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COGNITIVE & EXPERIMENTAL PSYCHOLOGY | RESEARCH ARTICLE

Differential effect of music on memory depends on emotional valence: An experimental study about listening to music and music training

Nadia Justel[1*], Verónika Diaz Abrahan[1], Julieta Moltrasio[2] and Wanda Rubinstein[2]

Abstract: Research has shown that memory is influenced by emotion. Several studies demonstrated the effectiveness of pharmacological and non-pharmacological interventions to modulate emotional memory pursuing clinical and educational aims. Music has been identified as a potential memory modulator, with results differing widely depending on whether the participant had musical training or not. The current study examined the effect of listening to music on musicians' and non-musicians' positive (study 1) and negative (study 2) emotional memory, in a group of 163 volunteers, aged 18–40. After the information was encoded, the groups of participants were exposed to arousing music (Symphony No. 70, D major by Joseph Haydn) or a control stimulus (white noise) for three minutes. Then memory was evaluated through free recall and recognition (immediate and deferred measures). Memory performance was compared between musicians (people with five or more years of music education) and non-musicians. Positive and negative images were better recalled than neutral ones, positive images were better recognized than neutral ones however neutral images were better recognized than negative ones. In

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Study 1, listening to white noise enhanced recall compared to listening to music. In Study 2, listening to arousing music enhanced recall compared to listening to white noise, and this effect was more pronounced in musicians than non-musicians. Our findings suggest that music has a great impact on memory, especially in those with experience in the field, which is reflected in cognitive performance.

Subjects: Neuropsychology; Psychological Science; Music
Keywords: arousing music; modulation; music training; emotional memory

Research has shown that memory is influenced by emotion. An emotional event or stimulus could influence the memory formation process (Cahill & McGaugh, 1998; McGaugh, 2004), either improving or decreasing recall. There is strong evidence that *emotional arousal* acts as a modulator of memory encoding and consolidation (Cahill & McGaugh, 1995; Liu et al., 2008), being considered one of the essential elements for the retention of emotional information over time (Kilpatrick & Cahill, 2003; McGaugh, 2018). Besides, the role of arousal in the emotional memory process may differ depending on the valence of the information, which refers to the pleasantness or unpleasantness of an emotional stimulus (Mickley Steinmetz et al., 2010). This difference is associated with the divergent processing of each stimulus and the impact on amygdala activity (Berntson et al., 2007). Nevertheless, research indicated contradictory findings depending on the experimental paradigm and population employed (Kauschke et al., 2019) since studies found cognitive advantages for positive stimuli (Crossfield & Damian, 2021), negative stimuli (Gotlib & Joormann, 2010), or no differences (Garavan et al., 2001; Kousta et al., 2009).

Besides, distinct outcomes have been found when short, moderate, or long-term memory was evaluated because each of these periods affects different neurobiological mechanisms. Furthermore, evidence shows that consolidation of memory depends on two periods requiring synthesis of new mRNAs: one around the time of training and another 3–6 h after training (I. Izquierdo & McGaugh, 1987; L. A. Izquierdo et al., 2001; Wang & Sun, 2015). The immediate effect could be related to a cognitive element (for instance attention), while the deferred effect could be related to emotion or arousal (Schwarze et al., 2012; Talmi, 2013).

In parallel with the analysis of the characteristics and mechanisms underlying emotional memory, research in recent decades has focused on the effect of treatments, chronic and focal (acute) interventions that can modify memory. The implementation of pharmacological (i.e. drugs) and non-pharmacological interventions (i.e. behavioral proposals) can cause modifications in memory, increasing or deteriorating the consolidation of the initially labile memory (Cahill & McGaugh, 1995). Within the body of research, music is tested and used to modulate memory pursuing clinical and educational aims (Ballarini et al., 2013; Diaz Abrahan et al., 2021; Justel & Rubinstein, 2013; Moltrasio et al., 2020; Strong & Midden, 2018).

Music offers many types of activities, and it is often cited as an effective tool for the regulation of cognitive function and promotion of well-being since it facilitates positive emotional states (Diaz Abrahan et al., 2020b; Koelsch, 2014; N. Rickard et al., 2005). These activities include the use of music-based interventions (e.g., listening to music) and music training.

Different lines of research have investigated the efficacy of acute or focal music-based interventions and their relationship with music, emotion, and memory (Diaz Abrahan, Bossio, et al., 2019). In this line, listening to music is a valid method to moderate arousal and emotion (Bottiroli et al., 2014; N. Rickard, 2004); however, it is important to consider when the musical activity is performed. While listening to music before (Lopez et al., 2021) or during (Jäncke & Sandmann, 2010) an encoding task has been shown to have no effect on memory, implementing the musical approach after learning the information enhances (Justel & Rubinstein, 2013; Justel et al., 2016) or impairs (Justel et al., 2015; N. S. Rickard et al., 2012) memory. The differential effects of music listening on memory are associated with the characteristics of the music itself. One of the primary mechanisms by which music induces a strong emotional response in listeners is the unexpected changes in the musical features of intensity and tempo, which in turn enhance tension and anticipation (Arjmand et al., 2017).

