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RESEARCH ARTICLE

Impact of music-based intervention on verbal memory: an experimental behavioral study with older adults

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Abstract
Normal age-related declines have been reported in different cognitive functions, such as episodic memory. Some environmental factors have the potential to reduce cognitive decline and promote healthy aging. In this research, we employed musical improvisation as a focal music-based intervention to explore its effects as a modulator of verbal memory. We evaluated two types of verbal memory: a neutral one, employing the Rey Auditory Verbal Learning Test (Study 1), and an emotional one, implementing the Spanish version of Affective Norms for English Words (Study 2) in a volunteer group of older adults. After the acquisition of neutral (Study 1) or emotional (Study 2) verbal information, the participants were exposed to musical improvisation (experimental condition) or two control conditions (rhythmic reproduction as a musically active control condition or a rest condition as a passive control condition) for 3 min. Then, memory was evaluated through two memory tasks (immediate and deferred free-recall and recognition tests). In both studies, we compared memory performance among musicians (with five or more years of music training) and non-musicians. We found a significant improvement in neutral verbal memory among participants involved in musical improvisation, who remembered more words than those in the control conditions. Differences were also found according to the musical experience of the sample, with musicians outperforming non-musicians. The current research supports the late-life cognitive benefits of music-based intervention and music training.

Keywords Music-based intervention · Musical improvisation · Music training · Verbal memory · Aging

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Introduction

The cognitive neuroscience of aging is a growing disciplinary area that studies the factors and mechanisms that affect aging at neuroanatomic and cognitive levels (Diaz and Pereiro 2018). Cognitive changes are a consequence of aging, a period of life when several cognitive functions are affected. Normal age-related declines have been reported in different cognitive functions, such as attention, processing speed, working memory, spatial skills, and reasoning (Erel and Levy 2016; Grandi and Tirapu-Ustárroz 2017; Hedden and Gabrieli 2004; Salthouse 2010), among others. A cognitive function that received special interest is memory, defined as the capacity that allows the storage of new information for later restitution or evocation with a specific goal (Alberini and LeDoux 2013; McGaugh 2002). Short-term memory (Rhodes and Katz 2017), working memory (Rieckmann et al. 2017), and long-term episodic memory (Fjell et al. 2016) are the memory systems most affected by aging.

However, the aging process and its consequent cognitive decline show inter-individual differences (Fauvel et al.

2014). Hence, the interest in brain plasticity during adulthood and the environmental factors that could affect aging has increased, with special emphasis on the factors that impact on cognitive reserve, i.e., the compensatory neurocognitive mechanisms that attempt to maximize the performance against brain damage or deterioration through the use of structures or non-compromised brain networks (Stern 2009; Stern et al. 2018). Several investigations have identified specific protective factors that benefit cognition in old age, such as physical activity (Erickson et al. 2011), educational level (Evans et al. 1993), type and level of occupation (Adam et al. 2013), intellectual skills, social interactions, and lifestyle activities (Seinfeld et al. 2013; Wang et al. 2012). Some of these protective factors have been associated with a lower risk of dementia (Hall et al. 2009; Verghese et al. 2003; Wilson et al. 2002).

Music has also been identified as a protective factor (Kraus and Chandrasekaran 2010; Skoe and Kraus 2012). Studies suggest that long-term music learning and some musical activities promote healthy cognitive development throughout lifetime (Hanna-Pladdy and Gajewski 2012; Strong and Mast 2018; Thaut and Hoemberg 2014) and that they could mitigate the cognitive deterioration that emerges in the aging process (Wang and Schlaug 2010), influencing the neuroendocrine and autonomic nervous system (Chanda and Levitin 2013). In addition, music activates the brain extensively, engaging temporal, frontal, parietal, and limbic regions (Benz et al. 2016; Justel and Diaz 2012; Zatorre et al. 2007; Zhao et al. 2017; Zuk et al. 2014). Nevertheless, music is a complex phenomenon and the proposals that emerge from it are innumerable (Peretz 2006). For this reason, recent research has specialized in identifying the specific effect of music-based interventions by isolating its musical components (Särkämö 2018; Särkämö et al. 2016). In this framework, those interventions that involve active (e.g., music playing, singing, dancing; Schneider et al. 2018) and receptive proposals (e.g., music listening; Särkämö et al. 2008) have been studied. One benefit of these interventions is that they are flexible enough to be employed regardless of the participants' formal knowledge of music (Diaz Abrahan et al. 2019).

By linking music and memory, different lines of research have investigated the efficacy of acute or focal music-based interventions, focusing either on perceptive or receptive activities (Ferreri et al. 2013; Ferreri and Rodriguez-Fornells 2017; Justel and Rubinstein 2013; Justel et al. 2016; Ratovohery et al. 2018). For example, Judde and Rickard (2010) had adults listen to music for 3 min (with positive or negative valence, experimental groups) or white noise (control group) after the acquisition of verbal information. Their results indicated that both experimental groups had better deferred memory performance than the control group. Similar results were found by Justel et al. (2015). On the other hand, studies on music-based interventions that involve music-making are scarce.

Divergent thinking, the ability to generate ideas, was significantly associated with episodic memory (Addis et al. 2016; Madore et al. 2019). This relationship is justified by the associative cognitive mechanisms involved in the divergent thinking task. In the music field, music improvisation, the ability to generate music, also showed this type of association (Limb and Braun 2008). Indeed, creative musical tasks involve decision-making processes and activates several cortical and subcortical areas, such as the premotor cortex, supplementary motor areas, language areas, insula, cingulate cortex, medial prefrontal cortex, and temporal areas (Beaty 2015; Engel and Keller 2011; Loui 2018; McPherson et al. 2014).

The cognitive associative demands involved in the creation of music engage memory and other cognitive functions. Our research team has focused on this line of research by investigating the effect of a creative musical activity. We employed musical improvisation, from a music-therapy perspective, as a cognitive modulator (Diaz Abrahan et al. 2019). In this study, older adults watched neutral and emotional images and were then randomly exposed to one of three different interventions: a free musical improvisation, the imitation of a rhythmic pattern, or a period when the participants remained silent. The findings indicated that the participants in the improvisation group remembered more neutral and emotional information than the other groups. Similar results were found with young adults (Diaz Abrahan et al. 2018, 2019). However, not all types of memory were evaluated under this approach, and how musical interventions would impact verbal learning is still unknown.

Finally, the samples are frequently divided depending on their formal knowledge of music, since it is known that music learning and practice generate a brain adaptation that affects the cognitive performance (Justel and Diaz 2012). Long-term musical practice seems to prevent age-related decline in higher-order cognitive functions such as non-verbal memory, naming, and executive processes (Hanna-Pladdy and MacKay 2011). However, the results are controversial since some studies found positive associations and correlations between music and cognition (Franklin et al. 2008; Hanna-Pladdy and MacKay 2011), but others did not (Fauvel et al. 2014).

The current study

Following the methodology used in previous studies (Diaz Abrahan et al. 2018, 2019), the goal of our work was twofold: (1) to investigate the effect of free musical improvisation, as a focal music-based intervention, on the verbal memory of older adults and (2) to determine whether musical expertise protects the aging brain from deterioration of verbal memory. Therefore, we present two studies in which the effect of musical improvisation was compared with two control activities (active and passive) in a neutral (Study 1) and an emotional (Study 2) verbal memory task. In both studies, formal musical experience was taken as a between-subjects factor. We predicted that musical improvisation would improve neutral and emotional verbal memory and expected musicians to have better mnemonic performance than non-musicians.

Study 1: neutral verbal memory

Participants

A priori power analysis revealed that to detect a small- to medium-sized effect ($\eta^2=.06$) with 90% power, the study required total sample size of 78 (software G*power, Faul et al. 2007), based on a previous study (Diaz Abrahan et al. 2019). Eighty-four volunteers aged between 60 and 90 ($M=72.28$; SD = .81) participated in this study (81% women). Twenty-four were musicians (M) with more than 5 years of formal and/or informal music training (schools, institutes, music conservatories, private practice), and 64 were considered non-musicians (NM). They were recruited from different adult day programs and music conservatories through online announcements. The participant exclusion criteria included visual or hearing impairment, amusia, or any music-related pathology, cognitive impairment, and depression. Musicians had an average of 19 years of music training, and 26% of them were not musically active, while the remaining 74% were. In the musicians' sample, 44.8% played string instruments (piano and violin mostly), 10.03% wind instruments (flute and harmonica), 13.79% percussion instruments, and 31.03% were singers. Non-musicians had less than 6 months of musical experience, and only two volunteers reported playing guitar. 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 completed a questionnaire where sociodemographic and musical expertise information was requested. The procedure was approved by the University of Buenos Aires Ethics Committee.

