The effect of listening to loud music in the performance of three higher-level cognitive functions

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Abstract

For some people, listening to music can be a pleasant collateral activity during working hours. Occasionally considered to be an important stress reducing strategy in situations when planning, and decision making are required. For that reason, in this work we seek to assess the effect of listening to music at sound pressure levels L_{eq} of 74 to 78 dB-A, in three higher-level cognitive functions: planning, inhibition and visuospatial working memory, in a group of 22 young adults 22 to 39 years old from Mexico City using a two-phase quasi experimental design. During phase 1, all participants were screened for good hearing health through a standard pure-tone audiometry, and then performed four neuropsychological tests while listening to loud music. During phase 2, participants performed the same neuropsychological tests applied during phase 1, but without presenting the musical stimulus in a quiet laboratory environment with a background noise level L_{eq} of 24 to 30 dB-A. In both phases participants were also physiologically tested for possible stress markers. The results demonstrate that listening to loud music might negatively affects daily life cognitive abilities like planning, inhibition, and visuospatial working memory.

Introduction

Executive function

What are Executive functions (EFs) useful for? It is commonly accepted that it is easier to repeat well known habits than it is to innovate, or that it is much simpler to follow known or desired strategies than to modify, resist, fight, or oppose them. In other words, that it is easier to display automatic or instinctive behavior, rather than it is to produce specific or *ad-hoc* responses, because using EFs is generally more difficult and uncertain. EFs are also called higher-level cognitive functions, executive control, or cognitive control, and they constitute a meaningful top-down mental process in the daily life of human beings. EFs are useful when it is necessary to plan, to pay attention, or solely to stay quiet (concentrate). They make it possible to work out ideas, taking the time to think before acting, meeting novel situations, deal with unanticipated challenges, avoid temptations, and desires, and staying focused (Diamond 2013). EFs do not have a commonly accepted definition, unlike some other principles of learning (Kalbfleisch 2017). The strategies and neuronal mechanisms involved in EFs can be defined as a multidimensional cognitive construct that allows the gain of strategic control over the mental process (Bowmer, Mason, Knight and Welch, 2018) related with planning, inhibition, and visuospatial working memory. Probably this is the reason why some researchers have found a narrow relation between EFs and academic performance in kids and adults (Barkley 2012; Zuk, Benjamin, Kenyon, Gaab, 2014), specifically regarding readiness to learn (Bowmer et al., 2018; Diamond, 2013; Mulder, Verhagen, Van der Ven, Slot, Leseman, 2017). The EFs construct covers other mental processes like cognitive flexibility, involved in the capacity of the human brain to adapt in a cognitive-behavioral level to changes in the environment (Tirapu-Ustarroz, Bausela-Herreras, Cordero-Andres, 2018). EFs also relate to metacognition, that is the capacity to enquire about our own information processing, as well as about the tools required for any mental process (Bowmer et

al., 2018); in other words, metacognition makes it possible for the human's mental capacity to know that it knows.

Planning

The ability to anticipate well-organized and efficient answers and strategies in a wide range of situations considering environmental stimuli, general knowledge and our own previous experience, is known as planning (Kaller, Rahm, Spreer, Weiller, Unterrainer, 2011). From a neuroanatomical perspective, it has been found that it is the medial region of the dorsolateral prefrontal cortex (dlPFC) the structure in the human brain that seems to play an important function in the neural network that underlies planning process (Owen 1997). Planning is crucial to the self-organization that is involved in setting a goal, creating a checklist of all necessary requirements to achieve it, and execute each one until the goal is achieved (Uytun, 2018). In other words, the essence of planning is to get a goal following a defined number of steps having in mind that these steps taken separately would not necessarily lead directly to the goal (Baker et al. 1996). Some studies about EFs, have found deficiencies in planning, both in children and in adolescents, something normal considering that this ability develops throughout adolescence (Cromer, Schembri, Harel, Maruff, 2015; Luciana, Conklin, Hooper, Yarger, 2005). Simple planning abilities begin to be shown in small children as early as 4 years old (Welsh, Pennington, Groisser, 1991), almost at the same time that they start to display capacities in the creation of new concepts (Jacques and Zelazo 2001) But it is from 6 years old and more when children begin to display a better performance in planning abilities, insomuch as in face of a given task, they are able to create detailed plans to reach the goal (Klahr and Robinson 1981).

The improvement in planning abilities continues during adolescence until 20-year-old, the period of human neural development when important progress can be seen in this mental process (Huizinga, Dolan, Van der Molden, 2006). Although some correlation has been shown to exist between planning abilities and IQ, as well as with someone other mental tools assessed by means of neuropsychological tests during the adolescence, when planning abilities are mostly developed.