According to the musical features, studies have compared the cognitive effect of arousing musical pieces (characterized by high intensity, tempo and polyphonic density, major mode, unexpected changes in melody, use of instruments with strident timbres, for example Symphony No. 70, D major by Joseph Haydn) and relaxing musical pieces (characterized by low intensity, tempo and polyphonic density, minor mode, expected changes in melody, use of instruments with warm timbres, for example Pachelbel Canon in D major; Chanda & Levitin, 2013; Fancourt et al., 2014; Juslin & Västfjäll, 2008; Knight & Rickard, 2001). For example, N. S. Rickard et al. (2012) exposed participants to relaxing or arousing music during or after the presentation of a story with emotional content, and they found that subjects exposed to relaxing music had diminished emotional memory. The mechanism by which memory modulation occurs could be akin to the modulatory effect of stress on memory, through secretion of stress hormones (Marin et al., 2010), i.e., relaxing music decreases arousal levels while arousing music raises them and this could have repercussions on memory consolidation mechanisms (Justel & Rubinstein, 2013). Justel et al. (2015) exposed older adults to a series of emotional and neutral images and then the participants listened to arousing vs relaxing music vs white noise for three minutes. Participants exposed to relaxing music had lower recall and recognition, while those who listened to arousing music showed better performance. Moreover, in a study with a similar protocol, patients with Alzheimer's disease showed decreased false recognition after listening to arousing music (Moltrasio, Detlefsen, et al., 2020). Enhancement effects of arousing music were obtained in verbal emotional memory by Justel et al. (2016) and Moltrasio, Detlefsen, et al. (2020). In this sense, the use of arousing music is appropriate to increase the recall of stored information. However, there are few studies on the topic.

In studies of cognitive modulation through music, a substantial aspect that is considered is the participant's musical knowledge (V. Diaz Abrahan & N. R. Justel, 2019). Music training could modulate cognitive function (Gaser & Schlaug, 2003; Groussard et al., 2010; Schellenberg, 2020), and it has been associated with academic, cognitive, and psychosocial benefits (Benz et al., 2016; Swaminathan & Schellenberg, 2021). Regarding memory, some studies have reported that musicians show better memory scores than non-musicians (V. Diaz Abrahan & N. R. Justel, 2019,; Talamini et al., 2018). In long-term memory tasks, musicians performed better than non-musicians in learning and recalling verbal information (Franklin et al., 2008; Ho et al., 2003). For example, A. Taylor and Dewhurst (2017) presented four lists of words to a group of musicians (with four or more years of musical experience) and to another group with no knowledge in the area. Subsequently, they assessed free recall of the lists. The results indicated that musicians recalled more words than non-musicians. These findings on verbal memory are related to neuroanatomical and functional brain divergences between musicians and non-musicians as the consequence of years of study involved in becoming a musician (V. Diaz Abrahan & Justel, 2019, ; Lappe et al., 2008; Talamini et al., 2018). Regarding visual emotional memory, there are few studies with contradictory results involving musical experience (Hanna-Pladdy & MacKay, 2011; Talamini et al., 2018). For example, when comparing the performance of adults who received music training, the studies highlight the effect on verbal but not visual memory (Fauvel et al., 2014). A study conducted by Diaz Abrahan, Bossio, et al. (2019) found difference between musicians and non-musicians in neutral visual memory but not visual emotional ones. Therefore, more studies are needed to corroborate this memory difference in musical training.

2. Objectives of the present study

In accordance with the evidence presented, this investigation aims to analyze two relevant variables in the study of memory modulation, i.e., emotion and music. For this purpose, we evaluated the possible effect of music on emotional memory, investigating music from two different perspectives: as a focal intervention and as music training. Specifically, the current study examined the effect of listening to music on the emotional memory of musicians and non-musicians. Previous research has shown that perception or production of music could modulate emotional memory (V. Diaz Abrahan & Justel, 2019; Diaz Abrahan, Shifres, et al., 2019; Diaz Abrahan et al., 2020b; Justel & Rubinstein, 2013), but the procedures employed in those studies used negative, positive, and neutral images altogether, making it difficult to disentangle the effect of positive vs negative stimuli itself. To this effect, we want to conduct separate studies were positive vs neutral and negative vs neutral effects could be observed. Moreover, studying these relevant variables together would help find possible interactions between them, and later reveal the implications of the interactions.

According to the antecedents about the influence of emotion on memory formation process (Cahill & McGaugh, 1998; McGaugh, 2004), our first prediction was that emotional information will be better recalled and recognized than neutral information. Regarding the effects of music-based interventions on memory (Diaz Abrahan, Bossio, et al., 2019; Justel & Rubinstein, 2013; Justel et al., 2015, 2016; N. S. Rickard et al., 2012), the second prediction was that participants who listen to arousing music will have higher memory scores than subjects who listen to white noise. Finally, in line with the studies that indicate that musical training affects memory performance (V. Diaz Abrahan & N. R. Justel, 2019; Franklin et al., 2008; Ho et al., 2003; Talamini et al., 2018) the third prediction was that musicians will have better memory performance than non-musicians. However, considering the controversial results concerning valence differences found in previous work, no predictions were made regarding positive and negative visual stimuli.