Measures

General cognitive state evaluation

Standardized psychometric tests were used to evaluate the general cognitive state (administered individually at the beginning of the procedure). The Mini Mental State Examination (MMSE, Folstein et al. 1975) was employed as a screening test to evaluate cognitive impairment. Scores between 9 and 11 are considered to be within the dementia range, scores between 12 and 24 signal cognitive impairment, and scores between 24 and 26 suggest sensitivity to dementia. For schooled participants under 75 years of age, 27 points were the cut score; when the schooled participants were over 75 years of age, 26 was the score selected to exclude participants (Butman et al. 2001). The Yesavage Geriatric Depression Scale (GDS, Martinez de la Iglesia et al. 2002; Sheikh and Yesavage 1986) was administered to measure depression specifically in older adults by assessing anhedonia, sadness, loss of interest, etc. Scores between 0 and 10 are considered to be within the normal range, scores 11–14 show sensitivity to depression, and scores over 14 signal depression. In this work, participants with a score of 11 or higher were excluded.

Verbal memory evaluation

The Rey Auditory Verbal Learning Test was used to evaluate neutral verbal memory (RAVLT, Dalmás 1993; Rey 1941, 1964; Ryan and Geisser 1986). The dependent variables of memory performance were the number of words recalled and recognized, immediately and deferred. The list was reproduced in wma format, with a Flip 3 JBL speaker (volume intensity according to the hearing of older adults), with an inter-word interval of 9 s for the acquisition task, and 7 s for the recognition task.

Interventions

Music improvisation (MI)

A music-therapy perspective of improvisation was used. During these real-time musical experiences, different sounds, melodies, and rhythms are created and combined spontaneously with the available resources, according to the possibilities of the subject in musical interaction with other people (Bruscia 1998, 1999; Wigram 2004). For this reason, musical improvisation is considered a musical experience that is flexible enough to be adapted to people with and without musical skills (Diaz Abrahan et al. 2018). Although non-musicians are not trained to play pieces of music, they are able to improvise and create melodies and rhythms (Sági and Vitányi 1988). In this study, the researcher performed a rhythmic pattern of two 4/4 bars played as a loop (ostinato), with a percussion instrument at a medium volume, during 3 min as a base, encouraging participants to join the performance (Diaz Abrahan et al. 2018, 2019). For this musical intervention, the participants were allowed to choose either percussion instruments (e.g., drums, maracas, bells, woodblocks, shakers, and tambourine) or melodic/harmonic instruments (e.g., guitar, melodica, xylophone, flutes). These instruments were included because they were easy to play. After choosing a musical instrument, the participants combined and produced musical patterns with the instruments or their voices or bodies, spontaneously creating some musical feature fitting the context provided by the base pattern.

Rhythmic imitation (RI)

The researcher performed a rhythmic pattern as a loop, the one used in MI, repeatedly during 3 min as a model to be imitated by the participants with their instruments, voices, or bodies (the participants could choose from the same array of musical instruments as that used in the improvisation intervention). This pattern was performed with a percussion instrument at a medium volume. The instructions included imitating the pattern heard as faithfully as possible, avoiding variations or new musical materials. This intervention was designed as an active control condition, and it was meant to control for possible effects of movements, music perception, and musical instruments, among others, that could explain the results.

Rest (REST)

The participants remained seated and silent for 3 min. They were asked not to write in their notebooks and not to use cell phones or have conversations with each other. This intervention was designed as a passive control condition, without sound or movement.

General procedure

A schematic design of the general procedure is depicted in Fig. 1. The study was divided into two sessions separated by a 1-week inter-session interval.

In the first session, four immediately consecutive phases were performed. In the first phase (information phase, 15 min), the participants signed the informed consent form and completed the sociodemographic and musical background questionnaire. Then, the MMSE and GDS tests were individually administered. In the second phase (acquisition, 9 min), the participants listened to the 15 words from RAVLT once. Simultaneously, they were asked to rate on a 0–10 scale "how emotional" or "activating" they felt each word was. This evaluation aimed to keep the attention of the participants during the task and to use the procedure implemented in Study 2. In the third phase (treatment phase, 3 min), the participants were exposed to the interventions (music improvisation, rhythmic imitation, or rest). They were randomly and blindly assigned to the different groups and always tested in groups, with a minimum of four and a maximum of 10 participants, to control the involvement of each participant in the music performance. In the musical improvisation intervention (Diaz Abrahan et al. 2018, 2019), the participants were instructed as follows: "We will listen to a rhythmic base, from which you have to create something musical as a group. This rhythmic base will help you to start the improvisation at any time you want. You can use instruments, your voice or your body. It is important to listen not only to the base but also to your group". In the rhythmic imitation intervention, the participants were instructed as follows: "We will listen to a rhythmic base and, anytime you want, you can start to imitate me. You can use instruments, your voice or your body". The rest condition was instructed as follows: "We ask you to remain silent and please do not do anything for a few minutes". Before starting, the researcher corroborated that all the participants had understood the instructions. Then, the participants freely chose the musical instrument that they wished to play (MI and RI interventions), and they performed the improvisation or rhythmic imitation task in groups for 3 min, while the REST group remained seated together and silent for 3 min. Soon afterward, the fourth phase (test phase, 11 min), a two-task memory test, was run. Participants were given paper and pencil to write down as many words as they could remember from the RAVLT (*Immediate Free Recall* task), and then the 15 words of the RAVLT were mixed with 15 new words and the participants were asked to indicate whether they had listened to the item before or not (*Immediate Recognition* task).

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

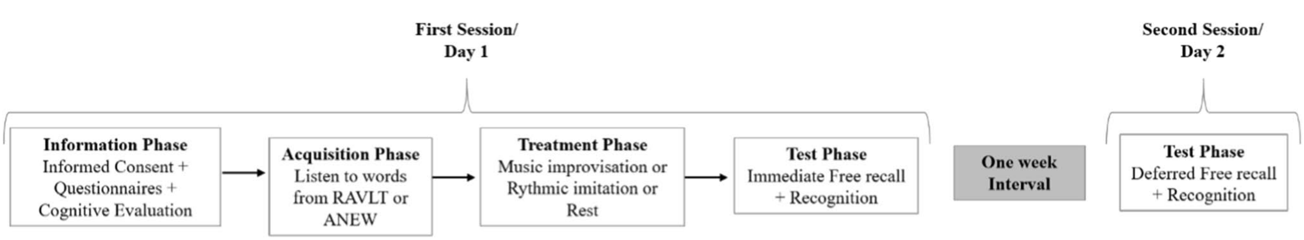

Fig. 1 Scheme of the general procedure used in Studies 1 and 2

Musical experience analysis

To ensure that each group complied with the instructions given, three external evaluators were recruited to watch the videotapes and assess the following parameters using a 5-point scale: (1) the level of detachment from the rhythmic base, (2) the presence and variation of melodic patterns, (3) the degree of participation of each participant, and (4) the degree of creativity in the music production. In order to estimate the inter-rate reliability, the correlation between evaluators was analyzed. The Pearson correlation results showed a high level of agreement $r(9) = .915$, $p < .01$.

Data analysis

Age, years of Academic Education, and years of Musical Education were analyzed independently via univariate analysis of variance (ANOVA), where *Intervention* (Music Improvisation vs Rhythmic Imitation vs Rest) and *Training* (Musicians vs Non-musicians) were the between factors, while Sex was analyzed via χ^2.

Free recall and recognition (immediate and deferred) were analyzed independently with an analysis of covariance (ANCOVA). The between factors were Intervention (Music Improvisation vs Rhythmic Imitation vs Rest) and Training (musicians vs non-musicians), while Sex, Age, and Academic Education were the co-variables used to ensure that the factors were isolated.

Post hoc least-significant difference (LSD) pairwise comparisons were conducted to analyze significant main effects and significant interactions. The partial Eta square ($\eta^2 p$) 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.

Results

Sample characteristics

The final sample was composed of 78 participants because six evaluations were discarded due to cognitive deficit and/or depression. The final number of participants per group was as follows: M/MI = 10; M/RI = 10; M/REST = 12; NM/MI = 13; NM/RI = 19; and NM/REST = 14.

