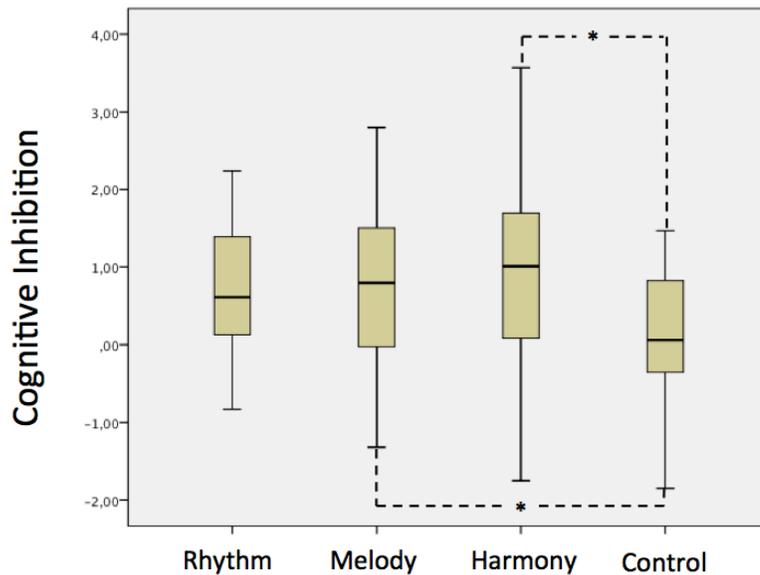
Cognitive inhibition

Table 8.2

Post-hoc analysis for Cognitive Inhibition

Group	Comparison	Mean dif.	Stn. Error	<i>p</i>
Rhythm	Melody	-.082	.233	1.00
	Harmony	-.107	.235	1.00
	Control	.593	.235	.076
Melody	Harmony	-.024	.231	1.00
	Control	.676	.231	.024*
Harmony	Control	.700	.233	.019*

*Significant at $\alpha < .05$



*Significant at $\alpha < .05$

Figure 3.2. Differences between groups for Cognitive Inhibition

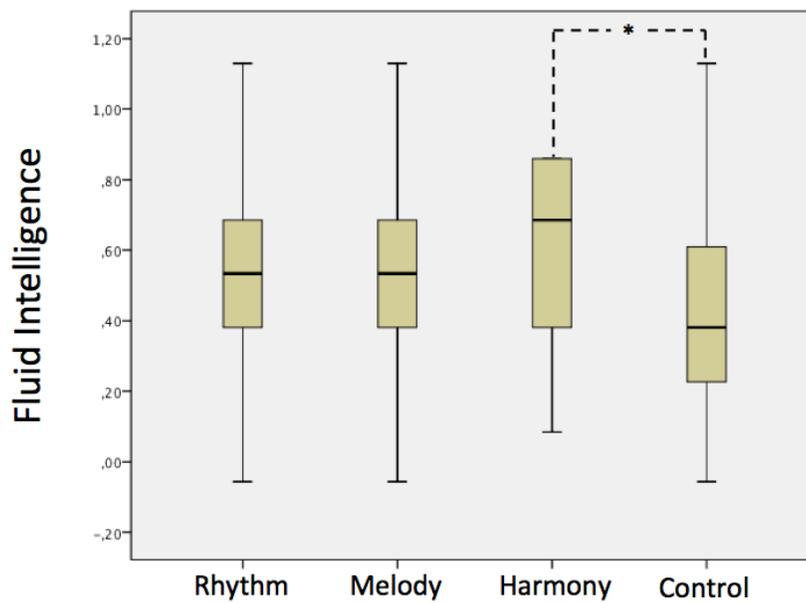
Fluid intelligence

Table 9.2

Post-hoc analysis for Fluid Intelligence

Group	Comparison	Mean dif.	Stn. Error	<i>p</i>
Rhythm	Melody	-.030	.063	1.00
	Harmony	-.086	.064	1.00
	Control	.090	.064	.951
Melody	Harmony	-.057	.063	1.00
	Control	.121	.063	.356
Harmony	Control	.178	.064	.038*

*Significant at $\alpha < .05$



*Significant at $\alpha < .05$

Figure 4.2. Differences between groups for Fluid Intelligence

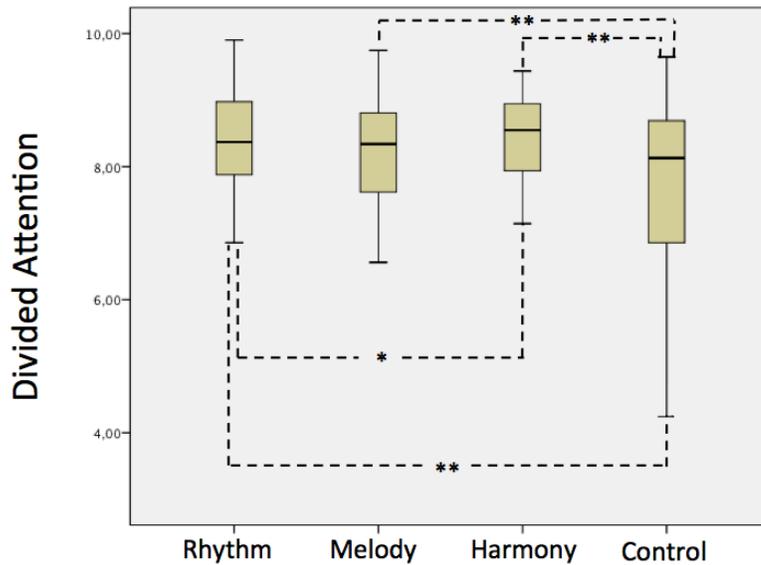
Divided attention

Table 10.2

Post-hoc analysis for Divided Attention

Group	Comparison	Mean dif.	Stn. Error	<i>p</i>
Rhythm	Melody	-.198	.076	0.060
	Harmony	-.220	.064	0.028*
	Control	.354	.064	0.000**
Melody	Harmony	-.022	.076	1.000
	Control	.552	.076	0.000**
Harmony	Control	.574	.076	0.000**

* Significant at $\alpha < .05$, **significant at $\alpha < .001$



*Significant at $\alpha < .05$, **significant at $\alpha < .001$

Figure 5.2. Differences between groups for Divided Attention

In the case of verbal working memory, the differences were significant between musicians and the control group, in favour of the groups with musical training. In the case of the comparison between musicians, the results showed that rhythmic performers differed from harmonic performers in a significant way.

For processing speed, analysis of variance showed significant differences in favour of all groups of musicians compared to the control group. In the case of this variable, there were no significant differences in performance between musicians. The average among all the musicians in processing speed was $X=598.61$ milliseconds ($SD=80.973$), and for the control group $X=673.06$ ($SD=115.204$), showing an advantage in the speed of response to this type of stimuli (go/no-go).

As for cognitive inhibition, there were significant differences in favour of harmonic and melodic musicians, in comparison to the control group, but not for rhythmic musicians, where there was no statistical significance. The findings show that, in this measurement, rhythmic musicians had a similar performance to the control group, and there was no significant cognitive processing advantage, which would mean the performance of a rhythmic musician resembles more that of a non-musician than that of their colleagues who play other instruments.

In the case of fluid intelligence, a single significant difference was shown between the group of harmonic musicians and the control group. These findings suggest that, for this variable, the performance of a rhythmic or melodic musician does not differ from that of a person without musical training, unlike that of the group of harmonic instrumentalists.

Finally, in terms of divided attention, the results show that in all cases there were significant differences between the control group and the musicians, who scored better. In turn, there was a significant difference between the rhythmic and harmonic musicians, with the second group at an advantage, which suggests several levels of performance in divided attention between musicians, and between musicians and non-musicians.

Discussion

The main objective of this study is to show evidence -from the perspective of cognitive psychology- of the difference in the processing of musicians who have different musical training, based on the performance of different aspects of cognition, and the neurological differences in the processing of the three elements of music in the brain.

The findings of this investigation agree with the theoretical and empirical evidence of studies that suggest or show different neurological processes for the elements of music, through the differentiated cognitive performance of rhythmic, melodic and harmonic musicians. Some of these differences are more visible than others, since in some cases there is statistical significance among the musicians while in others there is none. However, these differences are also reflected in comparisons with the control group, which we believe shows at least a trend in the differences proposed in the study.

Considering this framework, and unlike studies that sub group musicians between melodic and rhythmic, such as Slater et al. (2017), our research suggests that

the statistically significant differences would be between the harmonic and rhythmic musicians, where the first group of musicians shows an advantage in verbal working memory and divided attention.

The musical skills required by each instrument vary. The study of some rhythmic instruments for example (drums, Latin percussion, among others) does not involve knowledge in other domains of music such as frequency or musical notes. This does not mean that they are less complex instruments, however, based on the results of the tests administered in this study, it is suggested that the cognitive load of the harmonic instruments is greater than that of the rhythmic instruments, and in part, the differences in performance in favour of harmonic musicians could be explained by that.

Conclusion

Music has an endless number of edges to explore and only a small part was investigated in this study. The findings showed differences in cognitive performance among rhythmic, melodic and harmonic musicians, although, in accordance with the literature in the area, the biggest differences are still in favour of musicians compared to non-musicians.

According to this evidence, future research in this area should consider the type of musical training in musician populations. Finally, it was concluded that the main hypothesis of the study is correct, cognitive performance is not the same among all types of musicians.

Limitations

No musical training is “pure”. The differences between the musical trainings that arise here are based on the hours of solo study each musician had with their instrument, and it becomes difficult, or almost impossible, to control the cognitive stimulation that the performers have in rehearsals with other musicians, where theoretically there would be stimulation of all the elements of music. This aspect suggests contrast to future stimulation in the autonomous work of the musicians, versus the stimulations obtained in group rehearsals.

This study used a battery of tests which was built based on the needs of inquiry in various aspects of cognition, and not a single battery, which brings together, for example, all the measurements of executive functions or intelligence. This characteristic becomes an advantage to open up aspects that have been less explored in the literature, but it also reduces some aspects of its reliability.

References

- Beratis, I. N., Ravabilas, A. D., Kyprianou, M., Papadimitriou, G. N., & Papageorgiou, C. (2013). Investigation of the link between higher order cognitive functions and handedness. *Journal of Clinical and Experimental Neuropsychology*, 35(4), 393-403. doi:10.1080/13803395.2013.778231
- Besson, M., & Faïta, F. (1995). An Event-Related Potential (ERP) Study of Musical Expectancy: Comparison of Musicians With Nonmusicians. *Journal of Experimental Psychology: Human Perception and Performance*, 21(6), 1278-1296. doi:10.1037/0096-1523.21.6.1278
- Bever, T.G., & Chiarello, R.J. (1974). Cerebral dominance in musicians and nonmusicians. *Science*, 185, 537-539. doi:10.1126/science.185.4150.537
- Beyer, R. (1999). *Sounds of our times: two hundred years of acoustics*. Springer Ed.
- Bialystok, E., Craik, F., Green, D., & Gollan, T. (2009). Bilingual minds. *Psychological Science in the Public Interest*, 10(3), 89-129. doi:10.1177/1529100610387084
- Bialystok, E., & DePape, A. (2009). Musical expertise, bilingualism, and executive functioning. *Journal of Experimental Psychology: Human Perception and Performance*, 35(2). doi:10.1037/a0012735
- Bidelman, G., Hutka, S., & Moreno, S. (2013). Tone language speakers and musicians share enhanced perceptual and cognitive abilities for musical pitch: evidence from bidirectionality between the domains of language and music. *PLoS One* 8: e60676. doi:10.1371/journal.pone.0060676
- Bonferroni, C. (1935). Il calcolo delle assicurazioni su gruppi di teste. *Studi in Onore del Professore Salvatore Ortu Carboni*. Rome: Italy, pp. 13-60.
- Braun, J. (1998). Divided Attention: Narrowing the gap between brain and behavior. In: Parasuraman, R., editor. *The Attentive Brain*. Cambridge, Massachusetts: MIT Press. p. 327-351.
- Bugos, J. (2004). The effect of individualized piano instruction on executive functions in older adults (ages 60-85) (Tesis doctoral). De la base de datos de Proquest Dissertation and Theses.
- Cattell, R. (1963). Theory of fluid and crystallized intelligence: A critical experiment. *Journal of Educational Psychology*, 54, 1-22. DOI: 10.1037/h0046743