3. Study 1. Positive emotional memory

3.1. Participants

Calculations were run using G*power software (Faul et al., 2007). To estimate the approximate sample size, we based on previous studies that analyzed emotional memory performance comparing music-based interventions (Music Condition [MC] vs. Control Condition [CTRL]) and different musical expertise (Musicians [M] vs Non-musicians [NM]; Diaz Abrahan et al., 2020a, 2020b; Justel & Rubinstein, 2013). An *a priori* power analysis revealed that to detect a small to medium-sized effect ($\eta 2 = .25$), with 80% power, with 4 groups (M/MC, M/CTRL, NM/MC, NM/CTRL) and 2 dependent variables (free recall and recognition) the study required a total sample size of 80.

Eighty volunteers aged between 18 and 40 ($M = 27.33$; $SD = 0.34$) participated in this study (71% women). Musicians were considered those subjects who reported at least five years of formal and informal musical experience, understanding experience as the ability to play a musical instrument or sing (Fauvel et al., 2014; Watanabe et al., 2007). Forty-five were musicians (M) with more than five years of formal and/or informal music training (schools, institutes, music conservatories, private practice), and 35 were considered non-musicians (NM). They were recruited from different Argentine universities. The participant exclusion criteria included visual or hearing impairment, amusia, psychiatric history, any music-related pathology, and cognitive impairment.

Each participant signed a written informed consent form according to current ethical principles for research involving human subjects (World Medical Association Declaration of Helsinki, 2013), and they completed a questionnaire requesting sociodemographic and musical expertise information.

3.2. Emotional memory evaluation

The material for the emotional memory task consisted of forty-eight pictures selected from the International Affective Pictures System (IAPS; Lang, 1995). According to previous works (Kilpatrick & Cahill, 2003; Justel, Psyrdellis, & Ruetti, 2014), positive and neutral pictures were selected, which covered a wide range of arousal (from 3.44 to 6.36) and valence (from 5.01 to 7.31) in line with the manual by Lang (1995).

3.3. Conditions

3.3.1. Music Condition (MC)
Participants listened for three minutes to Symphony No. 70, D major by Joseph Haydn at medium volume (Justel & Rubinstein, 2013; Justel et al., 2015, 2016; Kreutz et al., 2008), this is an arousing musical piece which is characterized by high intensity, tempo and polyphonic density, major mode, unexpected changes in melody, use of instruments with strident timbres.

3.3.2. Control Condition (CTRL)
Participants listened for three minutes to white noise (20-20 kHz, same intensity throughout; N. S. Rickard et al., 2012).

3.4. Experimental design
Because there were two interventions (Music Condition vs. Control Condition) the participants had different musical expertise (Musicians vs Non-musicians), and two types of images were employed (positive and neutral, as a within measure) a 2(Condition) × 2(Training) x 2(Image) experimental design was run, with four groups (since image was a within measure) experimental design was run, with four groups with the following number of subjects: (1) M/MC: musicians' music group ($n = 23$); (2) M/CTRL: musicians' control group ($n = 22$); (3) NM/MC: non-musicians' music group ($n = 18$); and (4) NM/CTRL: non-musicians' control group ($n = 17$). Participants were randomly and blindly assigned to the different conditions (Music Condition or Control Condition) and they were always tested in groups.

3.5. Procedure
The study was divided into two sessions with a one-week intersession interval. The first session consisted of four immediately consecutive phases. In the first phase (information phase, about 15 minutes), the participants signed the informed consent form and completed the sociodemographic questionnaire (age, gender, occupation, years of academic and music education).

In the second phase (acquisition phase, about 7 minutes), the participants observed 48 selected pictures (24 positive and 24 neutral) for seven seconds each. The pictures were presented with a projector screen in random order except for the first and last locations in the series, which met the condition of being a neutral picture (Kilpatrick & Cahill, 2003). Simultaneously, the participants were asked to rate on a 0–10 scale "how emotional" or "arousing" they felt each image was (from 0 = not arousing at all to 10 = highly arousing). This behavioral task (*Arousal* task) was included to ensure that the participants paid attention to each image and to validate the selection of IAPS images for this research context.

In the third phase (treatment phase, about 3 minutes), the participants listened to music or white noise. Soon afterward, in the fourth phase (test phase, about 11 min), a two-task test was run. The participants were asked to describe in one word or short phrase as many pictures as they could recall (*Immediate Free Recall* task). Then, they observed the 48 original pictures mixed with 48 new pictures in random order and they were asked to mark on a sheet of paper if they had seen the image before or not (*Immediate Recognition* task).

The second session (11 min) was held a week later, when the two-task test was run again (*Deferred Free Recall* task and *Deferred Recognition* task).