Regarding sociodemographic information, the groups were balanced in terms of Age and Academic Education, but significant differences emerged for Sex, regarding the Training factor, $\chi^2 = 8.01$, $p = .005$. Regarding Music Education, the ANOVA indicated significant differences in Training $F(1, 71) = 70.88$, $p < .0001$, $\eta^2 p = .500$, where musicians had a higher music education than non-musicians, as expected, and the ANOVA also indicated a main effect of Intervention $F(2, 71) = 3.86$, $p = .026$, $\eta^2 p = .098$ and a significant effect in the double interaction Training x Intervention $F(2, 71) = 4.30$, $p = .017$, $\eta^2 p = .108$, which indicated that musicians who participated in the musical improvisation intervention had fewer years of musical experience than the musicians who participated in the other two interventions (Table 1).

Memory performance

Immediate measures

After the interventions (improvisation, rhythmic imitation, or rest), the participants were asked to recall as many words as possible. The ANCOVA yielded no significant differences for free recall ($p > .05$).

After the free recall, the participants listened to the 15 original RAVLT words randomly, intermixed with 15 new ones. They had to discriminate the new words from the original ones (recognition task). False recognitions were

Table 1 Sociodemographic and general cognitive state information from Study 1

Groups	Age		Academic education		Music education		MMSE		GDS		Sex (%)
	M	SD	*M*	SD	*M*	SD	*M*	SD	*M*	SD	Women
M/MI	65.40	.65	14.50	1.32	10.40	1.61	29.43	.29	2.71	.48	90
M/RI	70.60	3.42	14.60	1.09	25.40	6.20	27.90	.33	4.90	.58	50
M/REST	71.25	2.93	15.33	.71	24.17	4.65	28.40	.34	4.73	.61	42
NM/MI	69.38	1.73	14.00	1.43	.75	.39	28.75	.32	4.62	.85	100
NM/RI	73.21	1.51	13.47	.93	.21	– 12.00	28.57	.22	4.32	.63	90
NM/REST	69.64	1.13	15.86	.51	.57	.33	28.14	.27	4.57	.71	86

Mean and standard deviation, for age, years of academic education, years of musical education, MMSE, and GDS

M/MI: musicians' improvisation group; M/RI: musicians' rhythmic imitation group; M/REST, musicians' rest group; NM/MI, non-musicians' improvisation group; NM/RI, non-musicians' rhythmic imitation group; NM/REST, non-musicians' rest group subtracted from the total recognition score. The ANCOVA yielded no significant differences for free recall ($p > .05$).

Deferred measures

The two memory tests were administered again a week after the first session. Figure 2a illustrates the results of the deferred free-recall task. The ANCOVA indicated a main effect of Training $F(1, 58) = 5.118$, $p = .027$, $\eta^2 p = .081$ and Intervention $F(2, 58) = 19.653$, $p < .0001$, $\eta^2 p = .404$. The post hoc analysis showed that the musicians remembered more words than the non-musicians ($p = .027$) and that the musical improvisation groups remembered more words than the other two interventions (rhythmic imitation and rest; $p < .001$).

The second memory task was recognition, illustrated in Fig. 2b. The ANCOVA indicated a main effect of Intervention $F(2, 58) = 5.69$, $p = .006$, $\eta^2 p = .164$, and the post hoc analysis showed that the musical improvisation groups recognized more words than did the rhythmic imitation ($p = .013$) and rest ($p = .002$) groups.

Study 2: emotional verbal memory

Participants

Ninety-one new volunteers participated in this study (81% women), and they were aged between 60 and 90 ($M = 71.91$; $SD = .85$). Twenty-four were musicians (M) with more than

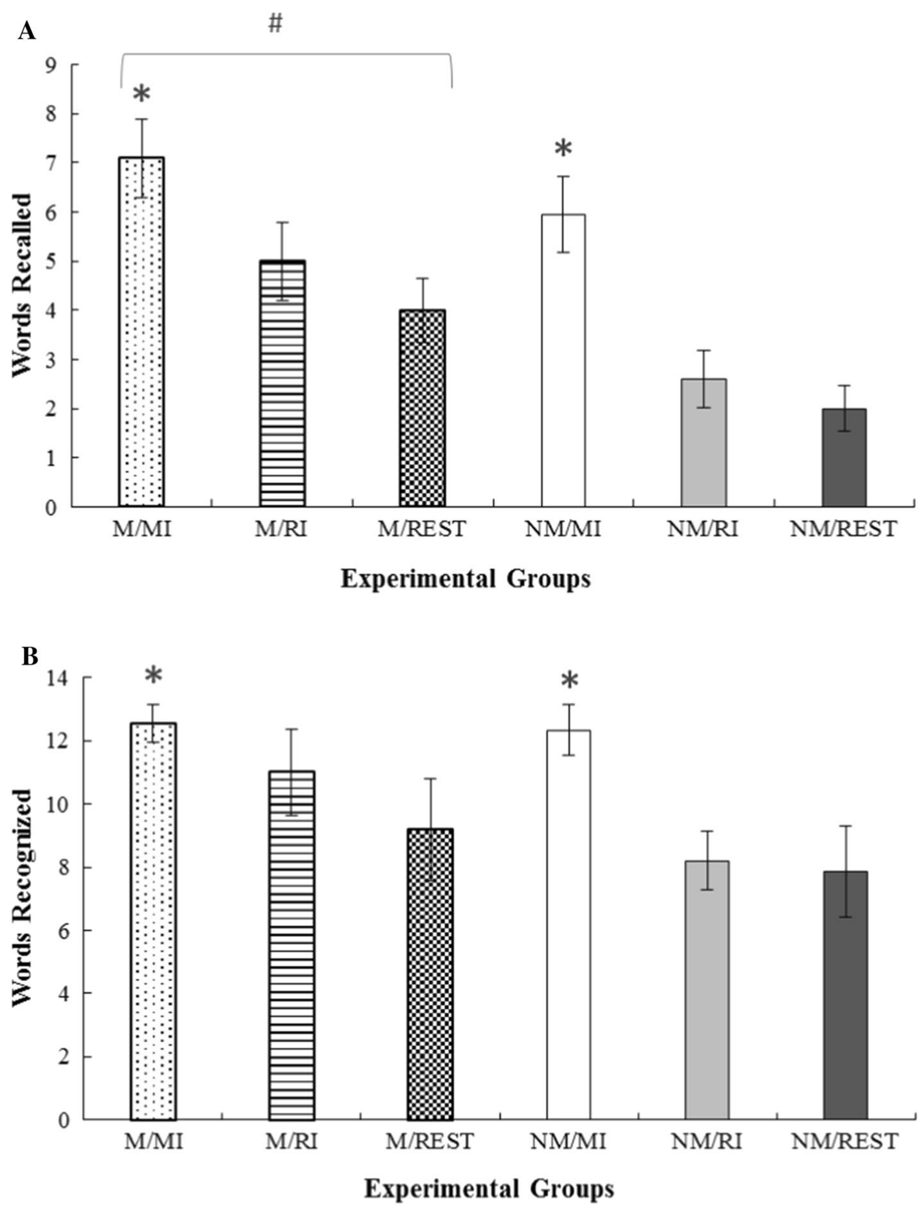

Fig. 2 Deferred free recall and recognition. Mean number of words that the groups could remember (**a**) and recognize (**b**) a week after the first session. M/MI: musicians' improvisation group; M/RI: musicians' rhythmic imitation group; M/REST: musicians' rest group; NM/MI: non-musicians' improvisation group; NM/RI: non-musicians' rhythmic imitation group; NM/REST: non-musicians' rest group. *Significant differences in Intervention, #Significant differences in Training. Vertical lines represent standard errors of the mean

5 years of formal and/or informal music training (schools, institutes, music conservatories, private practice). Fifty-seven were considered non-musicians (NM). Musicians had an average number of 17 years of musical experience, 63% of the musicians were not musically active, while 37% were. In the musicians' sample, 56.66% performed string instruments (piano and violin mostly), 2.66% wind instruments (flute and harmonica), and 36.66% were singers. Non-musicians had formal music training of less than 3 months and only two volunteers reported playing guitar and piano. The exclusion criteria, recruitment criteria, and ethical aspects were those used in Study 1.

Measures

General cognitive state evaluation

See Study 1.