- Center on the Developing Child at Harvard University, (2011). Building the Brain's "Air Traffic Control" System: How Early Experiences Shape the Development of Executive Function: *Working Paper* (No. 11). Boston. Reviewed for www.developingchild.harvard.edu
- Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Erlbaum.
- Degé, F., Kubicek, C., & Schwarzer, G. (2011). Music lessons and intelligence: a relation mediated by executive functions. *Music Perception*, 29(2), 195-201. doi:10.1525/mp.2011.29.2.195
- Diamond, A. (2013). Executive functions. *Annual review of psychology*, 64, 135. doi:10.1146/annurev-psych-113011-143750
- Emmerich, E., Engelmann, M., Rohmann, M., & Richter, F. (2015). Hearing Impairment in Professional Musicians and Industrial Workers – Profession-Specific Auditory Stimuli Used to Evoke Event-Related Brain Potentials and to Show Different Auditory Perception and Processing. *Update On Hearing Loss*, chapter 7. University of Brasilia. doi:10.5772/59528
- Ericsson, K., Krampe, R., & Tesch-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychology Review*, 100(3). 363-406. doi:10.1037/0033-295X.100.3.363
- Franklin, M., Moore, Y., Jonides, J., Rattray, K., & Moher, J. (2008). The effects of musical training on verbal memory. *Psychology of Music*. 36, 353-365. doi:10.1177/0305735607086044
- George, E., & Coch, D. (2011). Music training and working memory: an ERP study. *Neuropsychologia* 49: 353-365. doi:10.1016/j.neuropsychologia.2011.02.001
- Golden, C. J. (2007). *Stroop test de colores y palabras, manual* (5^o ed.). Madrid: TEA Ediciones.
- Grant, D., & Berg, E. (1948). A behavioral analysis of degree of reinforcement and ease of shifting to new responses in a Weigel-type card-sorting problem. *Journal of Experimental Psychology*, 38, 404-411. doi:10.1037/h0059831
- Hahn, B., Wolkenberg, F., Ross, T., Myers, C., Heishman, S., Stein, D., Kurup, P., & Stein, E. (2008). Divided versus selective attention: evidence for common processing mechanisms. *Brain Research*, 1215. 137-146. doi:10.1016/j.brainres.2008.03.058

- Hanna-Pladdy, B., & MacKay, A. (2011). The relation between instrumental musical activity and cognitive aging. *Neuropsychology*, 25(3), 378–86. doi:10.1037/a0021895
- Heaton, R. (1981). *Wisconsin Card Sorting Test Manual*. Odessa (FL). Psychological Assessment Resource Inc.
- Hetland, L. (2000). Learning to make music enhances spatial reasoning. *Journal of Aesthetics in Education*, 34(3/4), 179-238. doi:10.2307/3333643
- Jaschke, A., Honing, H., & Scheder, E. (2018). Longitudinal Analysis of Music Education on Executive Functions in Primary School Children. *Frontiers in Neuroscience*, 12(103). doi:10.3389/fnins.2018.00103
- Kaganovich, N., Kim, J., Herring, C., Schumaker, J., & MacPherson, M. (2013). Musicians show general enhancement of complex sound encoding and better inhibition of irrelevant auditory changes in music: an ERP study. *European Journal of Neuroscience*, 37, 1295-1307. doi:10.1111/ejn.12110
- Levitin, D. (2006). *This is your Brain on Music: The Science of a Human Obsession*. Dutton/Penguin.
- Liégois-Chauvel, C., Peretz, I., Babai, M., Laguitton, V., & Chauvel, P. (1998). Contribution of different cortical areas in the temporal lobes to music processing. *Brain*, 121(10), 1853-1867. doi:10.1093/brain/121.10.1853
- MacKenzie, C. (1986). Motor skills in music performance: Comments on Sidnell. *Psychomusicology*, 6(1-2), 25-28. doi:10.1037/h0094196
- McGrew, K. (2005). The Cattell-Horn-Carroll (CHC) theory of cognitive abilities. Past, present and the future. In D. Flanagan, & Harrison (Eds.), *Contemporary intellectual assessment. Theories, tests, and issues* (p.136-202). New York. Guilford Press.
- 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), 914–9. doi:10.1177/0956797610373933
- Miyake, A., Friedman, N., Emerson, M., Witzki, A., Howerter, A., & Wager, T. (2000). The unity and diversity of executive functions and their contributions to complex “frontal lobe” tasks: a latent variable analysis. *Cognitive Psychology*, 41(1), 49-100. doi:10.1006/cogp.1999.0734

- Moreno, S., Bialystok, E., Barac, R., Schellenberg, E. G., Cepeda, N. J., y Chau, T. (2011). Short-term music training enhances verbal intelligence and executive function. *Psychological Science*, 22(11), 1425-1433. doi:10.1177/0956797611416999
- Moreno, S., & Farzan, F. (2015). Music and inhibitory control: a multidimensional model. *Annals of the New York Academy of Sciences*, 1337(1). 147-152. doi:10.1111/nyas.12674
- Moreno, S., Wodniecka, Z., Tays, W., Alain, C., & Bialystok, E. (2014). Inhibitory Control in Bilinguals and Musicians: Event Related Potential (ERP) Evidence for Expertise-Specific Effects. *PLoS ONE* 9(4): e94169. doi:10.1371/journal.pone.0094169
- Nettle, D. (2003). Hand laterality and cognitive ability: A multiple regression approach. *Brain and Cognition*, 52(3), 390-398. doi:10.1016/S0278-2626(03)00187-8
- Oldfield, R. (1971). The assessment and analysis of handedness: "The Edinburgh inventory". *Neuropsychologia* 9(1): 97-113. doi:10.1016/0028-3932(71)90067-4
- Ollen, J. (2006). *A Criterion-related Validity Test of Selected Indicators of Musical Sophistication Using Expert Ratings*. (Electronic Thesis of Dissertation). Retrieved from <https://etd.ohiolink.edu/>
- Omahen, D.A., (2009). The 10,000-hour rule and residency training. *Canadian Medical Association Journal*, 180(12), 1272. doi:10.1503/cmaj.090038
- Pallesen, K. J., Brattico, E., Bailey, C. J., Korvenoja, A., Koivisto, J., Gjedde, A., & Carlson, S. (2010). Cognitive control in auditory working memory is enhanced in musicians. *PLoS ONE*, 5(6), e11120. doi:10.1371/journal.pone.0011120
- Parasuraman, R. (1998). *The attentive brain: issues and prospects*. *The Attentive Brain*. Cambridge, Massachusetts: MIT Press.
- Parbery-Clark, A., Skoe, E., Lam, C., & Kraus, N. (2009). Musician enhancement for speech-in-noise. *Ear and Hearing*, 30(6). 653-661. doi:10.1097/AUD.0b013e3181b412e9
- Peretz, I., & Kolinsky, R. (1993). Boundaries of separability between melody and rhythm in music discrimination: A neuropsychological perspective. *Quarterly Journal of Experimental Psychology*, 46A(2). 301-325. doi:10.1080/14640749308401048
- Peretz, I. & Morais, J. (1989). Music and Modularity. *Contemporary Music Review*,

4(1). 279-293. doi:10.1080/07494468900640361

- Petschke, H., Lindner, K., & Rappelsberger, P. (1988). The EEG: An adequate method to concretize brain process elicited by music. *Music Perception*, 6(2). 133-160. doi:10.2307/40285422
- Pretto, M., & James, C. (2015). Principles of Parsimony: fMRI Correlates of Beat-Based Versus Duration-Based Sensorimotor Synchronization. *Psychomusicology*, 25(4). 380-391. doi:10.1037/pmu0000122
- Ramachandra, V., Meighan, C., & Gradzki, J. (2012). The impact of musical training on the phonological memory and the central executive: A brief report. *North American Journal of Psychology*, 14(3), 541-548.
- Riva, D., Cazzniga, F., Esposito, S., & Bulgheroni, S. (2013). Executive functions and cerebellar development in children. *Applied Neuropsychology Child*, 2(2). doi:10.1080/21622965.2013.791092
- Rosas, R. & Santa Cruz, C. (2013). *Dime en qué colegio estudiaste y te dire qué CI tienes: Radiografía al desigual acceso al capital cognitive en Chile*. Ediciones Universidad Católica de Chile.
- Schellenberg, E. G. (2011). Examining the association between music lessons and intelligence. *British Journal of Psychology*, 102(3), 283. doi:10.1111/j.2044-8295.2010.02000.x
- Schmidt-Jones, C. (2014). *The Basic Elements of Music*. Textbook Equity.
- Slater, J., Azem, A., Nicol, T., Swedenborg, B., & Kraus, N. (2017). Variations on the theme of musical expertise: cognitive and sensory processing in percussionists, vocalists and non-musicians. *European Journal of Neuroscience*, 45(7). 952-963. doi:10.1111/ejn.13535
- Slevc, L. R., Davey, N., Buschkuehl, M., & Jaeggi, S. (2016). Tuning the Mind: Exploring the connections between musical ability and Executive Functions. *Cognition* 152(1), 199-211. doi:10.1016/j.cognition.2016.03.017
- Sturm, I., Blankertz, B., & Curio, G. (2017). Multivariate EEG Analysis Reveals Neural Correlates for the Differential Perception of Chord Progressions. *Psychomusicology: Music, Mind and Brain*, 27(4). 281-296. doi:10.1037/pmu0000196
- Sturm, I., Miklody, D., Dähne, S., Treder, M., Purwins, H., Blankertz, B., & Curio, G. (2015). Extracting the Neural Representation of Tone Onsets for Separate Voices of

- Ensemble Music Using Multivariate EEG Analysis. *Psychomusicology: Music, Mind and Brain*, 25(4). 366-379. doi:10.1037/pmu0000104
- Tan, S. L., Pfordresher, P., & Harré, R. (2010). *Psychology of Music: From Sound to Significance*. Psychology Press. New York.
- Tramo, M. (1992). *Brain mechanisms in harmony perception*. Abstract from the Second International Conference on Music Perception and Cognition. Los Angeles.
- Wechsler, D., Rosas, R., Pizarro, M., y Tenorio, M. (2013). *WAIS-IV: Manual de administración y corrección*. NCS Pearson. P. 221.
- Wright, A., & Diamond, A. (2014). An effect of inhibitory load in children while keeping working memory load constant. *Frontiers in Psychology*, (5)213. doi:10.3389/fpsyg.2014.00213
- Zatorre, R. (1983). Category-boundary effects and speeded sorting with a harmonic musical-interval continuum: Evidence for dual processing. *Journal of Experimental Psychology: Human Perception and Performance*, 9(5). 739-752. doi:10.1037/0096-1523.9.5.739
- 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), e99868. doi:10.1371/journal.pone.0099868

3. Third Study

Musical sophistication explains a good deal of cognitive performance.

A cross-sectional study of musicians and non-musicians.

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A cross-sectional study of musicians and non-musicians.

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Title:

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A cross-sectional study of musicians and non-musicians.

Abstract

Musical sophistication is a psychometric construct that can be measured both in people with musical training, and those without. Through backgrounds related to musical activities in their lifetime, and other indicators referring to their current activities, the person's sophistication can be estimated with a relatively high level of reliability. In turn, few studies have covered the relationships between variables of this type and cognitive performance, leaving an area of research with little evidence. This study explores the relationship between musical sophistication and cognition, taking a sample of 36 musicians and 36 non-musicians. The objective was to determine to what extent musical sophistication explains cognitive performance. The Ollen Musical Sophistication Index (Ollen, 2006) was used to measure this variable, and a battery of tests were used for the measurement of cognitive performance, which considered verbal and visuo-spatial working memory, inhibition, flexibility, a go/no-go test, processing speed, fluid intelligence and divided attention. The results show that 6 out of 8 cognitive aspects correlate positively with musical sophistication, and that this explains 26% of cognitive performance, after controlling for demographic variables.

Keywords

Musical sophistication, cognitive performance, executive functions.

Introduction

A variety of evidence shows that music strengthens the development of complex cognitive representations (Koelsch, Rohrmeier, Torrecuso, & Jentschke, 2013; Oeschlin et al., 2013; Oeschlin, Van De Ville, Lazeyras, Hauert, & James, 2013; Patel, 2008). While other studies have shown improved cognitive performance in expert musicians, both in simple aspects, as well as complex aspects. These cognitive advantages can be seen in both near transfer skills and in distant transfer skills (Miendlarzewska & Trost, 2014). It has been shown that children who have received musical training have significant advantages in the cognitive performance of executive functions⁴ (e.g. Jaschke, Honing, & Scherder, 2018; Moreno et al., 2011; Sachs, Kaplan, Der Sakissian, Alissa, & Habibi, 2017), as well as in other aspects of cognition such as intelligence (e.g. Doxey & Wright, 1990; Schellenberg, 2011), phoneme discrimination (Lamb & Gregory, 1993), phonological awareness (e.g. Degé, Kubicek, & Schwarzer, 2011; Moreno et al., 2011), speech perception (Francois & Schön, 2011), and even academic performance (e.g. Schellenberg, 2006; Young, Cordes, & Winner, 2013). Other findings have shown that the musically trained adult and elderly population has similar cognitive advantages to children in executive functions (e.g. Bugos, Perlstein, McCrae, Brophy, & Bedenbaugh, 2007; Franklin, Moore, Jonides, Rattray, & Moher, 2008; Parbery-Clark, Skoe, Lam, & Kraus, 2009), particularly in tasks associated with working memory (Pallesen et al., 2010).