Inhibition

Inhibitory control is not just one of the EFs of the brain, but it is probably one of the most important mental tools within the neural and social development of the human being. Inhibitory control, a subconstruct of EFs (Miyake, Emerson, Friedman. 2000), is important for several cognitive abilities and adaptative behaviors (Uytun 2018) and is a very important aspect of executive control behavior (Mansouri, Acevedo, illipparampil, Fehring, Fitzgerald, et al., 2017). This EF refers to the capacity to inhibit instinctive behaviors or, in other words, the ability to suppress an immediate dominant response (Hennessy, Sachs, Ilari, Habibi, 2019). Another aspect of inhibitory control is attention; because the capacity to staying focused and attentive when performing a given task, avoiding distraction from external stimuli or probably faster rewards not pertinent to the task, is due to inhibitory control (Rubiales, Bakker, Urquijo, 2013). For some researchers, inhibitory control is essential for the successful performance of EFs (Barkley 2006). Executive inhibitions are related to the frontal dopaminergic and

frontostriatal system (Nigg 2000) and it is activated differently according to motor or cognitive needs (Sabagh Sabbagh 2008). Up to this point, Inhibitory control can be understood as the capacity to avoid emotional and behavioral answers prompted by external stimuli.

Inhibitory control is a particularly difficult skill for young children to master because it requires them to focus on a task, considering the information given, and suppressing their dominant response before acting (Bowmer et al., 2018). Notwithstanding, these abilities can be observed in children from 6 months of age when, for example, they are able to stop themselves from taking or eating something when asked not to by a parent. Some studies have reported than other mental abilities that require inhibitory control, improve during childhood, from about 4 years old (Davidson, Amso, Anderson, Diamond, 2006; Diamond 2002; Fuster 2002). Studies with fMRI have suggested a significant activity in frontal areas of the prefrontal cortex (PFC) in situations of inhibitory answer during late childhood and adolescence (Uytun, 2018). Early inhibition assessment has been used to measure or predict academic and career success, socio-emotional well-being, even health (Hennessy et al., 2019). For example, in a large longitudinal study carried out in New Zealand, researchers found that children with lower self-control (related with attention and inhibition skills) at ages 3–11, tended to have poorer health, and 30 years later in life to earn less and to be more prone to commit crimes (Moffitt and Gottschalk 2012).

Working memory

The term working memory (WM) is used at least in three different ways in cognitive science (Baddeley, 2012), for example, in the psychological terms that is used here, WM is referred to the temporary storage and manipulation of information (Goldman-Rakic 1995) and it is useful and necessary in cognitive functions and complex tasks like language comprehension, reasoning, learning (Baddeley 1986), and it is also involved in the neural network liable of musical processing (Zatorre and Salimpoor 2013; Van de Cavey and Hartsuiker 2016). The other two uses of the term WM is in experiments of animal learning in the laboratory and in artificial intelligence, both of which are not pertinent to the present research. Usually, short-term memory and WM tend to be confused with each other, nonetheless, short-term memory is a neural capacity to retain a certain amount of information for a short period of time, while, WM refers to the storing, manipulation and comparing of the information (Baddeley 2012) with the intention of creating a structural representation (Van de Cavey and Hartsuiker 2016). In other words, WM is an active and functional memory storage process in which all afferent information of all sensory inputs is held, and processing occurs for a short period of time with the intention to create an appropriate answer (Etchepareborda and Abad-Mas 2005).

In neuroanatomical terms, the prefrontal cortex (PFC) modulates the executive control process of the brain. Neuropsychological investigations, together with recent functional neuroimaging studies, have identified a specific region in PFC involved with the WM process, this region is the mid-dorsolateral frontal cortex (Barbey, Koenings, Grafman, 2013; Owen 1997). Some domain-general studies postulate that the lateral PFC is functionally organized depending on the type of WM operations that are engaged (Barbey et al. 2013), involving computational mechanisms for monitoring and manipulating items in WM (Duncan and Owen 2000; Owen, Evans, Petrides, 1996; Petrides, Tomaiuolo, Yeterian, Pandya, 2012).

Monitoring operations are thought to support the active retention of information in WM, while computational mechanisms are useful for manipulating items that are enlisted for updating (Petrides 2000), or selecting between these representations (Rowe, Tony, Josephs, Frackowiak, Passingham, 2000).