3.6. Data analysis
Age, years of Academic Education, and years of Musical Education were analyzed independently via univariate analysis of variance (ANOVA), where *Condition* (Music Condition vs Control) and

Table 1. Sociodemographic and memory performance in Study 1

	M/MC	M/CTRL	NM/MC	NM/CTRL
	Mean (*SD*)	**Mean (*SD*)**	**Mean (*SD*)**	**Mean (*SD*)**
Sociodemographic				
Age	24.91 (0.53)	26.91 (0.57)	31.33 (0.83)	26.94 (0.81)
Academic education	16.24 (0.33)	16.68 (0.38)	15.65 (0.34)	15.94 (0.44)
Music education	8.57 (0.44)*	10.2 (0.48)*	1.65 (0.33)	2 (0.30)
Arousal				
Neutral image	3.16 (0.25)	3.31 (0.24)	2.15 (0.27)	2.84 (0.29)
Positive image	6.75 (0.24)	6.76 (0.26)	6.28 (0.27)	5.80 (0.35)
Immediate Free Recall				
Neutral image	8.48 (0.3)	9.95 (0.40)	7.61 (0.40)	10.24 (0.44)
Positive image	11.13 (0.35)	10.55 (0.37)	9.39 (0.41)	11.53 (0.44)
Immediate Recognition				
Neutral image	18.13 (0.30)	17.59 (0.31)	18.71 (0.26)	19 (0.29)
Positive image	20.87 (0.29)	21.36 (0.34)	20.88 (0.31)	21.71 (0.29)
Deferred Free Recall				
Neutral image	8.91 (0.48)	8.50 (0.40)	7.33 (0.50)	8.35 (0.47)
Positive image	10.77 (0.48)	9.27 (0.37)	9.39 (0.51)	10 (0.47)
Deferred Recognition				
Neutral image	18.27 (0.29)	17.59 (0.31)	18.71 (0.25)	19 (0.29)
Positive image	20.91 (0.29)	21.36 (0.34)	20.88 (0.30)	21.71 (0.29)

Training (Musicians vs Non-musicians) were the between-factors. Arousal was analyzed with repeated measures (RM) Analysis of Variance (ANOVA) were *Training* (Musicians vs Non-musicians) was the between factors, and *Image* (Neutral and Positive) as the within factors as a repeated measure (RM).

Recall, and recognition were independently analyzed via repeated measures (RM) Analysis of Variance (ANOVA) *Condition* (Music Condition vs Control) and *Training* (Musicians vs Non-musicians) as the between factors, and *Image* (Neutral and Positive) and *Time* (immediate and deferred) as the within factors as a repeated measure (RM).

Post-hoc least-significant difference (LSD) pairwise comparisons were conducted to analyze significant main effects and significant interactions. The partial Eta square (η^2 p) was utilized to estimate effect size. The alpha value was set at .05, and the SPSS software package was used to compute descriptive and inferential statistics.

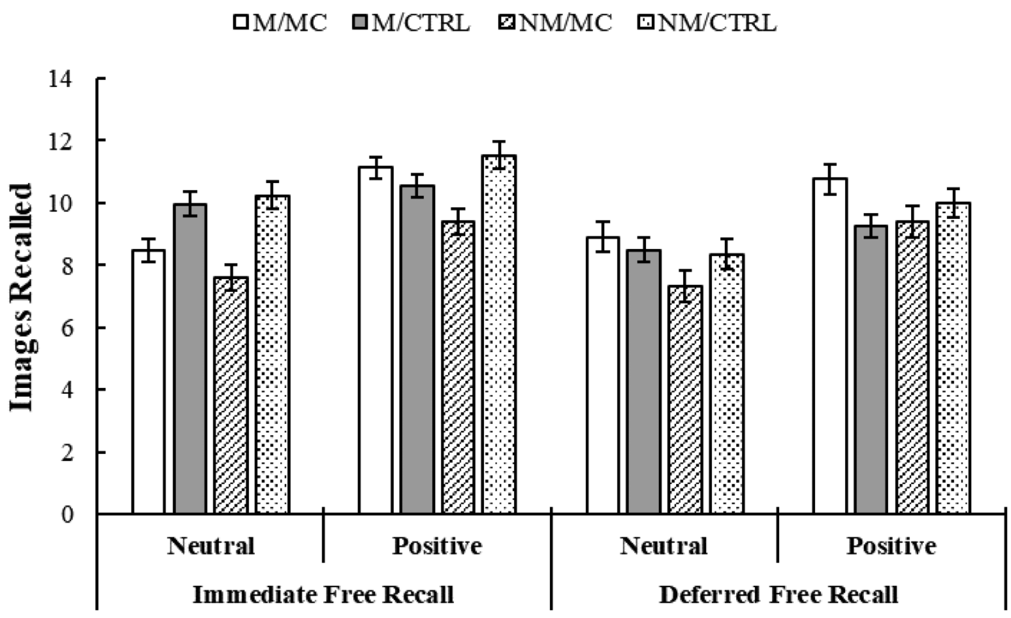
3.7. Results

The sociodemographic information showed that the groups were balanced in terms of Age ($p = .198$) and Academic Education ($p = .683$), and differed in terms of music education ($p < .001$), with musicians having, on average, 10.27 years of music training. All results are shown in Table 1.

3.7.1. Arousal

Arousal was the first dependent variable analyzed to ensure that the participants paid attention to each image and to validate the selection of IAPS images for this research context. Participants observed neutral and positive images and simultaneously rated how arousing the pictures were for them, on a scale from zero to ten. The ANOVA indicated a significant effect for Image $F(1,78) =$

Figure 1. Free Recall Measure in Study 1.