⁴ These are also called cognitive control or executive control (Miyake et al., 2000; Diamond, 2013).

But does cognitive performance vary according to the degree of musical expertise?

Musical expertise has not been satisfactorily defined in the literature. There are definitions according to the extra-curricular training at school (e.g. Degé et al., 2011; Moreno & Farzan, 2015), the musical interpretation of a particular instrument (e.g. Omahen, 2009; Ramachandra, Meighan, & Gradzki, 2012), experiments that only consider listening to music (e.g. Koelsch et al., 2013), and also imaginary studies in music (e.g. Lotze, Scheler, Tan, Braun, & Birbaumer, 2003). These definitions always depend on the design of the research study, and have considered separating expert musicians from inexperienced ones, typically categorizing them as musicians or non-musicians. This lack of a common criterion or Gold Standard measurement in the area has generated a significant weakness in the state-of-the-art with respect to this topic, starting in the 21st century.

Given this background, Ollen (2006) designed the Ollen Musical Sophistication Index (OMSI). This measurement does not seek to define musical expertise, but rather discriminates the level of musical sophistication of the interviewees, using good psychometric data collected through a questionnaire of ten items. The OMSI makes it possible to generate a scale of musical sophistication, according to the diverse musical backgrounds of the participants, considering the age of the individuals, the age of initiation of their musical activity, the number of years that they have received private classes in an instrument, the number of years of practice with their main instrument, the current amount of time invested in playing an instrument or singing, if they have studied

music at the university level, completed courses or degrees in music, their experience as musical composers, their attendance of concerts in the previous year, and their self-perception regarding professionalism in the discipline of music. Thus, the OMSI can determine the level of musical sophistication according to all the factors just mentioned, and deliver an indicator of musical sophistication on a scale of 1 to 1000.

The construction of this measurement instrument was based on previous studies by the same author and validated by expert musicians. From a considerable number of initial indicators, this measurement collected ten items, which are the most relevant in a person's musical trajectory, according to the results of previous research with expert musicians. Another aspect to mention is that the OMSI offers a categorization of people who are consistently sophisticated in music, and others who are not, according to the probability that a music expert would categorize a person, based on their musical background, as either "more musical sophisticated" or "less musical sophisticated". For example, if a participant scores 750 in the OMSI, the probability that an expert would categorize them as more sophisticated in music is $=.75$.

To make the formula, Ollen (2006) proposes a sum, according to the weight of each of the answers given by the participants, calculated logarithmically. According to the author's own data, a constant of -3.513 (logit) is used as a base, and the values presented in the table below are added (table 1.3), according to the participant's answers.

Table 1.3
Ollen Musical Sophistication Index variables factors

Item	Sub-Item	Description	Logit Factor
1	-	Age	.027
2	-	Age at commencement of musical activity	-.026
3	-	Years of private lessons	-.076
4	-	Years of regular practice	.042
5		Current practice	
	a	Rarely practice	0
	b	About 1 hour per month	-.060
	c	About 1 hour per week	-.098
	d	About 15 minutes per day	-.301
	e	About 1 hour per day	-1.211
	f	More than 2 hours per day	-1.528
6	-	Enrolled in music courses (college or university)	N/A
7		Music coursework completed	
	a	None	-.423
	b	1 or 2 NON-major courses	.274
	c	3 or more NON-major courses	-.616
	d	Introductory music program for Bachelor's level work	.443
	e	1 year of full-time coursework in a Bachelor Music degree	.055
	f	2 years of full-time coursework in a Bachelor Music degree	2.801
	g	3+ years of full-time coursework in a Bachelor Music degree	.387
	h	Completion of a Bachelor of Music degree program	1.390
	i	One or more graduate-level music courses or degrees	3.050
8		Experience in music composition	
	a	Never compose music	0
	b	Composed bits and pieces, but never completed a composition	.516
	c	Composed one or more completed compositions, but not performed	1.071
	d	Composed music just in an educational environment	.875
	e	Composed music performed for local audience	.456
	f	Composed music performed for regional or national audience	-1.187
9		Concerts attended in the last 12 months	
	a	None	0
	b	1 to 4	1.839
	c	5 to 8	1.394

	d	9 to 12	1.713
	f	13 or more	1.610
10		Self-description as musician	
	a	Non-musician	0
	b	Music-loving non-musician	-.553
	c	Amateur musician	.328
	d	Serious amateur musician	1.589
	e	Semiprofessional musician	1.460
	f	Professional musician	2.940

Since the interpretation based on logarithms can be confusing, a probability of prediction (P) is proposed through the following formula: $P = e^{Logit} / (1 + e^{Logit})$, where e = logarithmic natural base (approximately 2.718). As previously stated, if the result is higher than .50, the probability that an expert would categorize the participant as “more musical sophisticated” is more than 50%. The scale from 1 to 1000 delivered by the survey is an expression of the prediction probability within that range. The survey is available online at the following link: <http://marcs-survey.uws.edu.au/OMSI/index.php>

Unlike other tests used in the 20th century (e.g. Bentley, 1966; Gordon, 1989; Law & Zentner, 2012; Seashore, Lewis, & Saetveit, 1960; Wallentin, Nielsen, Friis-Olivarius, Vuust, & Vuust, 2010; Wing, 1962), the OMSI does not measure musical ability in a behavioural way, understood as playing a musical instrument or singing (Hallam & Prince, 2003) or as the musical talent associated with playing an instrument (Levitin, 2012). Nor does it measure musicality, typically associated with the emotional aspects that music can evoke (e.g. Gembris, 1999; Revesz, 1953). This characteristic of the OMSI is what allows it to measure the musical sophistication of musician and non-musician participants, i.e. people more sophisticated in music (> 500 points) or people

less sophisticated in music (<500 points), and in turn, discriminate within each of these groups on a scale of 500 points (each group).

On the other hand, there is robust evidence showing improved cognitive processing in the population with music training (e.g. Bugos, Perlstein, McCrae, Brophy, & Bedenbaugh, 2007; Degé et al., 2011; Franklin et al., 2008; Moreno et al., 2011; Miendlarzewska & Trost, 2014; Pallesen et al., 2010; Parbery-Clark et al., 2009; Zuk, et al., 2014). In the case of Slevc, Davey, Buschkuehl, and Jaeggi (2016), there is a clear relationship between musical ability in auditory discrimination, the level of sophistication and musical ability, and the relationships of these variables with executive functions. Their study shows that the greater the musical ability, the better the performance in some variables, such as working memory in auditory and visual aspects. Similarly, Müllensiefen, Gingras, Musil, and Stewart (2014) propose that musical sophistication, observable through individual musical backgrounds (such as those measured by the OMSI), can show differences in the cognitive system of both musicians and non-musicians. Although there are precedents that show diverse relationships between these variables, few studies have investigated the associations of musical sophistication with cognitive performance, both in complex cognitive processes (such as executive functions), and in simpler processes.

Among the factors that benefit from musical training are executive functions, understood as the ability to control and regulate our thoughts and behaviours. It is a concept that is used in a general way to describe several sub-processes of human cognition (Miyake et al., 2000; Diamond, 2013). Within these sub-processes, there are

three that have a more important relevance in one's lifetime: inhibition, working memory and flexibility (Diamond, 2013). Inhibition is understood as the ability to direct behaviours, thoughts, attention and emotions, thereby cancelling the internal predispositions of the individual and the external predispositions from the environment (Diamond, 2013). Working memory is understood as the ability to operate with a number of short-term mental representations. This ability allows decoding incoming information in an auditory channel, as well as in written systems or numerical symbolization (visual) in stages of learning (Baddeley & Hitch, 2010; Hoffman, Gschwendner, Friese, Wiers, & Schmitt, 2008; Santa Cruz & Rosas, 2017). Flexibility is understood as the ability to change problem-solving strategies in the face of new situations. It allows us to observe situations from more than one point of view, or to get rid of previously conceived ideas (Diamond, 2013). There are other cognitive aspects associated with music training. Fluid intelligence is understood as the ability to perceive relationships between new stimuli, independent of a specific practice or instruction regarding these same stimuli. It is associated, in turn, with the resolution of problems in emergent situations (Cattell, 1963). Processing speed is understood as the ability to perform simple cognitive tasks, in a repetitive, fast and fluid manner. It is a secondary skill compared to other aspects of cognition, although it has established itself as a good predictor of performance in complex cognitive tasks (McGrew, 2005). Divided attention is understood as the ability to execute more than one task simultaneously (Hahn et al., 2008), dividing or rapidly changing the attentional focus (Parasuraman, 1998). Although there are no specific studies for divided attention and musical training, the areas of the

nervous system associated with this ability are similar to those stimulated when hearing or interpreting music (e.g. Besson & Faïta, 1995; Levitin, 2006; Petsche, Lindner, & Rappelsberger, 1988; Pretto & James, 2015; Riva, Cazzniga, Esposito & Bulgheroni, 2013). As previously mentioned, all the cognitive aspects described here have been related to an improvement in performance, in a population that has had musical training, compared to people who have not received this type of training.

The objective of this study is to determine how much musical sophistication explains cognitive performance, in a balanced sample of people with and without musical training. To carry this out, various indicators of cognitive performance were considered, such as verbal working memory, visuo-spatial working memory, cognitive inhibition, a go/no-go test, cognitive flexibility, processing speed, fluid intelligence and divided attention, and musical sophistication was measured with the OMSI.

Method

Participants

In order to generate a balanced sample between musician and non-musician participants, we included 36 musical performers consistently sophisticated in music, and 36 not consistently sophisticated in music, who were monolingual and had an average age of 30.5 years old ($SD=6.38$). 31.9% of the participants were women.

The participants signed an informed consent form before the measurement, approved by the Research Ethics and Security Unit of Pontificia Universidad Católica de

Chile, respecting national and international regulations for research in Social Sciences.

The participants received no incentives of any kind for their participation in the study.

Instruments

The following test battery was administered to measure cognitive performance (Table 2.3).

Table 2.3
Battery test

Dependent Variable	Test	Test Type
Cognitive Flexibility	Wisconsin Card Sorting Test	Form
Verbal Working Memory	Digit Span (WAIS-IV)	Form
Cognitive Inhibition	Stroop Test	Form
Go/No-Go	Cats & Dogs (YellowRed)	Tablet
Visuospatial Working Memory	Binding (YellowRed)	Tablet
Divided Attention	Divided Attention (HAL2)	Tablet
Fluid Intelligence	FIX (HAL2)	Tablet
Processing Speed	Cats & Dogs (YellowRed)	Tablet

A Spanish translated version of the OMSI test was administered to measure musical sophistication. The test showed reliability similar to the original psychometric data (original $\alpha = .78$, present study $\alpha = .77$)⁵.

Cognitive flexibility was measured with an index that considered the variables of perseverative responses, perseverative errors, non-perseverative errors, completed categories, and learning to learn from the Wisconsin Card Sorting Test (Grant and Berg, 1948; Heaton, 1981). Verbal working memory was measured with an index of the three

⁵ Cronbach's Alpha

conditions of Digit Span (direct, inverse and sequence), a sub-test of the Wechsler Adult Intelligence Scale (WAIS-IV; Wechsler, Rosas, Pizarro, & Tenorio, 2013). Cognitive inhibition was measured with the Stroop Test, an index for its three conditions, in 45 seconds (Golden, 2007). Visuo-spatial working memory was measured in a Tablet with Binding, YellowRed sub-test, designed in the UC Development Centre of Inclusion Technologies (CEDETi UC). In this test, participants must remember drawings associated with numbers, which are presented on a screen. Then, on a second screen, the drawings appear in a different order, and the numbers are presented between distractors (other numbers). The participants must drag the number to the corresponding drawing. The test progressively increases the difficulty level, and has a cut-off criterion when the participant makes three consecutive mistakes. Cats & Dogs, YellowRed subtest, was used to measure go/no-go (CEDETi UC). This test is based on Hearts & Flowers (Wright & Diamond, 2014), and the participants respond to the same paradigm. The three test conditions (congruent, incongruent and random stimuli) were administered, although only the third condition (random stimuli) was considered for data analysis. Divided attention was measured with a sub-test of HAL2 (CEDETi UC) on a tablet. This test considers the resolution of two tasks simultaneously. The first task is to slide a finger up or down on one side of the tablet, as odd or even numbers appear. Simultaneously (task 2), the participant has to visually follow the trajectory of red circles that are in movement within an octagon, along with blue circles (distractors). After a few seconds, the red circles change to the colour of the distractors (blue) and continue moving. Afterwards, both tasks stop, and the circles are stopped on the screen.