Visuospatial sketchpad

WM is limited and susceptible to interruptions but, it is this susceptibility that allows WM to be as flexible as it is, allowing the constant reception of all kind of new information (Baddeley and Broadbent 1983). Likewise, a way in which WM carries all its functions out, is through the connection that it has with long-term memory, that gives access to all kind of knowledge (memories, feelings, past experiences, etcetera) related with online information in WM which are useful in problem solving (Etchepareborda and Abad-Mas 2005). In 1974 Baddeley and Hitch (Baddeley 2000) proposed a three-component model with respect to WM. This model includes an attentional control system, the central executive, which in turn is aided by two subsidiary slave systems: the phonological loop, and the visuospatial sketchpad, also known as visuospatial working memory (VWM). VWM is the cognitive system which is more directly assessed in the present work. The sketchpad or VWM is assumed to hold visuospatial information, and to be fractionable into separate visual, spatial, and probably kinesthetic components. It has been found that this process probably depends mainly on neural functions of the right hemisphere (Brodmann areas 6, 19, 40 and 47). When the inventor Nikola Tesla thought of designing a new device, it has been reported that he just ran a mental stimulation of the device for several weeks with the intention of devising the most adequate parts (O'Neil, 2006). Even if this story is only anecdotal, more systematic analysis of some creative scientific notebooks has allowed to appreciate the important role of visuospatial imagery in problem-solving tasks such as scientific discovery and invention (Sims and Hegarty 1997).

Effects of background music

The effects of listening to incidental or background music have been widely studied throughout the last two decades in various different research areas (Day, Lin, Huang, Chuang, 2009), for example, in advertising (Bruner 1990; Hahn and Hwang 1999; Kellaris, Cox, Cox, 1993), manufacturing (Furnham and Allass 1999; Furnham and Strbac 2002), and sports (Pates, Karageorghis, Fryer, Maynard, 2003). Although it has been suggested that the influence of background music is mediated by the multidimensional nature of the simultaneous tasks that are involved, as well as by individual differences (Furnham and Bradley 1997), and other contextual factors (Eroglu, Machleit, Chebat, 2005). It can be said that music could disrupt the mental processing of information, for example, the task of making decisions while listening to music involves the processing of visual, and audio perceptions simultaneously. It has been found that even when people have been explicitly instructed to ignore any sound they could hear; the performance of a serial recall task is still significantly impaired by the presence of concurrent irrelevant sound (Day et al 2009).

Day et al., (2009) proposed an integrated model for background music. First, processing of music consumes mental resources to generate pleasure. Second, when the consumed mental resources are lower than those involved in musical pleasure, the total of mental resources increase, while when the

consumed mental resources are higher than those required for pleasure, the total of mental resources decrease. Third, the fluctuation in mental resources has more influence on the performance of the coincident task than on the processing of music, because the processing of music is a more natural or familiar task, and therefore it consumes a minimum of resources. On the other hand, the effect of background music depends on the amount of mental resources that the coincident task demands, but, if the available mental resources can satisfy the demands of the concurrent work, the performance would be optimal. Somehow, an overload of resources may cause a deficient performance in coincident tasks.

So, how background music can affect some cognitive processes like language comprehension, or some EFs like planning or working memory? Jones, Madden, and Miles (1992) proposed the changing-state hypothesis (CSH) and established that the variation between successive acoustic entities within an acoustic stream will invoke a common process of seriation, responsible for keeping track of the order of the acoustic entities (Day et al. 2009). This seriation of acoustic entities is characterized as being compulsory and involuntary (Jones 1999). Thus, the effect of irrelevant sound could probably be the same as that of background music, resulting in an interference of the seriation of acoustic entities, in other words, the process of seriation is a kind of critical and limited mental resource for which the visual primary task, and the sound processing task compete at the same time (Day et al. 2009).

1. RESEARCH DESIGN

The aim of the experiment was to establish if loud music played back at relatively high sound levels could affect mental processes like planning, inhibition and VWM (listed above). The experimental design took into account the sound pressure levels in decibels (dB) reported to have been used by Kasof, (1997; 85 dB), Wolf & Weinar (1972; 95 dB), and Martindale and Greenough (1973, 75 dB), in experiments with pink and white noise in adults, as well as the increment of the difficulty in mental process reported by Threadgold et al., (2019) with participants confronted to diverse sounds in comparison with monotone sounds. In the present work, tests based on a quasi-experimental and longitudinal design were conducted in the study reported here, to evaluate three EFs or higher-level cognitive functions (planning, inhibition and VWM) under two different sounds conditions, with musical stimulus reproduced at sound pressure levels of *Leq* of 74 to 78 dB-A, and also without musical stimulus in a quiet laboratory environment with a background noise level *Leq* of 24 to 30 dB-A

1.1. Methods and materials

1.1.1. Sample

Due to the lack of information or knowledge of the population regarding the hearing damage caused by exposure to high volume levels of noise, a type of snowball or chain sampling was applied in order to reach people who met the established inclusion criteria.