484.82, $p < .0001$, $\eta^2\ p = .861$, which indicated that positive images were more arousing than the neutral ones $p < .0001$.

3.7.2. Free recall

Immediately after exposure to each condition (Music Condition vs Control Condition) and seven days later (deferred measure) the participants were asked to recall as many images as possible (see Figure 1). The ANOVA indicated a significant effect for Image $F(1,75) = 31.372$, $p < .001$, $\eta^2\ p = .295$where positive images were better recalled than neutral ones. On the other hand, the ANOVA indicated a significant effect for Time $F(1,75) = 7.055$, $p = .010$, $\eta^2\ p = .086$which indicated that that participants recalled more images in the immediate than in the deferred evaluation ($p = .001$). Also a significant effect in the double interaction Time x Condition was found $F(1,75) = 5.073$, $p = .027$, $\eta^2\ p = .063$, subjects in the Control Condition recalled immediately more images than participants in the Music Condition ($p = .039$). No other significant differences were found ($p > .05$).

3.7.3. Recognition

After the free recall, the participants observed the 48 original images randomly intermixed with 48 new ones (Table 1). They had to discriminate the new images from the original ones (recognition task). False Alarms (new items incorrectly recognized as old) were subtracted from Hits (correctly recognized old items) to calculate overall recognition. The ANOVA showed a significant effect for Image $F(1,74) = 140.95$, $p < .001$, $\eta^2\ p = .656$which indicated that participants recognized more positive images than neutral ones. No other significant differences were found ($p > .05$).

Alt text. Bars figure indicating the number of images recalled by the four groups immediately and seven days before acquisition. M/MC (musicians who listened to music); M/CTRL (musicians who listened to white noise); NM/MC (non-musicians who listened to music); NM/CTRL (non-musicians who listened to white noise). The vertical lines indicate the standard error.

In summary, the results showed that participants recalled more information in the immediate measures than seven days later. On the other hand, listening to white noise improved the recall of images, and finally, the emotional images were better recalled and recognized than neutral ones. Since literature used protocols where negative and positive information are intermixed, and the recall and recognition of negative information is stronger due to evolutionary and cognitive mechanisms (Cordon et al., 2013; Sheldon et al., 1996; S. E. Taylor, 1991; Vaish et al., 2008) we conducted the second study to test if the results would be different when negative emotional memory is tested.

4. Study 2. Negative emotional memory

4.1. Participants

Following the same logic that Study 1, an *a priori* power analysis revealed that to detect a small- to medium-sized effect ($\eta 2 = .25$) with 80% power, the study required a total sample size of 80.

Eighty-three volunteers (different sample from study 1) aged between 18 and 40 ($M = 26.67$; $SD = 0.30$) participated in this study (71% women). Thirty-five were musicians (M) with more than five years of formal and/or informal music training (schools, institutes, music conservatories, private tutor), and 48 were considered non-musicians (NM). They were recruited from different Argentine universities. The participant exclusion criteria included visual or hearing impairment, amusia, any music-related pathology, and cognitive impairment.

Each participant signed a written informed consent form according to current ethical principles for research involving human subjects (World Medical Association Declaration of Helsinki, 2013), and they completed a questionnaire where sociodemographic and musical expertise information was requested.

4.2. Emotional memory evaluation

The material for the emotional memory task consisted of 48 pictures selected from the International Affective Pictures System (IAPS; Lang, 1995 According to previous works (Kilpatrick & Cahill, 2003; Justel, Psyrdellis, & Ruetti, 2014), the researchers selected the negative and neutral pictures, which covered a wide range of arousal (from 3.44 to 6.36) and valence (from 2.36 to 5.01) in line with the manual by Lang (1995).

4.3. Conditions

The conditions were the same as those used in Study 1.

4.4. Experimental design

Because there were two interventions (Music Condition vs. Control Condition) the participants had different musical expertise (Musicians vs Non-musicians), and two types of images (neutral and negative, as a within measure) were employed, a 2(Conditions) × 2(Training) x 2(Image) experimental design was run, with four groups (since image was a within measure) with the following number of subjects: (1) M/MC: musicians' music group ($n = 19$); (2) M/CTRL: musicians' control group ($n = 16$); (3) NM/MC: non-musicians' music group ($n = 26$); and (4) NM/CTRL: non-musicians' control group ($n = 22$). Participants were randomly and blindly assigned to the different conditions (Music or Control Condition), and they were always tested in groups.

4.5. Procedure

Conditions were the same as those used in Study 1. The only difference was that participants observed **negative** and neutral pictures instead of positive and neutral ones.

4.6. Data analysis

Age, years of Academic Education, and years of Musical Education were analyzed independently via univariate analysis of variance (ANOVA), where *Conditions* (Music Condition vs Control Condition) and *Training* (Musicians vs Non-musicians) were the between-factors.