Emotional memory evaluation

Thirty-six words were selected from the Spanish version of the *Affective Norms for English Words* (ANEW, Bradley and Lang 1999; Redondo et al. 2007). Twenty-four words were emotionally arousing (12 with positive valence and 12 with negative valence), and 12 were non-arousing, neutral words. Following guidelines from previous works (Bradley and Lang 1999), we selected the words that covered a wide range of arousal (from 3.99 to 7.79) and valence (from 1.11 to 8.50). The dependent variables of memory were the number of words recalled and recognized, immediately and deferred.

Interventions

The interventions in Study 2 were the same as those in Study 1.

General procedure

This study was also performed in two sessions with a 1-week intersession interval (Fig. 1). The first session consisted of four immediately consecutive phases. The first phase was identical to that of Study 1. In the second phase (acquisition phase, 7 min), the participants listened to the 36 selected words for 7 s each. The words were presented in random order except for the first and last locations in the series, which were neutral words (Cahill et al. 2003). To validate the selection of the ANEW words for this research context, while listening to the words, the participants were asked to rate on a 0–10 scale "how emotional" or "activating" they felt each word was (from 0 = not arousing at all to 10 = highly arousing). The third phase (intervention) was identical to the one employed in Study 1. Soon afterward, in the fourth phase (test phase, 11 min), a two-task test was run. The participants were asked to write the words they could remember (*Immediate Free-Recall* task). Next, they listened to the 36 original words mixed with 36 new words in random order, and they were asked to mark on a sheet of paper if they had listened to the words before or not (Immediate Recognition task).

A week later, in the second session (11 min), the two-task memory test was run again (*Deferred Free-Recall* and *Recognition* tasks).

Data analysis

Age, years of Academic Education, and years of Musical Education were analyzed independently via univariate analysis of variance (ANOVA), where *Intervention* (Music Improvisation vs Rhythmic Imitation vs Rest) and *Training* (Musicians vs Non-musicians) were the between factors, while Sex was analyzed via χ^2.

Free recall and recognition (immediate and deferred) were analyzed independently with repeated-measures ANCOVA. The between factors were Intervention (Music Improvisation vs Rhythmic Imitation vs Rest) and Training (musicians vs non-musicians), while Word (neutral, positive, and negative) was the RM, and Sex, Age, and Academic Education were the co-variables, aimed at ensuring the isolation of the factors.

Post hoc least-significant difference (LSD) pairwise comparisons were made to analyze significant main effects or interactions. The partial Eta square ($\eta^2 p$) 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.

Results

Sample characteristics

The final sample consisted of 86 participants because four evaluations were discarded due to cognitive deficit and/or depression, and the final number of participants per group was as follows: M/MI = 13; M/RI = 10; M/REST = 10; NM/MI = 16; NM/RI = 21; and NM/REST = 16.

Regarding sociodemographic information, Sex yielded no significant differences, but Age did $F(1, 80) = 7.57$, $p = .007$, $\eta^2 p = .087$, with the non-musicians being older than the musicians. Also, Academic Education yielded significant differences $F(1, 75) = 19.46$, $p < .0001$, $\eta^2 p = .206$, with the musicians having a higher academic educational level than the non-musicians. Regarding Music Education, the ANOVA indicated significant differences in Training $F(1, 80) = 66.74$, $p < .0001$, $\eta^2 p = .455$, where the musicians had a higher music educational level than the non-musicians, as expected. The ANOVA also indicated a main effect of Intervention $F(2, 80)=4.11$, $p=.020$, $\eta^2p=.093$ and a significant effect for the double interaction Training x Intervention $F(2, 80)=4.21$, $p=.018$, $\eta^2p=.095$, which showed that the musicians who participated in the rhythmic imitation intervention had more years of musical experience than the musicians who participated in the other two interventions. Accordingly, Age and Academic Education were employed as co-variables (Table 2).

Memory

Immediate measures

The ANCOVA indicated a main effect of Word $F(2, 144)=3.233$, $p=.042$, $\eta^2p=.043$. The post hoc analysis showed that emotional words were better remembered than neutral words in the free-recall test ($p<.001$), and there were no differences between positive and negative words. No other significant differences were found in Intervention or Training factors in the free-recall and recognition tests ($p>.05$).

Deferred measures

The free-recall and recognition tasks were conducted again a week after the first session. Figure 3a shows the results of the free-recall task. The ANCOVA indicated a main effect of Training $F(1, 66)=12.89$, $p=.001$, $\eta^2p=.166$ The post hoc analysis showed that the musicians remembered more words than did the non-musicians ($p=.001$).

Figure 3b shows the results of the recognition task. The ANCOVA indicated a main effect of Training $F(1, 65)=10.70$, $p=.002$, $\eta^2p=.141$, and the post hoc analysis showed that the musicians recognized more words than did the non-musicians.

Discussion

The main goal of this investigation was to evaluate the effect of musical improvisation, as a focal music-based intervention, on neutral and emotional verbal memory in older adults. According to our previous studies, the first prediction was that musical improvisation would enhance both types of verbal memories. This prediction was confirmed to some extent. Overall, the results showed an effect of the type of intervention since the group involved in musical improvisation performed better than the other groups, though only in neutral verbal memory.

A novel approach to musical improvisation was implemented. Improvisation in music is generally associated with jazz, which requires high musical knowledge to for musicians to perform it (Limb and Braun 2008; Kleinmintz et al. 2014; McPherson and Limb 2013; McPherson et al. 2016). Here we opted for a music-therapy approach, where the technique has such flexibility that it can be applied to different populations, with or without musical knowledge (Abrahan and Justel 2015; MacDonald and Wilson 2014). In this perspective, the improvisation intervention was applied after learning of verbal information (neutral and emotional), and the performance was compared with two control groups.

Research on the effect of non-pharmacological or music-based interventions on the health of older adults has had methodological difficulties. For example, the studies that investigated *groups* of adults had no adequate control groups, which suggests that the positive effect of the interventions could be due to social variables (Belleville 2008; Reijnders et al. 2013). Therefore, we employed two different control groups, one active (rhythmic imitation) and one passive (rest) to control those variables that could explain the results. Musical improvisation, in comparison with rhythmic imitation and/or rest, enhanced recall

Table 2 Sociodemographic and general cognitive state data from study 2

Groups	Age		Academic education		Music education		MMSE		GDS		Sex (%)
	M	SD	*M*	SD	*M*	SD	*M*	SD	*M*	SD	Women
M/MI	68.38	1.51	16.46	1.13	11.62	2.27	27.75	.31	4.27	.90	90
M/RI	69.60	2.93	15.78	.86	26.10	6.76	28.71	.52	5.10	.99	40
M/REST	68.90	3.35	16.70	.94	15.60	4.21	29.13	.52	5.38	1.07	90
NM/MI	73.25	1.96	11.47	.94	.38	.27	27.83	.30	5.17	.88	87
NM/RI	72.52	1.78	11.37	1.23	.21	.15	28.78	.28	3.75	.80	90
NM/REST	76.06	1.82	14.06	.54	.04	.02	28.60	.34	3.92	.79	75

Mean and standard deviation, for age, years of academic education, years of musical education, MMSE, and GDS

M/MI: musicians' improvisation group; M/RI: musicians' rhythmic imitation group; M/REST: musicians' rest group; NM/MI: non-musicians' improvisation group; NM/RI: non-musicians' rhythmic imitation group; NM/REST: non-musicians' rest group