Once they are stopped, the participant must mark on the tablet the circles that were initially red. When the participants were able to do both tasks simultaneously and satisfactorily this was considered a correct answer, i.e. there were no errors in swiping and the circles were marked correctly. Fluid intelligence was measured with FIX, a sub-test of HAL2 (CEDETi UC) on a tablet. In this test, 2x2 matrices with different designs are presented, where the lower right space is always empty. Participants should select the answer they consider correct from a set of 5 alternatives (1 correct, 4 distractors), choosing the piece that adequately completes the design. The test has 10 items, and the gross value of the correct answers of each participant was considered to generate the index. Processing speed was measured with Cats & Dogs (CEDETi UC). The sum of the response speed of the 33 items of the last test condition (random) was used, i.e., the sum of all responses from the moment the stimulus appears on the screen until the participant presses with their finger. The time is recorded in milliseconds on the tablet.

Measuring control variables

The age of the participants was recorded through a questionnaire. Given the relationship between education in Chile, socio-economic level and cognitive performance (Rosas & Santa Cruz, 2013), an index of socio-economic level was generated that considered the type of school they graduated from (3 levels), and the current educational level (4 levels) of the participants. Laterality was controlled through the Edinburgh Handedness Inventory (Bryden, 1977; Oldfield, 1971) in Spanish, according to the findings of Nettle (2003), Powell, Kemp, and García-Finaña, (2012)

and Beratis, Ravabilas, Kyprianou, Papadimitriou, and Papageorgiou (2013), which show different performances for left-handed and right-handed people in terms of cognitive performance, in populations with and without musical training.

Procedure

The tests were administered in 2018 in Chile, in the cities of Santiago, Punta Arenas, Frutillar and Valparaíso. A single session was conducted with each participant, which lasted an average of 75 minutes. There were no noise or light distractors in the rooms during the measurements. Once the data was collected, it was analysed with SPSS version 24.

Results

The following descriptive data are shown cognitive measures for musicians, non-musicians, and all participants (table 3.3).

Table 3.3
Descriptive data for cognitive measures

Dependent variable	Musicians	Non-musicians	All participants
Verbal working memory	3.68(.32)	3.11(.26)	3.40(.41)
Cognitive inhibition	.84(1.07)	.12(.83)	.48(1.02)
Go/No-Go	.61(.22)	.42(.28)	.52(.27)
Processing Speed	24.84(1.33)	25.85(2.25)	25.34(1.90)
Divided Attention	8.31(.69)	7.51(1.63)	7.92(1.30)
Fluid Intelligence	.55(.30)	.41(.28)	.48(.30)
Cognitive Flexibility	.57(.31)	.44(.30)	.51(.31)
Visuo-spatial working memory	.58(.28)	.44(.28)	.49(.28)

Mean(standard deviation)

The variable of processing speed was inverted, considering that at a lower value the participants obtain a better performance. Subsequently, the correlations of musical sophistication with all dependent variables were analysed (Table 4.3).

Table 4.3
Correlations between musical sophistication and dependent variables

Dependent variable	<i>r</i> (Pearson)
Verbal Working Memory	.670**
Cognitive Inhibition	.383**
Go/No-Go	.383**
Processing Speed	.307**
Divided Attention	.331*
Fluid Intelligence	.269*
Cognitive Flexibility	.198
Visuo-spatial Working Memory	.177

*significant at $p < 0.05$, **significant at $p < 0.001$

Significant correlations were observed between musical sophistication and all dependent variables, except for cognitive flexibility and visuo-spatial working memory.

In order to determine how many factors could reduce cognitive performance, an exploratory factor analysis was performed, with all the variables that obtained significant correlations with musical sophistication. The maximum likelihood estimator was used, as suggested by Fabrigar, Wegener, MacCallum, and Strahan (1999) for this type of analysis with normal data distribution. The result showed just one factor in cognitive performance (table 5.3).

Table 5.3
Exploratory factor analysis for variables correlated with musical sophistication

Dependent Variable	Factor
Cognitive Inhibition	.558
Processing Speed	.545
Verbal Working Memory	.472
Go/No-Go	.455
Fluid Intelligence	.452
Divided Attention	.362

The data were calculated in a single factor (sum), with the objective of executing a two steps regression model. According to the control variables that can explain cognitive performance, in step 1, age, socio-economic level and laterality were included. In step 2, musical sophistication was included with the aim of determining how much variance this variable contributes to the single factor of cognitive performance. The results are shown in Table 6.3.

Table 6.3
Two steps regression model for cognitive performance

Variable	β	ΔR^2	gl	t	p
Step 1					
Age	-6,631	.144	3	-2.33	.034*
Socio-economic level					
Laterality					
Step 2					
Musical Sophistication	.005	.260	1	5.33	.000**

*Significant at $\alpha < .05$, **significant at $\alpha < .001$

In the first step, age, socio-economic status, and laterality show a change in r -square $=.144$ over the cognitive performance factor. Then, in step 2, musical sophistication explains 26% of the variance of the single factor of cognitive performance, after controlling the other variables that have an effect. This effect over the cognitive factor giving by musical sophistication was significant (also the control variables).

Discussion

The relationships between musical training and cognitive performance have been widely explored, in most cases, through studies comparing people with and without musical training, according to different definitions of this training, which depend on the research designs and the age range of the participants. The results tend to show that this type of training is favourable for cognition, although there is still a variety of contradictory evidence for some variables.

In our research, we chose to look at the relationship between musical sophistication and performance in executive functions, processing speed, fluid intelligence and divided attention. Musical sophistication correlated with verbal working memory, cognitive inhibition, go/no-go test, processing speed, fluid intelligence and divided attention. A balanced sample of musicians and non-musicians was tested, responding to paradigms such as those proposed by Ollen (2006), Musil, Elnusauri, and Müllensiefen (2013), and Müllensiefen et al. (2014), in which it is shown that musical

sophistication can be measured both: in populations with instrumental music training, and in people without this training.

The test we used was the Ollen Musical Sophistication Index, which, through a ten-item questionnaire, was able to satisfactorily discriminate these two types of populations. As previously mentioned, the original data of the test showed a Cronbach's alpha =.78, and in our case, the instrument -translated into Spanish- showed a similar reliability (=.77). In this way, our research also contributes as a validation of the Spanish questionnaire, given the high reliability shown by the test to measure a relatively new construct in the literature.

Finally, the data from this study show that musical sophistication and cognitive performance are widely related. Musical sophistication explained 26% of the variance in cognitive performance in people who were consistently and not consistently sophisticated in music. This evidence agrees with the findings of Slevc et al. (2016), which state that musical ability explains part of some variables of cognitive performance such as working memory, expanding the measurement paradigm of this type of variable to the entire population, and not only to people with musical training.

Conclusion

Musical sophistication is not exclusive to musicians and can be measured by activities related to the discipline in many other aspects, which do not necessarily correspond to playing a musical instrument. This sophistication, in turn, has a clear

relationship with cognitive performance, explaining an important part of its variance (26%). Even the typical control variables explained less variance in the cognitive factor (14.4%). Some aspects of executive functions were included, as well as other cognitive aspects. Our findings suggest that, however small a person's musical sophistication maybe, this variable is relevant in their cognition.

References

- Baddeley, A., & Hitch, G. (2010). Working Memory. *Scholarpedia*, 5(2). 3015. doi:10.4249/scholarpedia.3015
- Bentley, A. (1966). *Bentley measures of musical abilities*. London: Harrap.
- Beratis, I. N., Ravabilas, A. D., Kyprianou, M., Papadimitriou, G. N., & Papageorgiou, C. (2013). Investigation of the link between higher order cognitive functions and handedness. *Journal of Clinical and Experimental Neuropsychology*, 35(4), 393-403. doi:10.1080/13803395.2013.778231
- Besson, M., & Faïta, F. (1995). An Event-Related Potential (ERP) Study of Musical Expectancy: Comparison of Musicians With Nonmusicians. *Journal of Experimental Psychology: Human Perceptions and Performance*, 21(6). 1278-1296. doi:10.1037/0096-1523.21.6.1278
- Bryden, M. P. (1977). Measuring handedness with questionnaires. *Neuropsychologia*, 15(4), 617-624.
- Bugos, J., Perlstein, W., McCrae, C., Brophy, T., & Bedenbaugh, P. (2007). The effect of individualized piano instruction on executive functions in older adults. *Aging and Mental Health*, 11(4). 464-471. doi:10.1080/13607860601086504
- Cattell, R. (1963). Theory of fluid and crystallized intelligence: A critical experiment. *Journal of Educational Psychology*, 54(1). 1-22. doi:10.1037/h0046743
- Degé, F., Kubicek, C., & Schwarzer, G. (2011). Music lessons and intelligence: a relation mediated by executive functions. *Music Perception*, 29(2), 195-201.
- Diamond, A. (2013). Executive functions. *Annual review of psychology*, 64, 135. doi:10.1146/annurev-psych-113011-143750
- Doxey, C., & Wright, C. (1990). An exploratory study of children's music ability. *Early Childhood Research Quarterly*, 5(3). 425-440. doi:10.1016/0885-2006(90)90031-U
- Fabrigar, L., Wegener, T., MacCallum, R., & Strahan, E. (1999). Evaluating the Use of Exploratory Factor Analysis in Psychological Research. *Psychological Methods*, 4(3). 272-299. doi:10.1037/1082-989X.4.3.272
- Francois, C., & Schön, D. (2011). Musical Expertise Boosts Implicit Learning of Both Musical and Linguistic Structures. *Cerebral Cortex*, 21(10). 2357-2365. doi:10.1093/cercor/bhr022

- Franklin, M., Moore, Y., Jonides, J., Rattray, K., & Moher, J. (2008). The effects of musical training on verbal memory. *Psychology of Music*, 36, 353-365. doi:10.1177/0305735607086044
- Gembris, H. (1999). Historical phases in the definition of “musicality”. *Psychomusicology*, 16, 17-25.
- Golden, C. J. (2007). *Stroop test de colores y palabras, manual* (5° ed.). Madrid: TEA Ediciones.
- Gordon, E. (1989). *Advanced measures of music audiation*. Chicago: Riverside Publishing Company.
- Grant, D., & Berg, E. (1948). A behavioral analysis of degree of reinforcement and ease of shifting to new responses in a Weigel-type card-sorting problem. *Journal of Experimental Psychology*, 38, 404-411.
- Heaton, R. (1981). *Wisconsin Card Sorting Test Manual*. Odessa (FL). Psychological Assessment Resource Inc.
- Han, B., Wolkenberg, F., Ross, T., Myers, C., Heishman, S., Stein, D., Kurup, P., & Stein, E. (2008). Divided versus selective attention: evidence for common processing mechanisms. *Brain Research*, 1215, 137-146. doi:10.1016/j.brainres.2008.03.058
- Hallam, S., & Prince, V. (2003). Conceptions of musical ability. *Research Studies in Music Education*, 20, 2-22. doi:10.1177/1321103X030200010101
- Hoffman, W., Gschwendner, T., Friese, M., Wiers, R., & Schmitt, M. (2008). Working memory capacity and self-regulatory behavior: toward an individual differences perspective on behavior determination by automatic versus controlled processes. *Journal of Personality and Social Psychology*, 95(4), 962-977. doi:10.1037/a0012705
- Jaschke, A., Honing, H., & Scherder, E. (2018). Longitudinal Analysis of Music Education on Executive Functions in Primary School Children. *Frontiers in Neuroscience* 12(103). doi:10.3389/fnins.2018.00103
- Koelsch, S., Rohrmeier, M., Torrecuso, R., & Jentschke, S. (2013). Processing of hierarchical syntactic structure in music. *Proceedings of the National Academy of Sciences*, 110(38), 15443–8. doi:10.1073/pnas.1300272110