1.1.2. Inclusion and exclusion criteria

Selection criteria were as follows: 18 to 40 years old participants, Spanish speakers, with a minimum education of 10 years (equivalent to high school) who regularly listen to loud music in any type of environment for several hours a day. In order to verify this, each participant was asked to fill out a questionnaire via Google Forms in which they were asked to indicate on a scale of one to ten (with one being the lowest and ten the highest) the volume at which they usually listen to music, as well as the number of hours per day, together with some additional demographic data. Non-native Spanish speakers, hearing impaired people, and people with less than 10 years of education were not considered. Similarly, people outside the age ranges, or with declared psychiatric, psychological and cognitive disorders were also excluded. Education levels and years old edges was taking to the BANFE's rating and classification tables.

1.1.3. Participants

From 118 candidates registered via Google Forms, 85 fulfilled the requirements, and 55 confirmed via email their intention to voluntarily participate in the tests. Of the total number of persons scheduled, 35 participants were received in the first part of the test, with only 22 participants attending the second part (10 men and 12 women between 22–39 years old, $m = 29.0$ and $sd = 4.95$) (see Table 1). All participants were Spanish speakers with reports of visual, auditory, motor and cognitive normality. In order to be included in the study, all participants read and signed an informed consent form that explained in detail the procedures that would take place throughout the test. As a reward for voluntary participation, all participants received via email results of their own pure-tone audiometric test (hearing threshold analysis).

Table 1
General information of the participants.

	Age	Participants
N	22–39	22
Mean	29.0	11.5
SD	4.95	6.49

1.1.4. Neuropsychological test

Little attention has been given in published research to the effects of listening to loud music in the performance of higher-level cognitive functions such as Efs. A set of neuropsychological tests was selected to assesses the effect of listening to music played back at sound pressure levels of Leq of 74 to 78 dB-A in tasks involving planning, inhibition, and VWM tasks. From the 14-subtest included in the Executive Functions and Frontal Lobes Battery (BANFE-2), 3 representative subtests were chosen: Mazes test (typically used in the evaluation of planning process), self-directing signaling test (SDST, used to measure process related with VWM) and Stroop effect, (commonly used to assesses inhibition process). The Trail Making Test (TMT) is probably one of the most used neuropsychological tests to assesses EFs.

This test is divided into two parts (A and B) and is used as an indicator in visual scanning processes, graphomotor speed, working memory, inhibition control, mental flexibility and executive functions in general (Llinàs-Reglà, Vilalta-Franch, López-Pousa, Calvó-Perxas, et al., 2017; Sánchez-Cubillo, Periañez, Adrover-Roig, Rodríguez-Sánchez, Ríos-Lago et al., 2009).

By means of standardized scoring tables, BANFE-2 offers a standardized measurement in which, depending on the score, the participants can be divided into four rating levels ranging from severe-disruption to normal-high (see Table 2).

Table 2
Scoring and classification on BANFE-2

Total score for each participant	Classification
116 - onwards	Normal-high
85–115	Normal
70–84	Mildly moderate disruption
69 or less	Severe disruption

Contrary to BANFE-2, TMT, according to Spreen & Straus (1999) is not equipped with standardized criteria for evaluation by educational level and age, something which has been seen to seriously affect the test performance. According to Reitan (1958), Corrigan and Hinkeldey (1987), Gaudino, Geisler, and Squires (1995), and Lezak, Howieson, and Loring (2004), the results of TMT A and B can be reported based on the time measured in seconds required to complete the task, with higher scores revealing greater impairment in PFC (see Table 3).

Table 3
Scoring for TMT A and B.

	Average	Deficient	Severe impairment
TMT - A	29 s	78 s	More than 90 s
TMT - B	75 s	173 s	More than 3 min.

1.1.5. Selection of the musical stimuli

Berrocal (2018), Juslin (2013) and García-Casares et al., (2013) argue that rhythm, melody and emotion induced by musical lexicon affect the homeostatic processes of the organism. Accordingly, the musical stimulus used in this work was a piece of little known cinematic string music, lightly modified with the intention to reduce the rhythmic and the emotional sensation. Treatment of the audio signals was performed by digital means using Studio One compatible plugins and Sony Spectral Layers Pro. Audio used in phase 1 was played back in WAV format using Studio One 4.5.