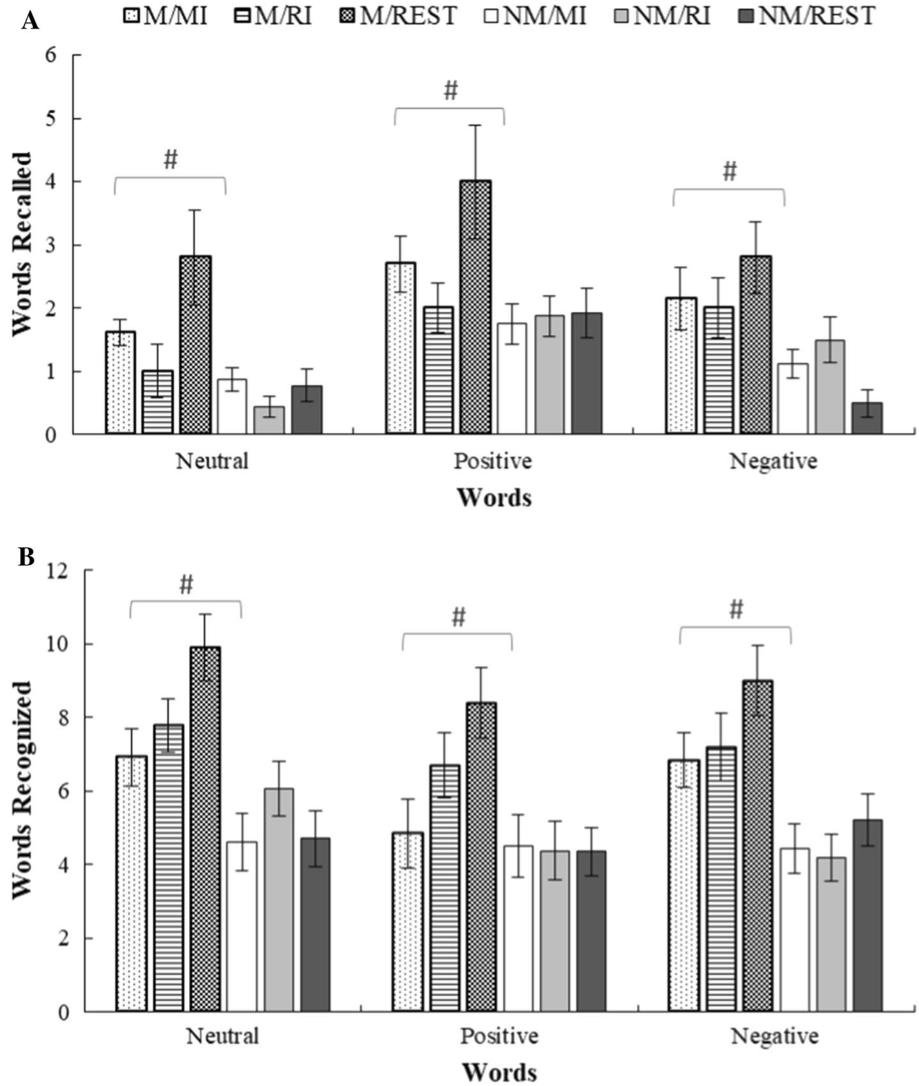

Fig. 3 Deferred free recall and recognition. Mean number of neutral, positive, and negative words that the groups could remember (**a**) and recognize (**b**) a week after the first session. M/MI: musicians' improvisation group; M/RI: musicians' rhythmic imitation group; M/REST: musicians' rest group; NM/MI: non-musicians' improvisation group; NM/RI: non-musicians' rhythmic imitation group; NM/REST: non-musicians' rest group. [#]Significant differences in Training. Vertical lines represent standard errors of the mean

and/or recognition of neutral verbal memory. As regards the improvisation and imitation groups, we intended to compare two interventions involving the same sensory and motor components, in order to isolate creative and interactive music behavior. In both interventions, the musical activities involved sound, and the participants listened to the same rhythmic pattern, played instruments in groups, and had the opportunity to use their bodies and/or voices. However, only music improvisation modulated memory, and therefore, the findings could be attributed to the characteristics of each musical experience. In the following paragraphs, we discuss the differences between these distinct music tasks.

As regards rhythmic imitation, the pattern employed in this study was an easy-to-reproduce rhythmic base. However, from a neurocognitive perspective, imitation tasks are far from simple (Engel et al. 2001; Raichle 2010). It has been shown that, in the general population, rhythm processing activates specific pathways in several brain areas, such as auditory cortices, as well as frontal, parietal, and motor regions, including the supplementary motor area, the basal ganglia, and the cerebellum (Grahn 2012; Grahn and Brett 2007; Merchant et al. 2015). The necessary sensory-motor coupling for rhythmic synchronization requires a sophisticated mechanism of temporal prediction and feedback (Miendlarzewska et al. 2013; Schroeder et al. 2010), which in turn makes high cognitive demands, especially attention, inhibitory control, and working memory (Benz et al. 2016). In this sense, imitation could impose restrictions due to its great cognitive demand (especially attention), which would "consume" the necessary resources for memory consolidation and result in an interference effect.

The research on the neurocognitive mechanisms of musical improvisation is focused on musicians (Limb and Braun 2008; Kleinmintz et al. 2014; McPherson and Limb 2013; McPherson et al. 2016), whereas studies on improvisations performed by non-musicians and those from a music-therapy perspective are scarce. However, a study conducted by Berkowitz and Ansari (2010) compared the brain activation during a musical improvisation (melodic and rhythmic) of musicians and non-musicians and found only one difference between the groups: the deactivation of the right temporoparietal junction (Fink et al. 2009). This research allows using the background that exists on musical improvisation to justify the results of the modulatory effect on memory.

Multiple studies reported that musical improvisation involved creative decision-making processes and activated the premotor cortex, supplementary motor areas, language areas, insula, cingulate cortex, medial prefrontal cortex, temporal areas (Loui 2018; McPherson et al. 2016), and amygdala (Beaty 2015; Engel and Keller 2011). This brain activation and its behavioral outcome with its consequent emotional state could play a decisive role in the modulation of memory performance by older adults who participated in musical improvisation, considering that emotion was identified as a modulator of acquisition and consolidation of memory (Shields et al. 2017; Tambini et al. 2017).

From music psychology and music-therapy perspectives, musical improvisation is a complex phenomenon with unique psychological features (MacDonald and Wilson 2014). In addition to the creative features of the process, another characteristic is that this kind of musical improvisation is social and it involves the contributions and communication of two or more individuals (in our case four to ten people), each of them creating and musically responding to the other(s) and their playing (Walton et al. 2018). It is spontaneous since music is formed as it is played through real-time responses to an immediate musical context. It is creative since improvising music produces novel musical items every time the participant plays, which may be similar to, but different from, any previous performance (MacDonald and Wilson 2014). This type of social characteristic present in improvisation could induce a positive emotional state that could modulate memory, but research in this line, with empirical studies, is scarce.

Study 2 was aimed at evaluating verbal emotional memory by means of a focal music-based intervention, which had no effects on memory measures. This unexpected result differed from our previous research on visual emotional memory, where musical improvisation had robust effects (Diaz Abrahan et al. 2019). A possible explanation is that the emotional induction of the material presented in the acquisition phase (emotional words) was combined with the emotional induction of the musical experience (Rickard et al. 2012), resulting in too much emotion, which may have saturated the system. Besides, in this relationship, both stimuli (coding information and modulating intervention) shared the same auditory sensory modality. This double interaction could have resulted in the overload of the system, thus interfering with consolidation (Duncan et al. 1997).

The second goal of this work was to identify the influence of music training on older adult's memory. A systematic review showed that musicians have better memory performance than non-musicians (Talamini et al. 2017) and two studies found that older adults who were instrumental musicians performed significantly better than non-musicians on tests of visual memory, executive functioning, and language (Hanna-Pladdy and MacKay 2011; Strong and Mast 2018). For this reason, we expected an effect of music training on both types of verbal memory. This prediction was partially confirmed because the effects were observed on deferred memory measures.

Neutral verbal memory has been widely investigated in studies contrasting older musicians and non-musicians. Some studies indicated that music training improved performance in long-term verbal memory (Franklin et al. 2008; Hanna-Pladdy and MacKay 2011) and short-term memory (Fauvel et al. 2014), while others found no effects (Strong and Mast 2018). Our results are in line with the first group of evidence. A plausible explanation for the better performance of musicians is that there are cerebral adaptations as a product of music training, which in turn enhance cognitive functions (Benz et al. 2016; Delogu et al. 2019; Justel and Diaz 2012; Zatorre et al. 2007; Zhao et al. 2017; Zuk et al. 2014). Neuroimaging studies showed that musical learning generated greater activation of the *temporal planum* and the left dorsolateral prefrontal cortex, areas involved in verbal processing (Taylor and Dewhurst 2017; Schlaug et al. 2005). Along the same lines, Patel (2003) suggested that although these two types of representations (words vs music) are stored in different neuronal substrates, the processing could share neural networks, and in this sense music training could induce changes in the neuronal circuits related to verbal memory.

However, the change reported for music training may not be intense enough or may not extend to the circuits of short-term memory or immediate evaluation, highly affected during aging (Rhodes and Katz 2017; Rieckmann et al. 2017), which could explain the lack of effect of music training on every immediate measure, compared to deferred evaluation. More studies are necessary to further investigate this result.