- Lamb, S., & Gregory, A. (1993). The Relationship between Music and Reading in Beginning Readers. *Educational Psychology*, 13(1). 19-27. doi:10.1080/0144341930130103
- Law, L., & Zentner, M. (2012). Assessing musical abilities objectively: Construction and validation of the Profile of Music Perception Skills. *PLoS ONE*, 7(12): e52508. doi:10.1371/journal.pone.0052508
- Levitin, D. (2006). *This is your Brain on Music: The Science of a Human Obsession*. Dutton/Penguin.
- Levitin, D. (2012). What does it mean to be musical?. *Neuron* 73. 635-637. doi:10.1016/j.neuron.2012.01.017
- Lotze, M., Scheler, G., Tan, H., Braun, C., & Birbaumer, N. (2003). The musician's brain: functional imaging of amateurs and professionals during performance and imagery. *NeuroImage*, 20(3). 1817-1829. doi:10.1016/j.neuroimage.2003.07.018
- McGrew, K. S. (2005). The Cattell-Horn-Carroll (CHC) theory of cognitive abilities. Past, present and future. In D. Flanagan, & Harrison (Eds.), *Contemporary intellectual assessment. Theories, tests, and issues* (p.136-202). New York. Guilford Press.
- Miendlarzewska, E., & Trost, W. (2014). How musical training affects cognitive development: rhythm, reward and other modulating variables. *Frontiers in Neuroscience*, 7(279). doi:10.3389/fnins.2013.00279
- Miyake, A., Friedman, N. P., Emerson, M. J., Witziki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology*, 41(1), 49-100. doi:10.1006/cogp.1999.0734
- Moreno, S., Bialystok, E., Barac, R., Schellenberg, E. G., Cepeda, N. J., y Chau, T. (2011). Short-term music training enhances verbal intelligence and executive function. *Psychological Science*, 22, 1425-1433. doi:10.1177/0956797611416999
- Moreno, S., & Farzan, F. (2015). Music training and inhibitory control: a multidimensional model. *Annals of the New York Academy of Sciences*, 1337(1), 147-152. doi:10.1111/nyas.12674
- Müllensiefen, D., Gingras, B., Musil, J., & Stewart, L. (2014). The Musicality of Non-Musicians: An Index for Assessing Musical Sophistication in the General Population. *PLoS ONE* 9(2): e89642. doi:10.1371/journal.pone.0089642

- Musil, J., Elnusairi, B., & Müllensiefen, D. (2013). Perceptual Dimensions of Short Audio Clips and corresponding Timbre Features. In Aramaki M., Barthelet M., Kronland-Mrtinet R., Ystad, S. (Eds.). From Sounds to Music and Emotions. CMMR 2012. *Lecture Notes in Computer Science*, (7900). Springer, Berlin, Heidelberg. doi:10.1007/978-3-642-41248-6_12
- Nettle, D. (2003). Hand laterality and cognitive ability: A multiple regression approach. *Brain and Cognition*, 52(3), 390-398. doi:10.1016/S0278-2626(03)00187-8
- Oeschlin, M. S., Descloux, C., Croquelois, A., Chanal, J., Van de Ville, D., Lazeyras, F., & James C. (2013). Hippocampal volumen predicts fluid intelligence in musically trained people. *Hippocampus* 23, 552-558. doi:10.1002/hipo22120
- Oechslin, M. S., Van De Ville, D., Lazeyras, F., Hauert, C.-A., & James, C. E. (2013). Degree of musical expertise modulates higher order brain functioning. *Cerebral Cortex*, 23(9), 2213–24. doi:10.1093/cercor/bhs206
- Omahen, D. (2009). The 10.000-hour rule and residency training. *Canadian Medical Association Journal*, 180(12), 1272. doi:10.1503/cmaj.090038
- Oldfield, R. C. (1971). The assesment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia*, 9, 97-113.
- Ollen, J. (2006). A criterion-related validity test of selected indicators of musical sophistication using expert ratings. (Electronic Thesis or Dissertation). Retrieved from <https://etd.ohiolink.edu/>
- Pallesen, K. J., Brattico, E., Bailey, C. J., Korvenoja, A., Koivisto, J., Gjedde, A., & Carlson, S. (2010). Cognitive control in auditory working memory is enhanced in musicians. *PloS one*, 5(6), e11120. doi:10.1371/journal.pone.0011120
- Parasuraman, R. (1998). The attentive brain: issues and prospects. In: Parasuraman, R., editor. *The Attentive Brain*. Cambridge, Massachusetts: MIT Press. p. 3-15.
- Parbery-Clark, A., Skoe, E., Lam, C., y Kraus, N. (2009). Musician enhancement for speech-in-noise. *Ear and Hearing*, 30, 653-661. doi:10.1097/AUD.0b013e3181b412e9
- Patel, A. (2008). Music, Language and the Brain. *Oxford University Press*.
- Petschke, H., Lindner, K., & Rappelsberger, P. (1988). The EEG: An adequate method to concretize brain process elicited by music. *Music Perception*, 6. 133-160.
- Powell, J. L., Kemp, G. J., & García-Finaña, M. (2012). Association between language

- and spatial laterality and cognitive ability: an fMRI study. *NeuroImage*, 59(2), 1818-1829. doi:10.1016/j.neuroimage.2011.08.040
- Pretto, M., & James, C. (2015). Principles of Parsimony: fMRI Correlates of Beat-Based Versus Duration-Based Sensorimotor Synchronization. *Psychomusicology*, 25(4), 380-391. doi:10.1037/pmu0000122
- Ramachandra, V., Meighan, C., & Gradzki, J. (2012). The impact of musical training on the phonological memory and the central executive: A brief report. *North American Journal of Psychology*, 14(3), 541-548.
- Revesz, G. (1953). *Introduction to the Psychology of Music*, London: Longmans.
- Riva, D., Cazzniga, F., Esposito, S., y Bulgheroni, S. (2013). Executive functions and cerebellar development in children. *Applied Neuropsychology Child*, 2(2). doi:10.1080/21622965.2013.791092
- Rosas, R. & Santa Cruz, C. (2013). *Dime en qué colegio estudiaste y te diré qué CI tienes: Radiografía al desigual acceso al capital cognitivo en Chile*. Ediciones Universidad Católica de Chile.
- Sachs, M., Kaplan, J., Der Sakissian, Alissa, & 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
- Santa Cruz, C., & Rosas, R. (2017). Mapping of Executive Functions / Cartografía de las Funciones Ejecutivas. *Estudios de Psicología*, 38(2). 284-310. doi:10.1080/02109395.2017.1311459
- Schellenberg, E. (2006). Long-Term Positive Associations Between Music Lessons and IQ. *Journal of Educational Psychology*, 98(2). 457-468. doi:10.1037/0022-0663.98.2.457
- Schellenberg, E. (2011). Examining the association between music lessons and intelligence. *British Journal of Psychology*, 102 (3), 283. doi:10.1111/j.2044-8295.2010.02000.x
- Seashore, C., Lewis, D., & Saeveit, J. (1960). *Seashore measures of musical talent*. New York: The Psychological Corporation.
- Slevc, L. R., Davey, N., Buschkuhl, M., & Jaeggi, S. (2016). Tuning the Mind: Exploring the connections between musical ability and Executive Functions.

Cognition 152(1), 199-211. doi:10.1016/j.cognition.2016.03.017

- Wallentin, M., Nielsen, A., Friis-Olivarius, M., Vuust, C., & Vuust, P. (2010). The musical ear test, a new reliable test for measuring musical competence. *Learning and Individual Differences*, 20(3), 188-196. doi:10.1016/j.lindif.2010.02.004
- Wechsler, D., Rosas, R., Pizarro, M., y Tenorio, M. (2013). *WAIS-IV: Manual de administración y corrección*. NCS Pearson. P. 221.
- Wing, H. (1962). *Wing standardized tests of musical intelligence*. Windsor: National Foundation for Educational Research.
- Wright, A., & Diamond, A. (2014). An effect of inhibitory load in children while keeping working memory load constant. *Frontiers in Psychology*, 5, 213. doi:10.3389/fpsyg.2014.00213
- Young, L., Cordes, S., & Winner, E. (2013). Arts involvement predicts academic achievement only when the child has a musical instrument. *Educational Psychology*, 34(7). doi:10.1080/01443410.2013.785477
- 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), e99868.

General Discussion

The main objective of the three studies included in this thesis was to explore the relationships between instrumental musical training and cognition. Among the cognitive aspects included, there are some executive functions, such as verbal and visuo-spatial working memory, cognitive inhibition, a go/no-go test, cognitive flexibility, and also other aspects of cognition such as fluid intelligence, processing speed and divided attention. On the music side, we worked exclusively with adult musical performers, that is, with legal age people who are experts at playing musical instruments, validated based on their musical sophistication. Other types of paradigms were excluded, such as experimental research, which are typically applied for music appreciation and the resolution of simultaneous cognitive tasks. This was due to the fact that one of the main hypotheses of the thesis is that musicians do not have similar neurological stimulations in their training, and this characteristic is only reflected in the autonomous study of the performers. In this way, the three studies presented are an exploration and description guide of the effects of playing a musical instrument on the cognitive aspects previously mentioned, in the adult population.

The impact that music has on cognition was covered from several angles. In the first study, this was done by comparing the cognitive performance of musicians versus non-musicians, as it is typically done in studies of these research areas. However, this thesis makes a contribution to these areas of study through the way in which it measured cognitive skills. On the one hand, in order to replicate and support the data of other studies, traditional tests for the measurement of cognitive variables were used in some

cases (verbal working memory, inhibition and cognitive flexibility). Following this line, it can be seen that in the measurements of executive functions that corresponded to traditional measurements, the variables of verbal working memory and cognitive inhibition were the only ones that showed differences in the musicians/non-musicians comparison. As for cognitive flexibility, which is also considered in this framework as an executive function, it was not possible to find a difference between musicians and non-musicians with the constructed index. On the other hand, in the less typical measurements, tests that are relatively new in the literature were included, which explore in a more daring way the cognitive constructs involved in this study. The variables that were measured with non-habitual tests, and that showed differences in favour of the musicians versus the control group, were processing speed, fluid intelligence, the go/no-go test and divided attention. However, the visuo-spatial working memory test -administered on a tablet- showed no differences between these groups. According to the data presented, these findings show that the cognitive advantages given by playing a musical instrument go beyond executive functions, and are measurable with various types of tests. In the case of the tests of the second group, which are relatively new in the literature, they proved to have good reliability, in addition to discriminating satisfactorily in both musicians and non-musicians.

Within other areas, although the original design of this thesis did not consider measuring motor aspects, three of the dependent variables are related in some way to these skills. By way of discussion, I would like to present qualitatively and quantitatively what I was able to discover regarding this type of skills when analysing

the data. The first case is that of cognitive flexibility. The index constructed for the thesis with the Wisconsin Card Sorting Test (WCST) showed no different results between musicians and non-musicians (study one), nor between musicians (study two). However, in the literature review, differences were found in Trail Making Tests, which were declared as a measure of cognitive flexibility in various studies of different age ranges. One possible explanation for this contradictory evidence is that musical training considers the development of motor aspects, and that in comparison to non-musician groups, these advantages could be reflected in this type of test (Trail Making Test), but not in others such as the WCST, because the second does not include a motor aspect. Another point of view to analyse this problem is to question whether or not Trail Making Tests measure cognitive flexibility, or if they should only be used for the measurement of skills such as psycho-motor speed. Certainly, by contrasting this contradictory evidence, an interesting line of research to investigate in populations of musicians of different age ranges emerges. The second component that had a motor aspect in its measurement was processing speed. The indicator used in this thesis to measure this variable was the response in milliseconds of each of the stimuli of the go/no-go test. This motor component included the use of the index fingers of both hands. With almost all musical instruments, the use of both hands is necessary (using only one would be limiting), and even, in some percussion instruments, the use of all the extremities is required. As a musician, I do not find it strange that my colleagues performed better in this variable, since in the case of many musical instruments, it is necessary to make a variety of large and small body movements while playing. This can be easily seen in

string instruments, which require pressing the string with one hand and then (milliseconds later) striking the string with the other, in order to create the sound at the exact moment. It is a repetitive and easy task, which with practice and time, can become an automatic motor response. As an anecdotal fact of this variable, in a conversation after collecting data from one of the musicians, he stated that he called those automatic responses “muscle memory”. Future research could be done on this phenomenon, looking at which movements musical performers automate, and how much this type of response contributes to their cognitive performance. A final motor aspect was seen in the divided attention test. Like the test that measured processing speed, the divided attention test required the use of both hands. Therefore, and considering the assumptions of the motor aspects in musicians in this section, it is not surprising that all of the musician groups scored significantly better than the control group (study 1). However, the group of harmonic musicians showed significant differences in performance in comparison with the rhythmic group (study 2). This exploratory finding could be explained given that the performers of the harmonic group were pianists and guitarists, which requires a degree of fine motor skills, greater than that of the rhythmic group (drummers, orchestra percussionists, Latin percussionists), since the training for harmonic instruments requires in all cases the use of the fingers, unlike the rhythmic group, which requires a greater management of the extremities, leaving aside skills specific to fine motor skills. In this way, the bibliographic review and the evidence gathered in this thesis show the reason why musicians have advantages in tasks of simple motor order, given that the musical

exercise itself, necessarily stimulates cognitive and motor aspects. Future studies should investigate these relationships.