The main intention of using little known movie string music was to reduce the bias possibly induced by musical lexicon.

1.1.6. Statistical analysis

Correlation analysis of the results was carried out by hypothesis test correlation using Spearman's non-parametric test coefficients with a 95% interval and a 5% margin of error, $p = 0.05$. Data analysis was done using the software Jamovi V. 1.0.

2. Procedure

2.1. First part of the test (phase 1 with musical stimulus)

All tests took place in a small sound isolated room with acoustic treatment including sound absorbers and sound diffusers at the Acoustics and Vibration Laboratory of the Institute of Applied Sciences and Technology (ICAT) at UNAM.

2.1.1. Audiometry

All participants were screened in terms of hearing health by means of an auditory analysis through automatic pure-tone audiometry (also known as Békésy audiometry) using an Audiometer B&K 1800.

2.1.2. Physiological records

Stress-related physiological data of the participants were recorded as heart rate (PRbpm) and blood oxygenation level (SpO2) measured using a pulse oximeter (Smart XIGNAL MD300C2). This was done at three different stages during the tests: before providing the first TMT sheet, at the end of the mazes, and after the last BANFE's subtest.

2.1.3. Test considerations

According to the study by Arbuthnott & Frank (2000), the residual switching cost effect between one task and another affects the performance of the second task. For this reason, a 60-second break period was provided between the TMT and the BANFE's subtests.

2.1.4. Development of the test

The musical stimulus was reproduced by means of a pair of five-inch (5") audio monitors (two 5 inch active monitors, Event Tuned, Reference T5), an audio card (M-Audio Fast Track Pro), driven from a laptop (Toshiba Satellite) running the Studio One 4.5 software under Windows 10. All audio levels measurements were taken with a Sound Level Meter Brüel & Kjaer type 2250. Each participant was provided with the relevant test and sub-test sheets, considering the corresponding breaks or pauses as mentioned above. After the last subtest of the BANFE-2 (the Stroop effect), the musical stimulus was withdrawn. After that, each participant was given a sheet with four Likert questions in which they had to

indicate their perception concerning to mood, perception of time, perception of the sound level (volume, or perceived loudness), and level of task difficulty perceived throughout the test.

2.2. Second part of the test (phase 2 without musical stimulus)

To eliminate any kind of bias due to retention of information relevant to the test, all participants were rescheduled for the test without musical stimulus with an interval of seven days between each.

As in the first part of the test, all participants were taken to an acoustically treated room where physiological records were taken employing a pulse oximeter (Smart XIGNAL MD300C2) during three moments throughout the test: before providing the first sheet of the TMT, finishing the mazes, and after the last subtest of the BANFE-2.

2.2.1. Development of the test

In the absence of musical stimulus, each participant was provided with the relevant sheets for each of the tests and subtests with the respective 60-second break between the TMT and the BANFE-2. Once the last subtest of the BANFE-2 (the Stroop effect) was completed, each participant was provided with a sheet with three Likert questions on which they indicated their perception regarding mood, time perception and level of task difficulty perceived throughout the test.

3. Results

Analysis of the collected data showed that there was a better performance in all participant's scores during phase 2 (without musical stimulus) with significant differences of $p = 0.012$ and a Spearman's correlation $\rho = 0.527$ for the processes of planning and visuospatial working memory (PI + VWM) evaluated through the BANFE-2. As for the TMT, it was observed that there were statistically significant results of $p = 0.020$ and a Spearman's correlation $\rho = 0.496$ for the planning, inhibition and WM processes evaluated using the TMT-B (see Table 4). A slight improvement in the inhibition tasks evaluated by BANFE-2 was observed during phase 2 compared to phase 1 (see Table 5). Regarding the assessed process throughout the TMT-A (visual scanning, graphomotor speed, and visuomotor processing speed), there was a decrease in the response time of each participant during phase 2, which, based on the TMT evaluation criteria, can be understood as an indication of a better performance. Despite this, no significant difference was obtained for the inhibition processes evaluated by BANFE-2 and the TMT-A process in both conditions (see Table 4). A better performance was observed in planning and VWM skills throughout BANFE-2 and TMT-B in phase 2 (see Table 5).

Table 4
Spearman's correlation between general results with and without music.