In recent years, research has focused on delimiting the relationship between music and cognitive performance. Several behavioral (Jakobson et al. 2008; Tamminen et al. 2015) and electrophysiological studies (Dittinger et al. 2016) indicate that the advantage of musicians over non-musicians in verbal and visual memory could be due to the employment of more effective encoding strategies by musicians when learning new material, and not due to better storage mechanisms. This type of evidence opens up new topics for discussion about the specific effects of music learning.

Limitations and future directions

The limitations identified in this study are associated with the characteristics of the samples. First, music and academic educational level have both been identified as protective factors of cognitive decline in aging. In this study, the academic level was evaluated in the statistical analysis of memory performance as a co-variable. In future studies, groups of musicians and groups of professional non-musicians with a high educational level should be compared. In addition, the groups of musicians were unbalanced according to their musical experiences. Although a group of elderly musicians is a difficult population to recruit, having homogeneous samples in terms of music training is a point to be considered in future studies.

Regarding the effect of music training, some studies investigated whether the protective effect is due to early experiences or whether it can be constructed in later stages of life (Herholz et al. 2013). We did not include this item in our musical background questionnaire, which could have yielded differences in memory performance. This would be another interesting point to investigate in the future.

Another activity identified as a protective factor during aging is the learning of a second language (Abutalei et al. 2015). Our sociodemographic questionnaire did not include questions about bilingualism, an aspect that should have been considered as an exclusion criterion due to the relationship between the type of learning and the type of memory that was evaluated in this study.

The research conducted in our laboratory was focused on different types of episodic memory, i.e., visual and verbal modalities (with or without emotional content). However, the effect of music training or participation in music-based interventions in implicit procedural memories was not investigated. In this line, future research could consider this topic.

Finally, to isolate the effect of musical intervention based on a creative task, we included music reproduction as a control condition because it does not include the creative component. The musical interaction involved in improvisation, but not in reproduction, was not controlled for, so future studies could compare music improvisation with another task that is musical and collaborative but not creative.

Conclusions

Our ability to perceive, produce, and enjoy music is considered a universal trait. Humans have the creative capacity to generate and modify patterns of sound in response to each other, from early infant–mother interactions onward to older age (Trevarthen 2002). Since all humans are musical improvisers to some extent, everybody can engage in improvisation at some level, unlike many other musical activities where specific technical skills or knowledge are required for people to participate. This approach was taken in the present work, and we found that musical improvisation modulates neutral verbal memory. The current results have implications for regular or pathological decline during aging. This accessibility of music and musical activities shows that it has the potential for a wide application as an intervention for cognitive stimulation and rehabilitation of older adults.

We also found that long-term musical practice also seems to prevent age-related decline in verbal memory cognition. Learning music may provide protective factors against age-related cognitive decline and affected cognitive reserve.

Experiencing a musically enriched environment, by learning music or participating in music-based intervention programs, affects our cognitive functions, such as the neutral and emotional verbal memory studied in this research, thus promoting healthy aging.

Author contributions VDA and NJ contributed to the conception and design of the studies. VDA conducted the studies. VDA and NJ contributed to data analysis. VDA, FS, and NJ participated in the writing of the paper and interpretation of the data. FS and NJ supervised and integrated the information.

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Compliance with ethical standards

Conflict of interest The authors report no conflict of interest.

Consent to participate 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).

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee (having approval from the Universidad de Buenos Aires) complying with the Helsinki Declaration, Convention of the Council of Europe on Human Rights and Biomedicin.

References

Abrahan V, Justel N (2015) La improvisación musical. Una mirada compartida entre la musicoterapia y las neurociencias. Psicogente 18(34):372–384. https://doi.org/10.17081/psico.18.34.512

Abutalei J, Guidi G, Borsa V, Canini M, Della Rosa P, Parris B, Weekes B (2015) Bilingualism provides a neural reserve for aging populations. Neuropsychologia 69:201–210. https://doi.org/10.1016/j.neuropsychologia.2015.01.040

Adam S, Bonsang E, Grotz C, Perelman S (2013) Occupational activity and cognitive reserve: implications in terms of prevention

of cognitive aging and Alzheimer's disease. Clin Interv Aging 8:377–390. https://doi.org/10.2147/cia.s39921
Addis DR, Pan L, Musicaro R, Schacter DL (2016) Divergent thinking and constructing episodic simulations. Memory (Hove, England) 24(1):89–97. https://doi.org/10.1080/09658211.2014.985591
Alberini CM, LeDoux JC (2013) Memory reconsolidation. Curr Biol 23(17):746–750. https://doi.org/10.1016/j.cub.2013.06.046
Beaty R (2015) The neuroscience of musical improvisation. Neurosci Biobehav Rev 51:108–117. https://doi.org/10.1016/j.neubiorev.2015.01.004
Belleville S (2008) Cognitive training for persons with mild cognitive impairment. Int Psychoger 20(1):57–66. https://doi.org/10.1017/s104161020700631x
Benz S, Sellaro R, Hommel B, Colzato L (2016) Music makes the world go round: the impact of musical training on non-musical cognitive functions—a review. Front Psychol 6:2023. https://doi.org/10.3389/fpsyg.2015.02023
Berkowitz A, Ansari D (2010) Expertise-related deactivation of the right temporoparietal junction during musical improvisation. Neuroimage 49(1):712–719. https://doi.org/10.1016/j.neuroimage.2009.08.042
Bradley MM, Lang PJ (1999) Affective norms for English words (ANEW): Instruction manual and affective ratings. Technical report C-1, The Center for Research in Psychophysiology, University of Florida
Bruscia K (1998) Musicoterapia. Métodos y prácticas. Editorial Pax México, México
Bruscia K (1999) Modelos de Improvisación en Musicoterapia. Agruparte Victoria-Gasteiz, España
Butman J, Arizaga RL, Harris P, Dranke M, Baumann D, de Pascale A et al (2001) El "Mini - Mental State Examination" en español. Normas para Buenos Aires. Rev Neurol Argent 26(1):11–15
Cahill L, Gorski L, Le K (2003) Enhanced human memory consolidation with post-learning stress: interaction with the degree of arousal at encoding. Learn Mem 10(4):270–274. https://doi.org/10.1101/lm.62403
Chanda M, Levitin D (2013) The neurochemistry of music. Trends Cogn Sci 17(4):179–193. https://doi.org/10.1016/j.tics.2013.02.007
Dalmás F (1993) La memoria desde la Neuropsicología. Roca Viva Editorial, Montevideo
Delogu F, Brunetti R, Inuggi A, Campus C, Del Gatto C, D'Ausilio A (2019) That does not sound right: sounds affect visual ERPs during a piano sight-reading task. Behav Brain Res 367:1–9. https://doi.org/10.1016/j.bbr.2019.03.037
Diaz Abrahan V, Shifres F, Justel N (2018) Musical improvisation modulates emotional memory. Psychol Music 9:1–16. https://doi.org/10.1177/0305735618810793
Diaz Abrahan V, Shifres F, Justel N (2019) Cognitive benefits from a musical activity in older adults. Front Psychol 10:652. https://doi.org/10.3389/fpsyg.2019.00652
Diaz F, Pereiro A (2018) Neurociencia cognitiva del envejecimiento. Aportaciones y retos. Revista Española de Geriatría y Gerontología 53(2):100–104. https://doi.org/10.1016/j.regg.2017.07.002
Dittinger E, Barbaroux M, D'Imperio M, Jäncke L, Elmer S, Besson M (2016) Professional music training and novel word learning: from faster semantic encoding to longer-lasting word representations. J Cogn Neurosci 28(10):1584–1602. https://doi.org/10.1162/jocn_a_00997
Duncan J, Martens S, Ward R (1997) Restricted attentional capacity within but not between sensory modalities. Nature 387(19):802–8010. https://doi.org/10.1038/42947
Engel A, Keller PE (2011) The perception of musical spontaneity in improvised and imitated jazz performances. Front Psychol 2:83. https://doi.org/10.3389/fpsyg.2011.00083
Engel AK, Fries P, Singer W (2001) Dynamic predictions: oscillations and synchrony in top-down processing. Nat Rev Neurosci 2(10):704–716. https://doi.org/10.1038/35094565
Erel H, Levy DA (2016) Orienting of visual attention in aging. Neurosci Biobehav Rev 69:357–380. https://doi.org/10.1016/j.neubiorev.2016.08.010
Erickson KI, Voss MW, Prakash RS, Basak C, Szabo A, Chaddock L et al (2011) Exercise training increases size of hippocampus and improves memory. Proc Natl Acad Sci 108(7):3017–3022. https://doi.org/10.1073/pnas.1015950108
Evans DA, Beckett LA, Albert MS, Hebert LE, Scherr PA, Funkenstein HH (1993) Level of education and change in cognitive function in a community population of older persons. Ann Epidemiol 3(1):71–77. https://doi.org/10.1016/1047-2797(93)90012-s
Faul F, Erdfelder E, Lang A, Buchner A (2007) G* Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav Res Methods 39(2):175–191. https://doi.org/10.3758/bf03193146
Fauvel B, Groussard M, Mutlu J, Arenaza-Urquijo EM, Eustache F, Desgranges B, Platel H (2014) Musical practice and cognitive aging: two cross-sectional studies point to phonemic fluency as a potential candidate for a use-dependent adaptation. Front Aging Neurosci 6:227. https://doi.org/10.3389/fnagi.2014.00227
Ferreri L, Rodriguez-Fornells A (2017) Music-relate rewards responses predict episodic memory performance. Exp Brain Res 235(12):3721–3731. https://doi.org/10.1007/s00221-017-5095-0
Ferreri L, Aucouturier JJ, Muthalib M, Bigand E, Bugaiska A (2013) Music improves verbal memory encoding while decreasing prefrontal cortex activity: a fNIRS study. Front Hum Neurosci 7:779. https://doi.org/10.3389/fnhum.2013.00779
Fink A, Graif B, Neubauer AC (2009) Brain correlates underlying creative thinking: EEG alpha activity in professional vs novice dancers. Neuroimage 46(3):854–862. https://doi.org/10.1016/j.neuroimage.2009.02.036
Fjell AM, Sneve MH, Storsve AB, Grydeland H, Yendiki A, Walhovd KB (2016) Brain events underlying episodic memory changes in aging: a longitudinal investigation of structural and functional connectivity. Cereb Cortex 26(3):1272–1286. https://doi.org/10.1093/cercor/bhv102
Folstein MF, Folstein SE, McHugh PR (1975) ''Mini-mental State'': a practical method for grading the cognitive state of patients for the clinician. J Psychiatr Res 12(3):189–198. https://doi.org/10.1016/0022-3956(75)90026-6
Franklin MS, Moore KS, Yip CY, Jonides J, Rattray K, Moher J (2008) The effects of musical training on verbal memory. Psychol Music 36(3):353–365. https://doi.org/10.1177/0305735607086044
Grahn JA (2012) Neural mechanisms of rhythm perception: current findings and future perspectives. Top Cogn Sci 4(4):585–606. https://doi.org/10.1111/j.1756-8765.2012.01213.x
Grahn JA, Brett M (2007) Rhythm and beat perception in motor areas of the brain. J Cogn Neurosci 19(5):893–906. https://doi.org/10.1162/jocn.2007.19.5.893
Grandi F, Tirapu-Ustárroz J (2017) Neurociencia cognitiva del envejecimiento: modelos explicativos. Revista Española de Geriatría y Gerontología 52(6):326–331. https://doi.org/10.1016/j.regg.2017.02.005
Hall CB, Lipton RB, Sliwinski M, Katz MJ, Derby CA, Verghese J (2009) Cognitive activities delay onset of memory decline in persons who develop dementia. Neurology 73(5):356–361. https://doi.org/10.1212/wnl.0b013e3181b04ae3
Hanna-Pladdy B, Gajewski B (2012) Recent and past musical activity predicts cognitive aging variability: direct comparison with general lifestyle activities. Front Hum Neurosci 6:198. https://doi.org/10.3389/fnhum.2012.00198