Because there were differences related to Academic Education (data shown in Results), Arousal was analyzed with repeated measures (RM) Analysis of co-Variance (ANCOVA) in which *Training* (Musicians vs Non-musicians) was the between factor, and *Image* (Neutral and Positive) was the within factor (RM).

Table 2. Sociodemographic and memory performance in Study 2

	M/MC	M/CTRL	NM/MC	NM/CTRL
	Mean (*SD*)	Mean (*SD*)	Mean (*SD*)	Mean (*SD*)
Sociodemographic				
Age	29.21 (0.66)	20.06 (0.33)	29.08 (0.47)	26.45 (0.63)
Academic education	17.95 (0.45)	14.75 (0.27)	16.46 (0.29)	15.05 (0.29)
Music education	8.32 (0.45)	9.75 (0.48)	0.92 (0.23)	0.75 (0.23)
Arousal				
Neutral image	2.73 (0.24)	2.85 (0.20)	2.65 (0.23)	2.27 (0.24)
Negative image	7.43 (0.22)	7.72 (0.25)	7.43 (0.23)	7.23 (0.23)
Immediate Free Recall				
Neutral image	10 (0.41)	6.25 (0.45)	10.20 (0.33)	7.23 (0.41)
Negative image	15.63 (0.42)	10.88 (0.56)	13.88 (0.40)	11.50 (0.43)
Immediate Recognition				
Neutral image	23.74 (0.20)	23.38 (0.20)	21.81 (0.41)	23.68 (0.16)
Negative image	22.68 (0.20)	21.94 (0.27)	20.12 (0.48)	22.91 (0.12)
Deferred Free Recall				
Neutral image	9.68 (0.45)	5.69 (0.49)	9.23 (0.39)	8.09 (0.35)
Negative image	14 (0.41)	7.85 (0.61)	11.73 (0.40)	11.50 (0.42)
Deferred Recognition				
Neutral image	22.21 (0.24)	21.92 (0.19)	21.27 (0.30)	21.68 (0.29)
Negative image	22 (0.25)	22.08 (0.26)	21.08 (0.30)	20.59 (0.40)

Free recall and recognition (immediate and deferred) were analyzed independently via repeated measures (RM) with an analysis of covariance (ANCOVA). *Conditions* (Music Condition vs Control) and *Training* (Musicians vs Non-musicians) as the between factors, and *Image* (Neutral and Positive) and *Time* (Immediate vs deferred) as the within factor (RM).

Post-hoc least-significant difference (LSD) pairwise comparisons were conducted to analyze significant main effects and significant interactions. The partial Eta square (η^2 p) was utilized to estimate effect size. The alpha value was set at .05, and the SPSS software package was used to compute descriptive and inferential statistics.

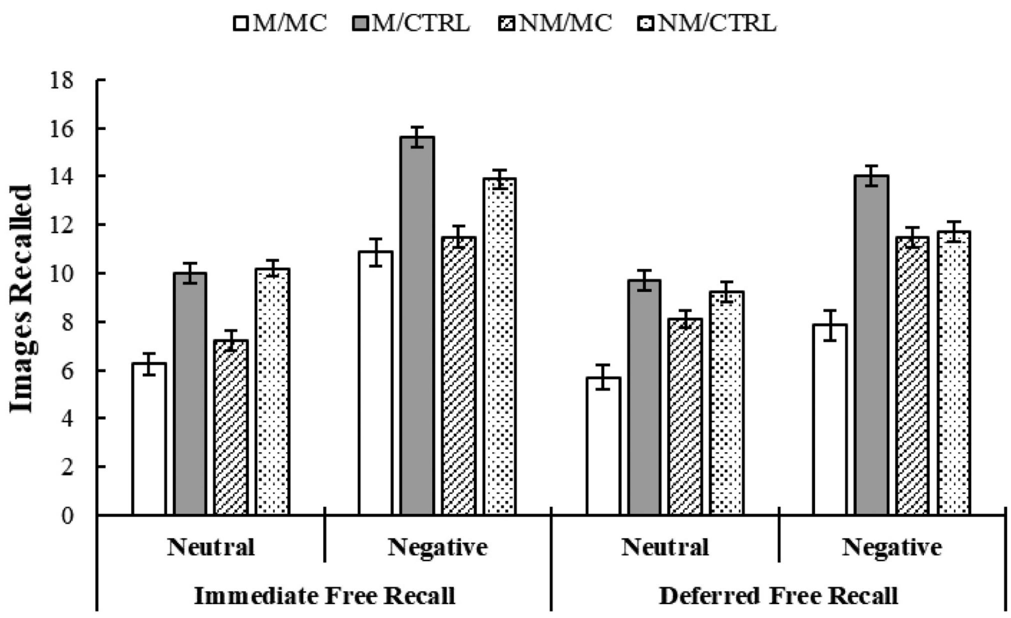
4.7. Results

The sociodemographic information indicated that the groups were balanced in terms of age and differentiated in terms of music education (musicians had an average of 8.97 years of music training, $p < .001$). However, significant differences emerged in Academic Education for Conditions $F(1, 79) = 19.674$, $p < .0001$, η^2 $p = .199$, which indicated that participants in the MC group had more years of academic education ($M = 17.02$) than participants in the CTRL group ($M = 14.98$). For this reason, Academic Education was incorporated as a covariable in the analysis of memory performance. All results are shown in Table 2.