Music		PI + VWM	Inhibition BANFE	TMT A	TMT B
Not music					
PI + VWM	Spearman's rho	0.527	0.294	0.070	0.015
	p-value	0.012	0.184	0.757	0.948
Inhibition BANFE	Spearman's rho	0.021	0.402	0.173	-0.121
	p-value	0.925	0.063	0.442	0.593
TMT A	Spearman's rho	0.537	-0.165	0.128	0.265
	p-value	0.010	0.463	0.568	0.233
TMT B	Spearman's rho	0.105	-0.320	0.181	0.496
	p-value	0.643	0.147	0.418	0.020

Table 5
Means and standard deviations (in parenthesis) of performance scores for all tests with music and without music.

Test	Executive function	Music	Not music
TMT - A	Inhibition	32.2 (9.77)	24 (8.42)
TMT - B	WM, Inhibition	62 (24.7)	46 (20.7)
Mazes, SDST	Planning & VWM	70.1 (21.6)	102 (23.1)
Stroop effect	Inhibition	100 (17.7)	108 (22.7)

3.1. Results by subtests

3.1.1. Self-directed signaling task

From the analysis of the self-directed signaling task (SDST), there was a better performance in all assessed elements during phase 2: Shorter response time, fewer replicated answers, fewer omissions, and a higher number of hits (see Table 6). A significant difference ($p = 0.024$) was observed in the number of omissions.

Table 6
Means and standard deviations (in parenthesis) of
the assessed elements of the SDST with and
without music.

Assessed elements	Music	Not music
Time	68.1 (34.6)	44.0 (25.5)
Replicated answers	2.73 (2.31)	1.00 (1.34)
Omissions	4.50 (2.69)	2.59 (2.36)
Hits	16.3 (4.27)	19.7 (5.85)

3.1.2. Mazes

In the mazes test, there was a better performance in all participants during phase 2. These results showed an increment in the participant's scores a long of the phase 2 in comparison to the phase 1 (see Table 7). Employing a Spearman's correlation, it was possible to see a significant difference in the numbers of crossing ($p = 0.005$) and in the time required to complete the test ($p = < .001$).

Table 7
Means and standard deviations (in parenthesis) of
the assessed elements of the mazes task with and
without music.

Assessed elements	Music	Not music
Touch	5.50 (6.64)	3.64 (3.72)
Crossing	2.09 (3.35)	1.86 (3.78)
Dead-end	2.73 (1.91)	1.91 (2.11)
Time	46.1 (40.8)	27.1 (13.7)

3.1.3. Stroop effect. As well as in the previous proof, the results obtained using the Stroop effect, allowed to see a better performance in all participant's scores throughout phase 2 (see Table 8). Nonetheless, in a Spearman's correlation, just two elements assessed showed a significantly different: time ($p = < .001$) and non-stroop faults ($p = 0.046$).

Table 8
Means and standard deviations (in parenthesis) of
the assessed elements of the Stroop effect with and
without music.

Assessed elements	Music	Not music
Hits	79.2 (4.12)	81.4 (2.22)
Time	88.4 (17.5)	76.1 (12.9)
Faults	1.32 (1.17)	0.591 (0.908)
Non-Stroop Faults	3.59 (3.40)	2.05 (1.70)

3.2. Physiological measurement results

A progressive increase in SpO2 levels was observed during phase 1 compared to phase 2. Likewise, an increase in heart rate was observed during the second part of the test. Thus, it could be inferred that there was a higher level of stress in all participants throughout the test without musical stimulus (phase 2). Despite this, no significant difference was obtained between the first and second stage of the test.

3.3. Hearing test results

The audiometric results indicate the impact that frequent exposition to loud music play back could have in the hearing health of the participants. Conversely, considering that all attendees reported listening to music at high sound levels for a considerable number of hours a day, the interest in this aspect became more relevant. Taking into account that the average age of all participants was 29 years old, a relatively young population, the results showed that of the hearing tests conducted in the 22 final participants during phase 1, just one of them had a normal hearing levels with hearing loss levels of less than 25 dB relative to normal hearing levels. Most other participants, nineteen of them, presented slight hearing loss levels from 25 to 40 dB, while finally, five participants showed moderate to severe hearing loss levels between 55 and 70 dB at frequencies between 3000 to 8000 Hz. Most of them were more frequently observed in the right ear.

4. Discussion

4.1. Overview

According to the results obtained in each test, it is evident that the performance of all participants was affected in presence of a loud musical stimulus, with predominance in task and processes where planning and VWM was required. These turns out to be in agreement with Thompson et al, (2012) in that music affects the correct performance of certain cognitive functions with a high attention demand, such as reading comprehension; although to this, Keeler & Cortina (2018), add that, like it has been seen, music can also negatively alter the performance of mental functions related to planning processes and working memory, as it is seen in the results of Table 5.