Hanna-Pladdy B, MacKay A (2011) The relation between instrumental musical activity and cognitive aging. Neuropsychology 25(3):378–386. https://doi.org/10.1037/a0021895

Hedden T, Gabrieli JD (2004) Insights into the ageing mind: a view from cognitive neuroscience. Nat Rev Neurosci 5(2):87–96. https://doi.org/10.1038/nrn1323

Herholz S, Herholz R, Herholz K (2013) Non-pharmacological interventions and neuroplasticity in early stage Alzheimer's disease. Expert Rev Neurother 13(11):1235–1245. https://doi.org/10.1586/14737175.2013.845086

Jakobson LS, Lewycky ST, Kilgour AR, Stoesz BM (2008) Memory for verbal and visual material in highly trained musicians. Music Percept 26(1):41–55. https://doi.org/10.1525/mp.2008.26.1.41

Judde S, Rickard N (2010) The effect of post-learning presentation of music on long term word list retention. Neurobiol Learn Mem 94(1):13–20. https://doi.org/10.1016/j.nlm.2010.03.002

Justel N, Diaz Abrahan V (2012) Plasticidad cerebral: participación del entrenamiento musical. Suma Psicol 19(2):97–108

Justel N, Rubinstein W (2013) La exposición a la música favorece la consolidación de los recuerdos. Boletín de Psicología 109:73–83

Justel N, O´Conor J, Rubinstein W (2015) Modulación de la memoria emocional a través de la música en adultos mayores: un estudio preliminar. Interdisciplinaria 32(2):247–259

Justel N, Diaz Abrahan V, Castro C, Rubinstein W (2016) Efecto de la música sobre la memoria emocional verbal. Anuario de Psicología 22(2):297–301

Kleinmintz OM, Goldstein P, Mayseless N, Abecasis D, Shamay-Tsoory SG (2014) Expertise in musical improvisation and creativity: the mediation of idea evaluation. PLoS ONE 9(7):e101568. https://doi.org/10.1371/journal.pone.0101568

Kraus N, Chandrasekaran B (2010) Music training for the development of auditory skills. Nat Rev Neurosci 11(8):599–605. https://doi.org/10.1038/nrn2882

Limb C, Braun A (2008) Neural substrates of spontaneous musical performance: an fMRI study of jazz improvisation. PLoS ONE 3(2):e1679. https://doi.org/10.1371/journal.pone.0001679

Loui P (2018) Rapid and flexible creativity in musical improvisation: review and a model. Ann N Y Acad Sci 1423(1):138–145. https://doi.org/10.1111/nyas.13628

MacDonald R, Wilson G (2014) Musical improvisation and health: a review. Psychol Well-Being Theory Res Pract 14(20):1–18. https://doi.org/10.1186/s13612-014-0020-9

Madore K, Thakral P, Beaty R, Addis D, Schacter D (2019) Neural mechanisms of episodic retrieval support divergent creative thinking. Cereb Cortex 29(1):150–166. https://doi.org/10.1093/cercor/bhx312

Martinez de la Iglesia J, Onis Vilches C, Dueñas Herrero R, Colomer C, Aguado-Tabernè C et al (2002) Versión española del cuestionario de Yesavage abreviado (GDS) para el despistaje de depresión en mayores de 65 años: Adaptación y validación. MEDIFAM 12(10):620–630

McGaugh JL (2002) Memory consolidation and the amygdala: a systems perspective. Trends Neurosci 25(9):456–461. https://doi.org/10.1016/s0166-2236(02)02211-7

McPherson M, Limb C (2013) Difficulties in the neuroscience of creativity: Jazz improvisation and the scientific method. Ann N Y Acad Sci 1303(1):80–83. https://doi.org/10.1111/nyas.12174

McPherson M, Lopez-Gonzales M, Rankin S, Limb C (2014) The role of emotion in musical improvisation: an analysis of structural features. PLoS ONE 9(8):e105144. https://doi.org/10.1371/journal.pone.0105144

McPherson MJ, Barrett FS, Lopez-Gonzalez M, Jiradejvong P, Limb CJ (2016) Emotional intent modulates the neural substrates of creativity: an fMRI study of emotionally targeted improvisation in Jazz musicians. Sci Rep 6:18460. https://doi.org/10.1038/srep18460

Merchant H, Grahn JA, Trainor L, Rohrmeier M, Fitch WT (2015) Finding the beat: a neural perspective across humans and non-human primates. Philos Trans R Soc B Biol Sci 370(1664):20140093. https://doi.org/10.1098/rstb.2014.0093

Miendlarzewska E, Elswijk G, Cannistraci C, van Ee R (2013) Working memory load attenuates emotional enhancement in recognition memory. Front Psychol. https://doi.org/10.3389/fpsyg.2013.0011

Patel AD (2003) Language, music, syntax and the brain. Nat Neurosci 6(7):674–681. https://doi.org/10.1038/nn1082