4.7.1. Arousal

The ANCOVA indicated a significant effect for Image $F(1,80) = 26.27$, $p < .0001$, η^2 $p = .247$, which indicated that negative images were more arousing than neutral ones.

Figure 2. Free Recall Measure in Study 2.



4.7.2. Free recall

Immediately after exposure to each condition (Music Condition vs Control Condition) and seven days later (deferred measure) the participants were asked to recall as many images as possible (see Figure 2). The ANCOVA indicated a significant effect for Image $F(1,74) = 5.226$, $p = .025$, η^2 $p = .266$, negative images were better recalled than neutral ones $p < .0001$. The effect of Condition was significant $F(1,74) = 17.197$, $p < .001$, η^2 $p = .189$, the Music Condition recalled more images than the Control Condition $p < .0001$. The double interaction Training x Condition yielded significant differences $F(1,74) = 4.585$, $p = .036$, η^2 $p = .058$, the musicians that listened to music recalled more images than musicians that listened to white noise $p < .0001$. Finally, the triple interaction Image x Condition x Training showed significant differences $F(1,74) = 5.677$, $p = .020$, η^2 $p = .071$, the *post-hoc* test indicated that musicians in the Music Condition recalled more negative ($p < .0001$) and neutral ($p = .001$) images compared to musicians in the Control Condition. Likewise, non-musicians in the Music Condition recalled more neutral images than non-musicians in the Control Condition ($p = .011$). No other significant differences in recall tests were found ($p > .05$).

4.7.3. Recognition

After the free recall (immediate and deferred), the participants observed the 48 original images randomly, intermixed with 48 new ones (Table 2). They had to discriminate the new images from the original ones (recognition task). False Alarms (new items incorrectly recognized as old) were subtracted from Hits (correctly recognized old items) to calculate overall recognition. The ANCOVA showed a significant effect for Image $F(1,75) = 8.857$, $p = .004$, η^2 $p = .106$which indicated that participants recognized more neutral images than negative ones. No other significant differences were found ($p > .05$).

Alt text. Bars figure indicating immediate and Deferred Free Recall. Images that the participants recalled after they were exposed to the interventions and seven days later. M/MC (musicians who listened to music); M/CTRL (musicians who listened to white noise); NM/MC (non-musicians who listened to music); NM/CTRL (non-musicians who listened to white noise). The vertical lines indicate the standard error.

In summary, the results show that participants recalled more negative than neutral images; however, they recognized more neutral than negative ones. Besides, the Music Condition recalled more images than the Control Condition.

5. Discussion

The present study examined the effect of listening to music on the emotional memory of musicians and non-musicians by employing two protocols, one with positive-neutral images and another with negative-neutral ones. The three principal predictions were that emotional information will be better recalled and recognized than neutral information, arousing music perception would modulate memory and that musicians would have a better memory performance than non-musicians. These predictions were partially corroborated since we found significant effects of music (as an intervention and training) only in study 2 with the negative-neutral images.

First, we expected participants to recall and recognize more emotional than neutral images. These predictions were partially corroborated since our results showed that participants recalled and recognized more positive images than neutral ones (Study 1), and they recalled more negative images than neutral ones (Study 2), nonetheless participants recognized more neutral images than neutral ones (Study 2). The results of Study 1 and recall of Study 2 agree with other studies that indicated that emotional stimuli are processed differently from non-emotional stimuli, the former being better recalled over time (Cahill & McGaugh, 1998; V. Diaz Abrahan & Justel, 2019; Justel et al., 2016; McGaugh, 2004). The emotional stimuli attract more attention (Talmi, 2013). From an evolutionary perspective, the emotional arousal, appetitive or aversive, signals an event or stimulus which would have immediate or deferred relevance for survival. Consequently, the initial level of activation and the posterior recall is an adaptation mechanism, which guarantees that important information is available in future occasions (McGaugh, 2000).

Regarding the recognition in Study 2, different studies, especially those related to emotional memory, reported the recognition of neutral images over emotional ones. Hourihan and Bursey (2017) conducted an experiment in which participants studied a mixed series of emotional and neutral images. Participants then completed an old/new recognition test. Participants consistently showed significantly higher recognition for neutral than emotional images. Musical studies with emotional memory found the same pattern of results in recognition tasks (Diaz Abrahan, Bossio, et al., 2019; Lopez et al., 2021). However, the neural and cognitive mechanisms that characterize the recognition task and differentiate it from free recall are still under evaluation (Robinson & Johnson, 1996; Sadeh et al., 2012; Wixted & Squire, 2010). More research is needed on the topic.

As a second prediction we expected that listening to arousing music would modulate memory, therefore participants who listened to music would recall and recognize more information than participants in the control condition. This prediction was partially corroborated since we found controversial results in the recall measures and no results regarding this topic in the recognition measures. Our results showed that in Study 1 with positive and neutral images participants who listened white noise recalled more images than participants who listened to music (only in the immediate measures); however, in Study 2, with negative and neutral images participants who listened to music recalled more images than participants in the control condition (immediate and deferred measures).