In a study conducted in the United States in the decade from 2000 to 2010, it was reported that around of 70% of the full-time workers listen to music during working hours (Keeler & Cortina, 2018). In addition, Haake (2011) reported that a higher number of full-time workers in the United Kingdom claimed to listen to music around 30% of their working hours. Now, taking into account the results obtained in phase 1, and the reports of other authors about the impact of some factors in music like tempo, rhythm, and melody in homeostatic states of the organism and sympathetic system related with instinct responses and PFC's low performance (Berrocal, 2018; Bigliassi et al., 2015; Day et al., 2009; Greitemeyer, 2009; Juslin, 2013), listening to music at high sound pressure levels of around 80 dB, could affect the performance of tasks with a high cognitive demand in a significant manner.

Baddeley (1983, 1986, 1992, 2000, 2012), Etchepareborda & Abad-Mas (2005), Kljajevic & Murasugi (2010) and, Van de Cavey & Hartsuiker (2016), state that WM is crucial in processes of information integration, and susceptible to interruptions. In addition, according to Koelsch, Gunter, Wittfoth, Sammler, (2005) there are overlaps in the processing of information integration, for example, when music and language stimulus are presented simultaneously. This could be understood as if the greater the distance between the coinciding tasks (music and planning, music and working memory, music and decision making, or music and reading comprehension), the greater the level of perceived difficulty. Therefore, considering that most neuropsychological assessment instruments involve the oral pathway in both comprehension and expression, the overlaps of information integration processing help to understand why the vast majority of participants required to listen at least twice to the instructions relevant to each subtest during the test with musical stimuli. Similarly, the lack of understanding of the instructions during phase 1 can be related to the possible affectation of the phonological loop proposed by Baddeley (1991) in his working memory model. This is because the phonological loop turns out to be indispensable in the process of linguistic tasks such as language comprehension, reading and writing, and conversation, as well as everything related to the handling of words, descriptions and numbers (Baddeley, 2000). It also turns out to be in charge not only of keeping active the information related to language as already mentioned, but also of manipulating it in order to achieve an objective (Etchepareborda & Abad-Mas, 2005). Another possible reason for the low performance in the results of the test with musical stimulus may be due to the addition of Day et al., (2009) stating that the effect of background music in the performance of certain tasks depends on the amount of resources demanded by the concurrent task, because an overload of resources will cause a poor performance in the coincident tasks. This also agrees with the statements of Koelsch et al., (2005).

Taking into account the data corresponding to the BANFE-2 scores (reported in Table 2) it can be seen that, in effect, in a comparison of the mean performances in the tasks referring to planning and VWM (see Table 5), there was a better performance during phase 2 with an average of 102, which means that quantitatively, there was an increase of 32 points compared to phase 1. Qualitatively, a "Normal" rating was observed during phase 2, compared to the "mildly moderate disruption" rating observed during phase 1.

Although the total mean performances of TMT A and B were in all cases below the means reported in Table 3, there was a better performance of all participants during phase 2 (see Table 5). The differences in the means reported in Table 3 and those obtained through the present research, could be due to the lack of standardized mechanisms that allow better results, just like the BANFE-2.

The results obtained in the inhibition processes evaluated by means of the BANFE-2, with values of $p = 0.063$, were not consistent with the reports made by Furnham & Allass (1999), and in which they affirm that music can alter in a negative way the performance of mental abilities related to inhibition tasks; in spite of this, there is a slight improvement in the participant's score throughout phase 2 like is observed in Table 5.

4.2. Subtest analysis and neuroanatomical influence

In the analysis by subtests it was observed that, in the SDST, there was a better performance throughout phase 2 in terms of the number of omissions with results of $p = 0.024$. The number of figures omitted during phase 1 may be related to the possible interference generated by music in the visuospatial sketchpad proposed by Baddeley (2000) within his working memory scheme. Among other things, it has been seen that the visuospatial sketchpad is involved in the learning of geographical maps and tasks involving memory of objects or figures such as chess (Etchepareborda & Abad-Mas, 2005). Another possible cause of the increase in the number of omissions throughout phase 1 can be related to the apparent interference of music in the dorsolateral prefrontal cortex (dlPFC), which in generating an overload in the networks of information processing and integration, would affect the performance of the coincident tasks, which is consistent with Day et al., (2009); Koelsch et al., (2005), Ochsner, Silvers, Buhle., (2012) and Sturm et al., (2016). In the same way, the possible effects of music in dlPFC that would be involved in the low performance of the tasks related to the visuospatial working memory, are reflected in the planning tasks evaluated by means of the mazes, due to the fact that, by inhibiting the correct performance of the dlPFC, the planning processes are affected, reflected not only in the time required by each participant for the resolution of the problem, but also in the number of times they crossed the walls of the mazes.