Furthermore, the findings shown in study 2 suggest that there might be a hierarchy of cognitive complexity in musicians, depending on whether their training is rhythmic, melodic or harmonic. This was reflected in several ways, according to the data presented in this thesis. The group of harmonic musicians is the only one that has significant and favourable differences in fluid intelligence in comparison with the control group, and in turn, shows better performance than the rhythmic musicians in verbal working memory and divided attention (significant differences). This harmonic group would be particularly favoured under this point of view. Moreover, in the variable of cognitive inhibition, there were differences in favour of the harmonic and melodic musicians, versus the control group. However, these differences were not seen in the rhythmic musicians and non-musicians. Certainly, the results show that musical, rhythmic, melodic and harmonic training have an effect on cognition, where the rhythmic group does not have that much advantage, the melodic one has a little more, and the harmonic leads the list. At the same time, this evidence agrees interdisciplinarily, given that the study of harmony is the most complex from the discipline of music, and typically, in music training programs, harmony is presented in the curriculum after the students show a handling of rhythm and melody. In other words, it is possible to state that there is an order of complexity in the elements of music, which require the development of different motor and cognitive skills, supported by evidence that showed a lower cognitive performance for rhythmic musicians, a medium

performance for melodic musicians, and the highest cognitive performance in harmonic musicians. These results were of an exploratory nature, given that, in one of the hypotheses of the thesis, differences between musicians were raised, but not a specific performance position for these three groups. Thus, future research on this topic should consider special measurements, which separate the independent variables by the elements of music, and if possible, extend the measurements to the cognitive and motor scopes for the analysis of their results.

Another way to investigate the relationship between musical interpretation and cognition is to analyse musical sophistication and its effect on cognitive performance. In this thesis, we chose to measure this variable, and not musical ability or musicality (for review of these concepts: Gembris, 1997; Levitin, 2012), given its characteristic of a psychometric and non-aesthetic construct measurable through musical background using a form and not through behavioural tests. In this case, the test showed a Cronbach's alpha very similar to that reported by the author of the original test (original =.78, thesis =.77). In the case of the original data (from Ollen's OMSI), the test was validated in the United States more than ten years ago. In this thesis, no variations were made in the items, scales or responses of the original test. A Spanish translation was made, and it was used in the Chilean population years after the original validation. In the literature referring to these areas, it has been practically impossible to generate a Gold Standard test that measures constructs like this one. However, the fact that this test has a similar reliability in a different culture and time, would suggest that the OMSI could be considered a type of Gold Standard measurement for the construct of musical

sophistication. At the same time, the test made it possible to discriminate musical sophistication between musicians (which was expected), but also in the non-musician population. This discrimination in non-musicians is based on the background of concert attendance, on having taken a choir or appreciation course at the undergraduate level, previous musical studies in their lifetime (like having played a musical instrument as a child), among other variables, which allowed for showing how much musical sophistication explains verbal working memory, cognitive inhibition, go/no-go, processing speed, divided attention and fluid intelligence. In this way, one of the conclusions of study 3 is that each person has a level of musical sophistication, which, even if it is small, has an effect on their cognitive performance (26% of the explained variance in the cognitive performance factor). Thus, the cognitive effects are not the same for a non-musician who has not had any relationship with the discipline compared to a person who does not play a musical instrument, but who is in contact with music or was during their lifetime. Given the results of this thesis, musical sophistication is a possible variable to explore more deeply in future studies.

The relationship between musical interpretation and cognitive performance was explored from several methodological points. In this way, the three studies that are part of this thesis made it possible to observe the important effect that music has on cognition. The investigation showed differences in the cognitive performance of musicians and non-musicians. It also revealed that performers do not share the same cognitive performance characteristics (given the basic elements of music). And finally,

there is evidence that musical sophistication, however small, has an important effect on cognition for people with and without musical training.

On the other hand, parallel to the three studies, demographic variables were included, which according to the literature review, could have an effect on cognitive performance in musicians and non-musicians. Within these variables, age, socio-economic level, bilingualism and laterality were included. As control variables, they were integrated in the analysis of variance of studies one and two, which made it possible to increase the effect in the differences, as shown by the various preliminary analyses. However, for the preliminary regression analysis of study 3, these control variables were integrated one by one, in order to understand all the effects musical sophistication had on cognition. In these cases, the data showed that, at least with the sample collected in this thesis, laterality did not have significant effect on cognition based on performance alone. This is different from age and socio-economic level, given that together they accounted for 10.9% of the variance in cognitive performance ($p=.000$). However, as previously mentioned with regards to laterality, instrumental musical training requires, practically in all cases, the use of both hands. The survey used to measure laterality is designed for all types of populations, but in the case of music, there are some specializations in the use of hands that the survey is not able to measure, given that according to the design of musical instruments, it becomes more complex to determine if the musicians are left-handed, right-handed, or even ambidextrous. In other words, the strings of a guitar or bass can be inverted, adjusting to left-handed performers, but other instruments do not allow this modification, such as the piano, or

the string instruments of the orchestra (i.e. violin, viola, violoncello, double bass). Thus, although the laterality measurement scale had a dichotomous separation (right-handed/left-handed), in many cases there were musicians who showed tendencies close to the centre, unlike the control group, where the participants were more towards the extremes. Qualitatively, a small group of left-handed musicians said that with the questions included in the survey, it was not possible to show their skills in both hands (4 participants). Thus, the data presented here show the need to thoroughly understand the laterality of the musical performers, given that the instruments have a tendency to be built for right-handed musical performance. Although it was not the objective of this thesis, it was not possible with the data of this study to determine if laterality had important effect on cognition for populations of musicians. This evidence is contradictory to some findings, which show that this variable may be relevant in this type of study.

Limitations and future avenues of research

This thesis included cross-sectional studies. However, one of the weaknesses of the literature is that there is a lack of a longitudinal understanding of the cognitive and musical aspects reviewed here. Specifically for children, the variables that can affect cognitive development, such as music, in some cases show contradictory findings, which generate the need to better understand these factors in cognitive performance. Due to time limitations, this research study was not able to design an investigation of the effect of long-term musical training in children (e.g. 1,000, 5,000 or 10,000 hours of training) nor have an intervention specifically designed for the study, and controlled with another type of training. This becomes a weakness and an opportunity for future research, in projects that can include a greater amount of time in their designs.

Within the specific area of the musical discipline, there is a population of musicians, namely composers, that has not been studied in cognitive psychology. In the state-of-the-art, you can find many definitions for this craft, however, responding to the definition of “music” used in this thesis, composers would be the people who design musical works, sorting sounds and silences. In the design of a piece of music, the elements of music are integrated in different ways, which requires the absolute management of each of these components. This population should be targeted in future research, given that theoretically, there could be a high cognitive performance in composers, according to the evidence presented here regarding the elements of music. In the future, even more specific comparisons could be made, taking a sample of composers that play musical instruments, and others that do not, and looking for

differences in cognitive performance (although it is hard to believe that there are composers who do not play instruments).

Two other limitations in this thesis are the measurements of laterality, and the non-measurement of specific motor aspects, which are presented in an inferential manner, and could be combined in a single test. In the first case, laterality, the test served as a control. However, what can be observed with the data of this measurement is that in populations of musicians, it would be correct to measure this variable with behavioural tests, which at the same time, include motor aspects, considering an adequate difficulty for these populations. Thus, from a paradigm like that, measuring this type of variable, and their associations with cognitive performance. Unfortunately, in the current state-of-the-art, there is no specially designed test to simultaneously measure both constructs. However, this creates an opportunity for the development of a tool to measure these factors and population.

Finally, there are many factors that music can offer to the discipline of psychology that were not covered in this thesis. No aesthetic, social, or emotional aspects were considered. In fact, the emotional aspect could be linked to studies like the ones covered here. Future research studies could investigate the neurological bases that stimulate emotions, and the association of emotional inhibitory control that musicians have. This could possibly explain part of their cognitive performance. From the discipline of music, an example for this variable (inhibition) is singers, who should inhibit their emotions when performing in front of an audience, because their interpretation may be affected otherwise (their voice could “crack”). Paradoxically, this

allows them to be more expressive in their interpretation, as they are in control of their emotions, which often generates a transmitting effect in the audience. At first glance, it seems to be a kind of emotional musician/listener transfer, but depending on the areas of the brain that are associated with the musical practice, the cognitive, emotional and musical aspects could be related to each other, and reflected with quantitative data. Although this feature is not specific to music (it is present in the performing arts in general), researching this would undoubtedly be a contribution to all these areas of scientific knowledge and the world of the arts.

References

- Adólfssdóttir, S., Haász, J., Wehling, E., Ystad, M., Lundervold, A., & Lundervold, A. J. (2014). Salient measures of inhibition and switching are associated with frontal lobe gray matter volume in healthy middleaged and older adults. *Neuropsychology*, 28(6), 859–869. doi:10.1037/neu0000082
- Altenmüller, E., Gruhn, W., Parlitz, D., & Liebert, G. (2000). The impact of music education on brain networks: Evidence from EEG-studies. *International Journal of Music Education*, 35(1), 47-53. doi:10.1177/025576140003500115
- Barenboim, D. (1992). *A Life in Music*. Scribner (1st Ed.).
- Beratis, I. N., Ravabilas, A. D., Kyprianou, M., Papadimitriou, G. N., & Papageorgiou, C. (2013). Investigation of the link between higher order cognitive functions and handedness. *Journal of Clinical and Experimental Neuropsychology*, 35(4), 393-403. doi:10.1080/13803395.2013.778231
- Besson, M., & Faïta, F. (1995). An Event-Related Potential (ERP) Study of Musical Expectancy: Comparison of Musicians With Nonmusicians. *Journal of Experimental Psychology: Human Perception and Performance*, 21(6), 1278-1296. doi:10.1037/0096-1523.21.6.1278
- Bever, T.G., & Chiarello, R.J. (1974). Cerebral dominance in musicians and nonmusicians. *Science*, 185(1), 537-539. doi:10.1126/science.185.4150.537
- Bhide, A., Power, A., & Goswami, U. (2013). A rhythmic musical intervention for poor readers: A comparison of efficacy with a letter-based intervention. *Mind, Brain, and Education*, 7(2), 113-123. doi:10.1111/mbe.12016
- Bialystok, E., & DePape, A. (2009). Musical expertise, bilingualism, and executive functioning. *Journal of Experimental Psychology: Human Perception and Performance*, 35(2). doi:10.1037/a0012735
- Bialystok, E., Craik, F., Green, D., & Gollan, T. (2009). Bilingual Minds. *Psychological Science in the Public Interest*, 10(3), 89-129. doi:10.1177/1529100610387084
- Bowmer, A., Mason, K., Knight, J. & Welch, G. (2018). Investigating the Impact of a Musical Intervention on Preschool Children’s Executive Functions. *Frontiers in Psychology*, 9(2389). doi:10.3389/fpsyg.2018.02389
- Bugos, J., Perlstein, W., McCrae, C., Brophy, T., & Bedenbaugh, P. (2007). Individualized piano instruction enhances executive functioning and working

- memory in older adults. *Aging & Mental Health* 11(4). 464-471. doi:10.1080/13607860601086504
- Bugos, J., & DeMarie, D. (2017). The effects of a short-term music program on preschool children's executive functions. *Psychology of Music*, 45(6). 855–867. doi:10.1177/0305735617692666
- Center on the Developing Child at Harvard University, (2011). Building the Brain's "Air Traffic Control" System: How Early Experiences Shape the Development of Executive Function: *Working Paper* (No. 11). Boston. Retrieved from www.developingchild.harvard.edu
- Costa-Giomi, E. (2006). Does music instruction improve fine motor abilities? *Annals of the New York Academy of Sciences*, 1060(1). 262-264. doi:10.1196/annals.1360.053
- Custodio, N., & Cano-Campos, M. (2017). Efectos de la música sobre las funciones cognitivas. *Revista de Neuropsiquiatría*, 80(1). 60-69. doi:10.20453/rnp.v80il.3060
- Degé, F., Kubicek, C., & Schwarzer, G. (2011). Music lessons and intelligence: a relation mediated by executive functions. *Music Perception*, 29(2), 195-201. doi:10.1525/mp.2011.29.2.195
- Doxey, C., & Wright, C. (1990). An exploratory study of children's music ability. *Early Childhood Research Quarterly*, 5(3). 425-440. doi:10.1016/0885-2006(90)90031-U
- Dumont, E., Syurina, E., Feron, F., & van Hooren, S. (2017). Music interventions and child development: a critical review and further directions. *Frontiers in Psychology*, 8(1). 1694. doi:10.3389/fpsyg.2017.01694
- Emmerich, E., Engelmann, M., Rohmann, M., & Richter, F. (2015). Hearing Impairment in Professional Musicians and Industrial Workers – Profession-Specific Auditory Stimuli Used to Evoke Event-Related Brain Potentials and to Show Different Auditory Perception and Processing. *Update On Hearing Loss*, chapter 7. University of Brasilia. doi:10.5772/59528
- Fajardo, C. (2010). Nuevas representaciones artísticas, otros receptores. *Aisthesis*, 47. 284-295. doi:10.4067/S0718-71812010000100020
- Fitzpatrick, K. (2006). The effect of instrumental music participation and socioeconomic status on Ohio Fourth-, Sixth-, and ninth-grade proficiency test performance. *Journal of Research in Music Education*, 54(1). 73–84. doi:10.1177/002242940605400106