Peretz I (2006) The nature of music from a biological perspective. Cognition 100(1):1–32. https://doi.org/10.1016/j.cognition.2005.11.004

Raichle ME (2010) Two views of brain function. Trends Cogn Sci 14(4):180–190. https://doi.org/10.1016/j.tics.2010.01.008

Ratovohery S, Baudouin A, Gachet A, Palisson P, Narme P (2018) Is music a memory booster in normal aging? The influence of emotion. Memory 26(10):1344–1354. https://doi.org/10.1080/09658211.2018.1475571

Redondo J, Fraga I, Padrón I, Comesaña M (2007) The Spanish adaptation of ANEW (Affective Norms for English Words). Behav Res Methods 39(3):600–605. https://doi.org/10.3758/bf03193031

Reijnders J, van Heugten C, van Boxtel M (2013) Cognitive interventions in healthy older adults and people with mild cognitive impairment: a systematic review. Ageing Res Rev 12(1):263–275. https://doi.org/10.1016/j.arr.2012.07.003

Rey A (1941) L´examen psychologique dans les cas d´encéphalopatie traumatique. Arch Psychol 28(112):286–340

Rey A (1964) L´examen Clinique en psychologia. Presses Universitaires de France, Paris

Rhodes RE, Katz B (2017) Working memory plasticity and aging. Psychol Aging 32(1):51–59. https://doi.org/10.1037/pag0000135

Rickard N, Wing Wong W, Velik L (2012) Relaxing music counters heightened consolidation of emotional memory. Neurobiol Learn Mem 97(2):220–228. https://doi.org/10.1016/j.nlm.2011.12.005

Rieckmann A, Pudas S, Nyberg L (2017) Longitudinal changes in component processes of working memory. eNeuro. https://doi.org/10.1523/eneuro.0052-17.2017

Ryan JJ, Geisser ME (1986) Validity and diagnostic accuracy of an alternate form of the rey auditory verbal learning test. Arch Clin Neuropsychol 1(3):209–217. https://doi.org/10.1016/0887-6177(86)90027-2

Sági M, Vitányi I (1988) Experimental research into musical generative ability. In: Sloboda J (ed) Generative processes in music: the psychology of performance, improvisation, and composition. Oxford University Press, New York

Salthouse TA (2010) Selective review of cognitive aging. J Int Neuropsychol Soc 16(5):754–760. https://doi.org/10.1017/s1355617710000706

Särkämö T (2018) Cognitive, emotional, and neural benefits of musical leisure activities in aging and neurological rehabilitation: a critical review. Ann Phys Rehabil Med 61(6):414–418. https://doi.org/10.1016/j.rehab.2017.03.006

Särkämö T, Tervaniemi M, Laitinen S, Forsblom A, Soinila S, Mikkonen M et al (2008) Music listening enhances cognitive recovery and mood after middle cerebral artery stroke. Brain 131(Pt 3):866–876. https://doi.org/10.1093/brain/awn013

Särkämö T, Altenmüller E, Rodríguez-Fornells A, Peretz I (2016) Editorial: music, brain, and rehabilitation: emerging therapeutic applications and potential neural mechanisms. Front Hum Neurosci 10:103. https://doi.org/10.3389/fnhum.2016.00103

Schlaug G, Norton A, Overy K, Winner E (2005) Effects of music training on the child's brain and cognitive development. Ann N Y Acad Sci 1060(1):219–230. https://doi.org/10.1196/annals.1360.015

Schneider CE, Hunter EG, Bardach SH (2018) Potential cognitive benefits from playing music among cognitively intact older adults: a

scoping review. J Appl Gerontol 38(12):1763–1783. https://doi.org/10.1177/0733464817751198
Schroeder CE, Wilson DA, Radman T, Scharfman H, Lakatos P (2010) Dynamics of active sensing and perceptual selection. Curr Opin Neurobiol 20(2):172–176. https://doi.org/10.1016/j.conb.2010.02.010
Seinfeld S, Figueroa H, Ortiz-Gil J, Sanchez-Vives M (2013) Effects of music learning and piano practice on cognitive function, mood and quality of life in older adults. Front Psychol 1(4):810. https://doi.org/10.3389/fpsyg.2013.00810
Sheikh JI, Yesavage JA (1986) Geriatric depression scale (GDS): recent evidence and development of a shorter version. Clin Gerontol J Aging Mental Health 5(1–2):165–173. https://doi.org/10.1300/j018v05n01_09
Shields GS, Sazma MA, McCullough AM, Yonelinas AP (2017) The effects of acute stress on episodic memory: a meta-analysis and integrative review. Psychol Bull 143(6):636–675. https://doi.org/10.1037/bul0000100
Skoe E, Kraus N (2012) A little goes a long way: how the adult brain is shaped by musical training in childhood. J Neurosci Off J Soc Neurosci 32(34):11507–11510. https://doi.org/10.1523/jneurosci.1949-12.2012
Stern Y (2009) Cognitive reserve. Neuropsychology 47(10):2015–2028. https://doi.org/10.1016/j.neuropsychologia.2009.03.004
Stern Y, Arenaza-Urquijo E, Bartés-Faz D, Belleville S, Cantilon M, Chetelat G et al (2018) Whitepaper: defining and investigating cognitive reserve, brain reserve, and brain maintenance. Alzheimers Dement S1552–5260(18):33491–33495. https://doi.org/10.1016/j.jalz.2018.07.219
Strong J, Mast B (2018) The cognitive functioning of older adult instrumental musicians and non-musicians. Aging Neuropsychol Cogn 26(3):367–386. https://doi.org/10.1080/13825585.2018.1448356
Talamini F, Altoè G, Carretti B, Grassi M (2017) Musicians have better memory than nonmusicians: a meta-analysis. PLoS ONE 12(10):e0186773. https://doi.org/10.1371/journal.pone.0186773
Tambini A, Rimmele U, Phelps EA, Davachi L (2017) Emotional brain states carry over and enhance future memory formation. Nat Neuroci 20(2):271–278. https://doi.org/10.1038/nn.4468
Tamminen J, Rastle K, Darby J, Lucas R, Williamson V (2015) The impact of music on learning and consolidation of novel words. Memory 25(1):107–121. https://doi.org/10.1080/09658211.2015.1130843
Taylor A, Dewhurst A (2017) Investigating the influence of music training on verbal memory. Psychol Music 45(6):814–820. https://doi.org/10.1177/0305735617690246
Thaut M, Hoemberg V (2014) Handbook of neurologic music therapy. Oxford University Press, Oxford
Trevarthen C (2002) Origins of musical identity: evidence from infancy for musical social awareness. In: MacDonald R, Miell D, Hargreaves D (eds) Musical identities. Oxford University Press, Oxford
Verghese J, Lipton R, Katz M, Hall C, Derby C, Kuslansky G et al (2003) Leisure activities and the risk of dementia in the elderly. New Engl J Med 348:2508–2516. https://doi.org/10.1056/nejmoa022252
Walton A, Washburn A, Langland-Hassan P, Chemero A, Kloos H, Richardson M (2018) Creating time: social collaboration in music improvisation. Topics Cogn Sci 10(1):95–119. https://doi.org/10.1111/tops.12306
Wang C, Schlaug G (2010) Music making as a tool for promoting brain plasticity across the life span. Neuroscientist 16(5):566–577. https://doi.org/10.1177/1073858410377805
Wang HX, Xu W, Pei JJ (2012) Leisure activities, cognition and dementia. Biochem Biophys Acta 1822(3):482–491. https://doi.org/10.1016/j.bbadis.2011.09.002
Wigram T (2004) Improvisation: methods and techniques for music therapy clinicians, educators, and students. Jessica Kingsley Publishers, England
Wilson RS, Bennett DA, Bienias JL, Aggarwal NT, Mendes De Leon CF, Morris MC et al (2002) Cognitive activity and incident AD in a population-based sample of older persons. Neurology 59(12):1910–1914. https://doi.org/10.1212/01.wnl.0000036905.59156.a1
Zatorre R, Chen J, Penhune V (2007) When the brain plays music: auditory–motor interactions in music perception and production. Nat Rev 8(7):547–558. https://doi.org/10.1038/nrn2152
Zhao T, Lam HM, Sohi H, Kuhl P (2017) Neural processing of musical meter in musicians and non-musicians. Neuropsychologia 106:289–297. https://doi.org/10.1016/j.neuropsychologia.2017.10.007
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. https://doi.org/10.1371/journal.pone.0099868