Regarding the data collected through physiological analysis of heart rate (PRbpm) and blood oxygen saturation level (%SpO₂), it was concluded that the results were not consistent with the reports given by Greitemeyer (2009) and Bigliassi et al, (2015) with respect to music-induced stress, since, contrary to expectations, higher levels of %SpO₂ and lower levels of PRbpm (related to lower levels of physiological stress) were evident throughout the test with musical stimulation; despite this, the results were not statistically significant.

4.3. Considerations of the results

Although in view of the proposed hypothesis, a lower performance in each of the tests was expected in response to a musical stimulus at a sound level close to 80 dB, the wide margin of difference in the responses in some particular cases recorded between the both phases of the test, observed in the low correlation data (see image 1 and 2), was probably due to the confusion variables. In this respect, Villasis-

Keever et al., (2016) state that the correlations inferred between the independent variables and the dependent variable are not always accurate, because sometimes these correlations are affected by particular circumstances or attitudes of the participants.

5. Conclusion

Experiments were conducted in order to assess the performance of a group of participants in tasks involving higher level cognitive functions (BANFE-2, TMT) under two different conditions: one condition in which participants performed the tasks while listening to loud music reproduced at sound pressure levels Leq in the range between 74 to 78 dB-A, and another under quiet laboratory conditions with sound pressure levels Leq around 24 to 30 dB-A. Results show that there was a better performance during phase 2 (without musical stimulus) with significant differences of $p = 0.012$ and a Spearman's correlation $\rho = 0.527$ for the processes of planning and visuospatial working memory (PI + VWM) evaluated through the BANFE-2. For the TMT, it was observed that there were statistically significant results of $p = 0.020$ and a Spearman's correlation $\rho = 0.496$ for the planning, inhibition and WM processes evaluated using the TMT-B. A slight improvement in the inhibition tasks evaluated by BANFE-2 was observed during phase 2 compared to phase 1. Regarding the assessed process throughout the TMT-A (visual scanning, graphomotor speed, and visuomotor processing speed), there was a decrease in the response time of each participant during phase 2, which, based on the TMT evaluation criteria, can be understood as an indication of a better performance. Despite this, no significant difference was obtained for the inhibition processes evaluated by BANFE-2 and the TMT-A process in both conditions. A better performance was observed in planning and VWM skills throughout BANFE-2 and TMT-B in phase 2.

Derived from these results it can be inferred that listening to loud music in high cognitive demand situations can affect the mental and emotional performance of some people causing an increase in the rate of failures in specific tasks, with a decrease in productivity and performance. The questions as to whether listening to loud music at sound pressure levels of Leq of 74 to 78 dB-A affects the performance of executive function, although it can be answered in positive terms, this answer cannot be totally conclusive. The statement that can be made based on the present results is that listening to music at sound pressure levels of Leq of 74 to 78 dB-A correlates slightly with a low performance in mental process where planning and VWM were required.

Declarations

Competing interest: Authors declare no competing interests.

Ethics Statement: This research has been approved by a neurocognitive researcher appointed by the academic committee of the UNAM's Master and Doctorate Program in Music.

Author contributions

CD, CG, FO and IG have equally contributed to the conception and design of the work. Data collection as well as analysis and interpretation have been realized by CD. Auditory analysis and grammar checking was under supervision of FO.

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Figures

Image 1. (A) Positive correlation of the inhibition process during phase 1 and 2. (B) Positive correlation of the TMT-A phase 1 and 2.

Figure 1

Caption found in figure.

Image 1. (A) Positive correlation of the inhibition process during phase 1 and 2. (B) Positive correlation of the TMT-A phase 1 and 2.

Figure 1

Caption found in figure.

Image 2. (A) Positive correlation of PI+VWM process during phase 1 and 2. (B) Positive correlation of the TMT-B phase 1 y 2.

Figure 2

Caption found in figure.

Image 2. (A) Positive correlation of PI+VWM process during phase 1 and 2. (B) Positive correlation of the TMT-B phase 1 y 2.

Figure 2

Caption found in figure.