- Forgeard, M., Winner, E., Norton, A., & Schlaug, G. (2008). Practicing a musical instrument in childhood is associated with enhanced verbal ability and non-verbal reasoning. *PLoS One*, 3(10). doi:10.1371/journal.pone.0003566
- Fraisse, P., Oléron, G., & Paillard, J. (1958). On the Sensory Cues That Permit Control of Movements Accompanying Periodic Stimuli. Translated by Repp, B. (2012). *Psychomusicology: Music, Mind and Brain*, 22(1). 77-83. doi:10.1037/a0028759
- Francois, C., & Schön, D. (2011). Musical expertise boosts implicit learning of both musical and linguistic structures. *Cerebral Cortex*, 21(10). 2357–2365. doi:10.1093/cercor/bhr022
- Franklin, M.S., Moore, K.S., Yip, C.Y., Jonides, J., Rattray, K., & Moher, J. (2008). The effects of musical training on verbal memory. *Psychology of Music*. 36(3). 353-365. doi:10.1177/0305735607086044
- Fuster, J. (2013). Cognitive Functions of the Prefrontal Cortex. *Frontiers in Human Neurociencie*, 4(1). 11-22. doi:10.3389/conf.fnis.2010.1400001
- Gaser, C., & Schlaug, G. (2003). Brain Structures Differ between Musicians and Non-Musicians. *The Journal of Neuroscience*, 23(27). 9249-9245. doi:10.1523/JNEUROSCI.23-27-09240.2003
- Gembris, H. (1997). Historical phases in the definition of musicality. *Psychomusicology*, 16(1-2). 17-25. doi:10.1037/h0094070
- Gray, J., Chabris, C., & Braver, T. (2003). Neural mechanisms of general fluid intelligence. *Nature Neurosciencie*, 6(3). 316-322. doi:10.1038/nn1014
- Hallam, S. (2001). The development of metacognition in musicians: Implications for education. *British Journal of Music Education*, 18(1). 27-39. doi:10.1017/S0265051701000122
- Hodges, D. A., & Sebald, D. C. (2011). *Music in the Human Experience: An Introduction to Music Psychology*. Routledge, New York.
- Hyde, K., Lerch, J., Norton, A., Forgeard, M. Winner, E., Evans, S., & Schlaug, G. (2009). Musical training shapes structural brain development. *Journal of Neuroscience*, 29(10). 3019-3025. doi:10.1523/JNEUROSCI.5118-08-2009
- Jäncke, L. (2009). Music drives brain plasticity. *Biology Reports*, 1(78). doi:10.3410/B1-78
- Jaschke, A., Honing, H., & Scherder, E. (2018). Longitudinal analysis of music

- education on executive functions in primary school children. *Frontiers in Neuroscience*, 12(103). doi:10.3389/fnins.2018.00103
- Kaganovich, N., Kim, J., Herring, C., Schumaker, J., & MacPherson, M. (2013). Musicians show general enhancement of complex sound encoding and better inhibition of irrelevant auditory changes in music: an ERP study. *European Journal of Neuroscience*, 37(8). 1295-1307. doi:10.1111/ejn.121110
- Koelsch, S., Rohrmeier, M., Torrecuso, R., & Jentschke, S. (2013). Processing of hierarchical syntactic structure in music. *Proceedings of the National Academy of Sciences*, 110(38), 15443–8. doi:10.1073/pnas.1300272110
- Krampe, R. & Ericsson, A. (1996). Maintaining Excellence: Deliberate Practice and Elite Performance in Young and Older Pianists. *Journal of Experimental Psychology*, 125(4). 331-359. doi:10.1037/0096-3445.125.4.331
- Lamb, S., & Gregory, A. (1993). The relationship between music and Reading in beginning readers. *Educational Psychology*, 13(1). 19–27. doi:10.1080/0144341930130103
- Lavelle, D. (1983). *Latin & American dances*. Pitman Publishers.
- Levitin, D. (1994). Absolute memory for musical pitch: Evidence from the production of learned melodies. *Perception & Psychophysics*, 56(4). 414-423. doi:10.3758/BF03206733
- Levitin, D. (2006). *This is your Brain on Music: The Science of a Human Obsession*. Dutton/Penguin.
- Levitin, D. (2012). What Does It Mean to Be Musical? *Neuron*, 73(4). 633-637. doi:10.1016/j.neuron.2012.01.017
- Levitin, D., Grahm, J., & London, J. (2018). The Psychology of Music: Rhythm and Movement. *Annual Review of Psychology*, 69(13). 13-25. doi:10.1146/annurev-psych-122216-011740
- Lezak, M., Howieson, D., Bigler, E., & Tranel, D. (2012). *Neuropsychological assessment* (5th ed.). New York, NY: Oxford University Press.
- Liégeois-Chauvel, C., Peretz, I., Babai, M., Laguitton, V., & Chauvel, P. (1998). Contribution of different cortical areas in the temporal lobes to music processing. *Brain*, 121(10). 1853-1867. doi:10.1093/brain/121.10.1853
- MacKenzie, C. (1986). Motor skills in music performance: Comments on Sidnell.

Psychomusicology, 6(1-2). 25-28. doi:10.1037/h0094196

- Magistro, D., Takeuchi, H., Kashkouli, K., Taki, Y., Sekiguchi, A., Nouchi, R., et al. (2015). The Relationship between Processing Speed and Regional White Matter Volume in Healthy Young People. *PLoS ONE*, 10(9). e0136386 doi:10.1371/journal.pone.0136386
- Matthews, T., Thibodeau, J., Gunther, B., & Penhune, V. (2016). The impact of instrument-specific musical training on rhythm perception and production. *Frontiers in Psychology*, 7(69). doi:10.3389/fpsyg.2016.00069
- Miendlarzewska, E., & Trost, W. (2014). How musical training affects cognitive development: rhythm, reward and other modulating variables. *Frontiers in Neuroscience*, 7(279). doi:10.3389/fnins.2013.00279
- Moreno, S., Bialystok, E., Barac, R., Schellenberg, E. G., Cepeda, N. J., & Chau, T. (2011). Short-term music training enhances verbal intelligence and executive function. *Psychological Science*, 22(11). 1425-1433. doi:10.1177/0956797611416999
- Moreno, S., Marques, C., Santos, A., Santos, M., Castro, S., & Besson, M. (2009). Musical training influences linguistic abilities in 8-year-old children: more evidence for brain plasticity. *Cerebral Cortex*, 19(3). 712–723. doi:10.1093/cercor/bhn120
- Müllensiefen, D., Gingras, B., Musil, J., & Stewart, L. (2014). The Musicality of Non-Musicians: An Index for Assessing Musical Sophistication in the General Population. *PLoS ONE* 9(2): e89642. doi:10.1371/journal.pone.0089642
- Nettle, D. (2003). Hand laterality and cognitive ability: A multiple regression approach. *Brain and Cognition*, 52(3), 390-398. doi:10.1016/S0278-2626(03)00187-8
- Norton, A., Winner, E., Cronin, K., Overy, K., Lee, D., & Schlaug, G. (2005). Are there pre-existing neural, cognitive, or motoric markers for musical ability? *Brain and Cognition*, 59(2). 124-134. doi:10.1016/j.bandc.2005.05.009
- Oechslin, M. S., Van De Ville, D., Lazeyras, F., Hauert, C. A., & James, C. E. (2013). Degree of musical expertise modulates higher order brain functioning. *Cerebral Cortex*, 23(9), 2213–24. doi:10.1093/cercor/bhs206
- Oechslin, M. S., Descloux, C., Croquelois, A., Chanal, J., Van de Ville, D., Lazeyras, F., & James C. (2013). Hippocampal volumen predicts fluid intelligence in musically trained people. *Hippocampus* 23(7). 552-558. doi:10.1002/hipo22120
- Ollen, J. (2006). A criterion-related validity test of selected indicators of musical

- sophistication using expert ratings. (Electronic Thesis or Dissertation). Retrieved from <https://etd.ohiolink.edu/>
- Orlandini, L. (2012). La interpretación musical. *Revista Música Chilena*, (218). 77-81.
- Pallesen, K. J., Brattico, E., Bailey, C. J., Korvenoja, A., Koivisto, J., Gjedde, A., & Carlson, S. (2010). Cognitive control in auditory working memory is enhanced in musicians. *PloS one*, 5(6), e11120. doi:10.1371/journal.pone.0011120
- Parbery-Clark, A., Skoe, E., Lam, C., & Kraus, N. (2009). Musician enhancement for speech-in-noise. *Ear and Hearing*, 30(6). 653-661. doi:10.1097/AUD.0b013e3181b412e9
- Patel, A. D. (2008). *Music, Language and the Brain*. Oxford University Press.
- Pelinsky, R. (2005). Corporeidad y experiencia musical. *Revista Transcultural de Música*, 9(1).
- Peretz, I. (2001). Listen to the Brain: A Biological Perspective on musical Emotions. In *Music and Emotion. Theory and Research*. Justin & Sloboda (eds.). 105-134. Series in affective science, Oxford.
- Peretz, I., & Kolinsky, R. (1993). Boundaries of separability between melody and rhythm in music discrimination: A neuropsychological perspective. *Quarterly Journal of Experimental Psychology*, 46A(2). 301-325. doi:10.1080/14640749308401048
- Peretz, I. & Morais, J. (1989). Music and Modularity. *Contemporary Music Review*, 4(1). 279-293. doi:10.1080/07494468900640361
- Petschke, H., Lindner, K., & Rappelsberger, P. (1988). The EEG: An adequate method to concretize brain process elicited by music. *Music Perception*, 6.(2) 133-160. doi:10.2307/40285422
- Plack, C., Oxenham, A., Fay, R., & Popper, A. (2005). *Pitch: Neural Coding and Perception*. New York: Springer.
- Powell, J. L., Kemp, G. J., & García-Finaña, M. (2012). Association between language and spatial laterality and cognitive ability: an fMRI study. *NeuroImage*, 59(2), 1818-1829. doi:10.1016/j.neuroimage.2011.08.040
- Pretto, M., & James, C. (2015). Principles of Parsimony: fMRI Correlates of Beat-Based Versus Duration-Based Sensorimotor Synchronization. *Psychomusicology*, 25(4). 380-391. doi:10.1037/pmu0000122

- Randel, D. M. (2003). *The Harvard Dictionary of Music*. Harvard University Press.
- Riva, D., Cazzniga, F., Esposito, S., & Bulgheroni, S. (2013). Executive functions and cerebellar development in children. *Applied Neuropsychology Child, 2*(2). doi:10.1080/21622965.2013.791092
- Rosas, R. & Santa Cruz, C. (2013). *Dime en qué colegio estudiaste y te dire qué CI tienes: Radiografía al desigual acceso al capital cognitive en Chile*. Ediciones Universidad Católica de Chile.
- Ruscheweyh, R., Deppe, M., Lohmann, H., Wersching, H., Korsukewitz, C., Duning, T., et al. (2013). Executive performance is related to regional gray matter volume in healthy older individuals. *Human Brain Mapping, 34*(12), 3333–3346. doi:10.1002/hbm.22146
- Rushworth, M., Passingham, R., & Nobre, A. (2005). Componentes of Attentional Set-switching. *Experimental Psychology, 52*(2). 83-98. doi:10.1027/1618-3169.52.2.83
- 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). When the music's over. Does music skill transfer to children's and young adolescent's cognitive and academic skills? A meta-analysis. *Educational Research Review, 20*(1). 55-67. doi:10.1016/j.edurev.2016.11.005
- Schellenberg, E. (2006). Long-term positive associations between music lessons and IQ. *Journal of Educational Psychology, 98*(2). 457-468. doi:10.1037/0022-0663.98.2.457
- Schellenberg, E. (2011). Examining the association between music lessons and intelligence. *British Journal of Psychology, 102*(3), 283. doi:10.1111/j.2044-8295.2010.02000.x
- Schlaug, G. (2015). Musicians and music making as a model for the study of brain plasticity. *Progress in Brain Research, 217*(1). 37-55. doi:10.1016/bs.pbr.2014.11.020
- Schmidt-Jones, C. (2014). *The Basic Elements of Music*. Textbook Equity Edition.
- Silvia, P., Thomas, K., Nusbaum, E., Beaty, R., & Hodges, D. (2016). How Does Music Training Predict Cognitive Abilities? A Bifactor Approach to Musical Expertise and Intelligence. *Psychology of Aesthetics, Creativity, and the Arts, 10*(2). 184-190. doi:10.1037/aca0000058