Research that uses music perception or production to modulate different types of memory justifies its effect on the positive emotional state that such musical experiences generate in the participants (V. Diaz Abrahan & Justel, 2019; Diaz Abrahan, Shifres, et al., 2019; Diaz Abrahan et al., 2020b, 2021; Justel & Rubinstein, 2013; Justel et al., 2016; Moltrasio, Detlefsen, et al., 2020). Although the present study is behavioral, neuroanatomical evidence could justify the results. Interventions or strategies that induce emotional states modulate memory acquisition and consolidation through amygdala stimulation and activation of hippocampal projections (Mickley Steinmetz et al., 2010; Shields et al., 2017; Tambini et al., 2017). In our study, this emotional induction through arousing music could have been weak or insufficient to affect positive images of the Study 1 (and the neutral ones that accompany the positive ones) but it is a possible explanation for the results of Study 2, which employed negative and neutral images. The amygdala plays a critical role in the valence effect. Coding of negative material involves more brain areas related to emotional processing than that of positive material (Mickley & Kensinger, 2008). For negative information, arousal increased the strength of amygdala connections to other emotional brain areas while, for positive information, arousal decreased the strength of these amygdala efferent pathways (Mickley Steinmetz et al., 2010). Evidence from lesion studies shows that the amygdala would be more involved in the recall of negative stimuli than in that of positive stimuli (Tranel et al., 2006). More studies are necessary to elucidate this potential difference between the effects of arousing music on different kinds of stimuli.

Our third prediction was that musicians would have a better memory performance than non-musicians. This prediction was not corroborated since the only difference regarding musicianship is related to an interaction in Study 2, where musicians that listened to music recalled more negative and neutral images than musicians in the control condition, and for non-musicians this effect was only for neutral but not negative images. One possible explanation is that listening to music could have a greater emotional effect on musicians, generating an optimal emotional level that would modulate memory. Becoming a musician involves training in a variety of musical and non-musical skills (Justel & Diaz Abrahan, 2012). This training generates a great activity in cerebral areas involved in emotion when musicians experience music (Beaty et al., 2016). Another possible explanation is related to the *function theory*, which explains the effect of emotional states on the acquisition of information (Forgas, 1999) where negative moods (in our case induced by a protocol with negative images) lead to more systematic and analytic processing strategies (Forgas, 1992; Tesoriero & Rickard, 2012). Musicians are characterized by analytical cognitive processing due to their musical training (Justel & Diaz Abrahan, 2012), and by listening to music, musicians may reinforce analytical processing, which facilitates recall of information.

Even though positive and negative emotional images were rated as more arousing than neutral ones (arousal measure) by the subjects in both studies, we found that music affected memory only in the protocol with the negative images. In this sense, it was the valence of the stimuli and not the arousal that determined the difference in recall between studies. There is evidence showing differences in perception and processing according to the emotional valence of the stimulus (Berntson et al., 2007; Crossfield & Damian, 2019). An important point is the music factor that cuts across both studies. The interaction between music and the differential processing of images could explain the differences.

The results of Study 2 were stronger in general terms than those of Study 1 since more results were found in the second study than in the first one. This could be explained from the theory of the negativity bias (Alexander et al., 2010; Leventon et al., 2014; Van Bergen et al., 2015). From an evolutionary perspective, the negative events must be recalled strongly to avoid future danger (Vaish et al., 2008), therefore the negative life experiences had a deeper and long-lasting emotional effect than the positive ones (Sheldon et al., 1996). This overestimation of the negative generates major efforts in physiological, cognitive, and behavioral levels (S. E. Taylor, 1991). The negative stimuli imply a cognitive effort, attract more attention and are more salient and complex than positive ones (Cordon et al., 2013).

5.1. Limitations and future directions

Our study had some limitations. One of them is the gender distribution across the sample. In both studies, 71% of the participants were women. Future studies could extend the sample. Besides, it would be interesting to study a different type of sample, such as older adults, and different types of memory, like non-emotional or procedural memory. Another important point to be considered in the future is the homogenization of the sample in terms of academic education. Although we opted for analysis of covariance to solve the differences between the groups, future studies could recruit participants with the same mean education. In addition, the musical piece used was tested in several studies in the literature; however, it would be interesting to evaluate the effect of other musical genres or songs associated with the context of each research group and community of participants.

Finally, the most important idea for future research that emerges from the present study is the need for an experiment that compares the effect of music on negative and neutral stimuli separately. This could be useful as a potential treatment of psychiatric disorders that affect memory, such as Post-Traumatic Stress Disorder.

6. Conclusion

The findings of these two studies provide a novel demonstration of the different effects of music on emotional memory depending on the emotional valence of the stimuli. By introducing music after an emotional learning task, we found that listening to music modulates the retrieval of negative-neutral images, but not positive-neutral ones.

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Disclosure statement
No potential conflict of interest was reported by the author(s).

Authors statement
All data are available in: https://osf.io/a6pv8/?view_only=4e3548969322498496498f06f814b7a1. The protocols employed could be found in http://linc.com.ar/#!/-ciencia-abierta/

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