- Steinberg, R., Stiltz I., & Rondot, P. (1992). EEG-Mapping during Music Stimulation. *Psychomusicology*, 11(2). 157-170. doi:10.1037/h0094123
- Sturm, I., Blankertz, B., & Curio, G. (2017). Multivariate EEG Analysis Reveals Neural Correlates for the Differential Perception of Chord Progressions. *Psychomusicology: Music, Mind and Brain*, 27(4). 281-296. doi:10.1037/pmu0000196
- Sturm, I., Miklody, D., Dähne, S., Treder, M., Purwins, H., Blankertz, B., & Curio, G. (2015). Extracting the Neural Representation of Tone Onsets for Separate Voices of Ensemble Music Using Multivariate EEG Analysis. *Psychomusicology: Music, Mind and Brain*, 25(4). 366-379. doi:10.1037/pmu0000104
- Tramo, M. (1992). *Brain mechanisms in harmony perception*. Abstract from the Second International Conference on Music Perception and Cognition. Los Angeles.
- Vuoskoski, J., Gatti, E., Spence, C., & Clarke, E. (2016). Do Visual Cues Intensify the Emotional Responses Evoked by Musical Performance? A Psychophysiological Investigation. *Psychomusicology: Music, Mind and Brain*. 26(2). 179-188. doi:10.1037/pmu0000142
- Wechsler, D. (2002). *WPPSI-III administration and scoring manual*. San Antonio, TX: Psychological Corp.
- Wechsler, D., Rosas, R., Pizarro, M., & Tenorio, M. (2013). WAIS-IV: Manual de administración y corrección. NCS Pearson. P. 221.
- Wechsler, D. (1955). *Manual for the Wechsler Adult Intelligence Scale*. NewYork: Psychological Corp.
- Young, L. N., Cordes, S., and Winner, E. (2014). Arts involvement predicts academic achievement only when the child has a musical instrument. *Educational Psychology: An International Journal of Experimental Educational Psychology*, 34(7). 849–861. doi:10.1080/01443410.2013.785477
- Zatorre, R. (1983). Category-boundary effects and speeded sorting with a harmonic musical-interval continuum: Evidence for dual processing. *Journal of Experimental Psychology: Human Perception and Performance*, 9(5). 739-752. doi:10.1037/0096-1523.9.5.739
- 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), e99868. doi:10.1371/journal.pone.0099868



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ACTA DE APROBACIÓN ÉTICA DEL COMITÉ ÉTICO CIENTÍFICO DE CIENCIAS SOCIALES, ARTES Y HUMANIDADES

Miembros del Comité

Sra. María Elena Gronemeyer Forni, Presidenta del CEC, Profesora de la Facultad de Comunicaciones UC

Sra. Alejandra Santana López, secretaria ejecutiva y ministro de fe del Comité UC

Sra. Carolina Altimir Colao, profesora de la Facultad de Ciencias Sociales UC

Sra. Inés Contreras Valenzuela, profesora de la Facultad de Educación UC

Sra. Natalia Hernández Mary, trabajadora social, integrante externo

Srta. Javiera Farías Soto, abogada, integrante externo

Sr. Antonio Mladinic Alonso, profesor de la Facultad de Ciencias Sociales UC

Sra. Paulina Ramos Vergara, abogada, profesora de la Facultad de Medicina UC

Sr. Ignacio Villegas Vergara, profesor de la Facultad de Artes UC

Sr. Andrew Webb, profesor de la Facultad de Ciencias Sociales UC

Participaron en la aprobación del protocolo titulado: Entrenamiento Musical y desempeño en Funciones Ejecutivas.

Investigador responsable: Felipe Porflitt Becerra.

Institución: Facultad de Ciencias Sociales, Pontificia Universidad Católica de Chile

Categoría: Tesista de Doctorado

Académico responsable: Ricardo Rosas Díaz

Institución: Facultad de Ciencias Sociales, Pontificia Universidad Católica de Chile

Categoría: Profesor Titular

Financiamiento: Tesis Doctoral

ID Protocolo: 170925009

Documentos revisados y aprobados por el comité:



ACTA DE APROBACIÓN ÉTICA DEL COMITÉ ÉTICO CIENTÍFICO DE CIENCIAS SOCIALES, ARTES Y HUMANIDADES

- Protocolo de evaluación ética de ciencias sociales, artes y humanidades
- Consentimiento informado
- Afiche
- Sub test
- Cuestionario muestra
- Modelo carta de autorización director de establecimiento
- Modelo carta de autorización de Vicerrector de Investigación VRI UC
- Proyecto de tesis
- Compromiso del investigador

Considerando:

- 1.- Que las metodologías, según se describe en el proyecto, aparecen como apropiadas a los objetivos y que en ellas se siguen los estándares internacionales al respecto,
- 2- Que los investigadores aludidos ya tienen experiencia realizando este tipo de estudios,
- 3- Que en toda la información entregada al público invitado a participar se evita entrar en detalles que podrían producir un sesgo o predisponer a los entrevistados a responder de una determinada manera (al hacerles explícitos los objetivos de la investigación, por ejemplo) dañando así los objetivos mismos de la investigación,
- 4.- Que ninguno de los métodos importa un riesgo físico para los participantes y que, garantizada la confidencialidad de las identidades de los informantes en la publicación de resultados tampoco importa un riesgo de menoscabo de su intimidad.

Y verificado que en el (los) documento(s) de consentimiento informado mencionado(s) se incluye:

- 1.- Una descripción general de los objetivos de la investigación,



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- 2.- Antecedentes sobre el uso que se dará a la información obtenida por cada uno de los procedimientos de investigación a utilizar,
- 3.- Un compromiso respecto de que el uso de dicha información sólo se realizará dentro de los marcos de la presente investigación y para el logro de dichos objetivos,
- 4.- El aseguramiento de la confidencialidad y anonimato de los datos entregados dentro de los marcos propios de cada instrumento,
- 5.- Información sobre la manera que cada instrumento contempla para recabar la información solicitada,
- 6.- Antecedentes respecto del costo en tiempo que tiene la participación en el estudio,
- 7.- La voluntariedad de la participación y la garantía para cada participante de tener la opción hacer abandono del estudio.

Se resuelve respecto de este proyecto:

- 1.- Que están tomadas las precauciones convencionales para el tratamiento ético de la información entregada por las personas que participen en la investigación,
- 2.- Y que ellas lo harán adecuadamente informadas de los objetivos generales de la investigación y del uso que se hará de la información que ellos entreguen, en los plazos necesarios para el éxito de la investigación.

Resolución CEC - Ciencias sociales, artes y humanidades:

Este proyecto ha sido discutido y aprobado con fecha 21 de noviembre de 2017 en la sesión n°20 del Comité. Constatados los cambios menores realizados, la vigencia rige desde el 21 de noviembre de 2017 hasta el 20 de noviembre de 2018.

El investigador deberá solicitar la renovación al menos 30 días antes del término del



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período de vigencia del proyecto. El investigador no puede seguir reclutando o investigando con los participantes si no ha recibido aprobación escrita de su solicitud de renovación. Si no se aprueba la continuación de la investigación, el investigador deberá detener las actividades del proyecto, y no podrá evaluar ni enrolar a ningún nuevo participante y no podrá realizar el análisis de los datos que identifiquen a los participantes.

En la eventualidad de querer incorporar modificaciones, por ejemplo, diseño o rediseño de instrumentos de recolección de datos, cambios en la muestra, el personal a cargo, los procedimientos especificados en el protocolo aprobado u otros, el investigador deberá notificarlo al comité para la evaluación y emisión de una nueva carta de aprobación ética antes de que el investigador ejecute esos cambios.

Los siguientes documentos han sido aprobados y están disponibles para ser descargados:

- [protocolo cs sociales artes y humanidades.doc](#)
- [COMPROMISO INV.pdf](#)
- [CONSENTIMIENTO FE EM.doc](#)
- [Afiche](#)
- [Sub Tests](#)
- [Cuestionario muestra](#)
- [Proyecto Tesis](#)
- [Modelo carta de autorización UC](#)
- [Consentimiento \(II versión\)](#)
- [Carta Autorización P Bouchon](#)
- [Carta Autorización genérica autoridades](#)
- [Consentimiento \(III versión\)](#)



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**ACTA DE APROBACIÓN ÉTICA DEL COMITÉ ÉTICO CIENTÍFICO DE CIENCIAS
SOCIALES, ARTES Y HUMANIDADES**

A handwritten signature in blue ink, appearing to read 'Alejandra López'.

Alejandra Santana López
Secretaria Ejecutiva

A handwritten signature in blue ink, appearing to read 'M. E. Gronemeyer'.

María Elena Gronemeyer Forni
Presidenta

Santiago, 27 de diciembre de 2017

CARTA DE CONSENTIMIENTO INFORMADO

Entrenamiento Musical y desempeño en Funciones Ejecutivas
Felipe Ignacio Porflitt Becerra
Pontificia Universidad Católica de Chile

Usted ha sido invitado a participar en el estudio Entrenamiento Musical y desempeño en Funciones Ejecutivas a cargo del investigador Felipe Ignacio Porflitt Becerra, docente de la Universidad Pontificia Universidad Católica de Chile. Esta investigación no cuenta con una fuente de financiamiento de ningún carácter. El objeto de esta carta es ayudarlo a tomar la decisión de participar en la presente investigación.

¿Cuál es el propósito de esta investigación?

Buscar diferencias de desempeño cognitivo en músicos que se encuentren en formación, o que ya tengan experticia, para medir diferentes aspectos de la cognición, poniendo el foco en las funciones ejecutivas (procesos cognitivos de niveles altos).

¿En qué consiste su participación?

Participará en una serie de pruebas cognitivas, que en su conjunto medirán algunos aspectos de la cognición.

¿Cuánto durará su participación?

La medición se realiza en una única sesión, y consta de una hora y quince minutos aproximadamente para su realización.

¿Qué riesgos corre al participar?

Usted no corre ningún riesgo por participar en la investigación.

¿Qué beneficios puede tener su participación?

No existen beneficios directos con su participación. Sin embargo, estará aportando al conocimiento en las áreas de música y psicología cognitiva.

¿Qué pasa con la información y datos que usted entregue?

Los investigadores mantendrán CONFIDENCIALIDAD con respecto a cualquier información obtenida en este estudio. Habrá un procedimiento de encriptación de los datos en tablets, y los documentos que se generan en papel son traspasados a una base de datos digital posteriormente. Pese a ello, las instancias en donde se divulgarán los resultados serán propiamente científicas, tales como seminarios, congresos, artículos de revista, libros, etc.

¿Es obligación participar? ¿Puede arrepentirse después de participar?

Usted NO está obligado de ninguna manera a participar en este estudio. Si accede a participar, puede dejar de hacerlo en cualquier momento sin repercusión alguna, ya que se trata de un proceso voluntario. Por otro lado, aunque el rector o el director haya autorizado la realización de esta investigación, usted es libre de decidir si participar o no, sin tener consecuencias negativas para usted.

¿A quién puede contactar para saber más de este estudio o si le surgen dudas?

Si tiene cualquier pregunta acerca de esta investigación, puede contactar a Felipe Porflitt Becerra, de la Pontificia Universidad Católica de Chile. Su teléfono es el +569 8 5355679 y su email es felipe@uc.cl. Si desease comunicarse con el académico responsable del estudio, puede hacerlo directamente a través de su correo electrónico: Ricardo Rosas Díaz, rrosas@uc.cl. Si usted tiene alguna consulta o preocupación respecto a sus derechos como participante de este estudio, puede contactar al **Comité Ético Científico de Ciencias Sociales, Artes y Humanidades**. Presidenta: María Elena Gronemeyer. Contacto: eticadeinvestigacion@uc.cl

HE TENIDO LA OPORTUNIDAD DE LEER ESTA DECLARACIÓN DE CONSENTIMIENTO INFORMADO, HACER PREGUNTAS ACERCA DEL PROYECTO DE INVESTIGACIÓN, Y ACEPTO PARTICIPAR EN ESTE PROYECTO.

Firma del/la Participante

Fecha

Nombre del/la Participante

Felipe Porflitt Becerra

Firma del la Investigador/Investigadora

Fecha

(Firmas en duplicado: una copia para el participante y otra para el investigador)



Santiago, 8 de abril de 2019.

Constancia

A través de la presente carta hago constar que Felipe Ignacio Porflitt está autorizado a incluir copia de su manuscrito titulado “Detrás de la escena: beneficios cognitivos de tocar un instrumento musical” en su tesis para optar al grado de doctor.

Para los fines legales que estime el interesado conveniente se extiende la presente constancia.

Saluda atentamente a ustedes.



Ricardo Rosas Díaz
Editor
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