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The potential cognitive benefits of musical training from childhood to healthy aging

(Los potenciales beneficios cognitivos de la práctica musical desde la infancia hasta el envejecimiento saludable)

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Musicians are loved by people. Really loved. Because they give them the ability to express their emotions and their memories. There's no other form that does that. I mean, I really think that musicians, probably musicians and cooks, are responsible for the most pleasure in human life. Like Motown music, which was very popular when I was a teenager, whenever I hear it, I instantly become happier. There's just no question that it makes me happier. This is true of almost nothing. Okay? Do I think Mowtown is the greatest music ever made? I don't. But if you ask me, "The second you hear this, do you feel happier?". I do. That's a very important thing to do for human beings. Music makes people happier and it doesn't harm them. Most things that make you feel better are harmful. It's very unusual. It's like a drug that doesn't kill you.

Franz Lebowitz
Pretend It's a City, 2021

AGRADECIMIENTOS

Concluir para volver a empezar. El inevitable comienzo que sigue a este final…

Aunque estas serán las primeras palabras de esta tesis, comencé a escribirlas justo cuando ya había volcado cada resultado, cada diálogo, cada idea, de lo que ha sido el hilo conductor de mi vida en los últimos años. Ese vertido es científico. Cualquiera que continúe leyendo se sumergirá en párrafos de datos, hipótesis, refutaciones y preguntas abiertas. Pero detrás de cada línea existe una historia alejada del laboratorio, junto a la playa, con música de fondo, entre conversaciones que se convierten en lo único que importa. Estas páginas no expresarán esos momentos, pero pido a cualquiera que se detenga ante ellas que sea sensible a su rastro. Las emociones, las revelaciones cotidianas, los momentos menos trascendentales pero más humanos son la verdadera intrahistoria detrás de cada hallazgo. Antes de empezar con la parte científica, quiero agradecer a las y a los protagonistas de esos relatos.

En primer lugar, a Juan, por sembrar en mí tu pasión imperturbable, por hacer tuyos mis éxitos y preocupaciones. Por enseñarme mucho más que ciencia, pues más allá de la aparente neutralidad de los datos, existen valores y una filosofía de vida que puede ser tan admirable como el propio ingenio del investigador. Llevo muchos años sintiéndome privilegiado por poder aprender de tu forma de entender y tratar a las personas que te rodean. Personas que a tu lado dejan de ser participantes o trabajadoras, para convertirse en realidades únicas que comprender y cuidar. En todos estos años a tu lado solo he vivido momentos de la más pura y llana honestidad. A Eli, por ser una luchadora y transmitirme la importancia de trabajar sin descanso por un mundo más justo. Gracias por enseñarme que las barreras del presente son solo humanas, que el *hic sunt dracones* de los mapas solo existen mientras nadie se aventura a enfrentarse a los dragones.

Y junto a Eli, quiero agradecer a todas mis hermanas y hermanos mayores en el laboratorio, a Conchi, Andrea, Mariagrazia y Fabiano. Desde el día en que llegué, vuestra sonrisa me abrió la puerta del laboratorio y desde entonces no ha vuelto a cerrarse. Realmente os he sentido así, como una gran familia. De las que no importa cuál es el motivo por el que toca reunirse, simplemente toca. Reuniones en las que aprendemos de ciencia, de *lindy hop*, de las costumbres italianas, de tiramisús, de las anécdotas de las noches de congresos, de las neuro-cosas… He sido muy feliz con todos esos momentos, quizá por eso algo de mí se resiste a dar otro paso, "¡si ya habíamos llegado!".

Había llegado a un lugar habitado por ti, Greta, con tu inquietud, por tu llama incesante. Por Josu y José Carlos, los corazones más nobles que podrían acompañarme en un viaje tan largo y profundo. Por Chema, que eres la voz, las palabras que nacen desde dentro e incensurables. Por Tao, una afortunada casualidad. Allá donde vas cautiva todo lo que eres; que nada ni nadie lo diluya. Por Jani, me encanta escribir así tu nombre y que me lo permitas, porque expresa todo el cariño que te tengo. Gracias por encontrarme en el laboratorio y por creer en mí. Admiro tu mochila valiente, tus pies honestos que solo pisan las baldosas de los lugares en los que eres feliz. No sabes lo afortunado que me hace sentir que hayas encontrado en mí una de esas baldosas. Por Cris y Belén, sois la sonrisa. No sé qué habría sido de nosotros sin vuestra forma de vivir los momentos. Nunca olvidaré la primera vez que me subí a un avión como científico y teníamos que hablar en inglés para un congreso, Cris. Todos estábamos

aterrorizados y, sin embargo, hiciste de aquel momento algo tan nuestro, algo que perdura. Nos veo ahora, y es increíble todo lo que hemos aprendido. Y si no, ¡ojito!, que nos lo diga la amiga Belén. Contigo he compartido la admiración secreta por la música discreta, la que solo las habitaciones en silencio y las persianas medio bajadas escuchan. La verdadera belleza de la música para mí es la semántica que encierra, la profundidad autonoética de sus emociones, que difícilmente se pueden expresar con lenguaje. No intentaré tampoco ahora apresar esa conexión, pero sí la fortuna de sentir que siento al mirar en ti y encontrar unos ojos que se habían posado sobre la misma superficie, que han reparado en el mismo detalle. Por Luis, la auténtica mirada. Nadie como tú sabe fotografiar nuestros momentos. Nadie como tú comprende el sentido más esencial y crítico de lo que hemos vivido. A veces me arrepiento de todo lo que hablo. Luego me doy cuenta de que me había convertido en una *general discussion* de las desenfrenadas, de las que especulan. Pero siempre llegas. Y junto a vosotros, Fer, Ana, Dani, Alba, Mar, María, Ana Paqui, Paloma, Alberto, Nuria, Marta, Giorgia, Filip, Isma, Carmen, Luis, Chiara. No puedo elegir un momento junto a vosotros. Quien me pregunte por qué ha sido tan especial este tiempo, les contaré sobre los días en el Planta Baja, en las PsychoBeers, en el Albaicín, en el Hamelin, en el Chaplin, en Faro, en Madrid, en el Llano de la Perdiz, en Motril… Me alegro de haber vivido momentos de tanta riqueza. Sois las responsables en gran medida de todo lo que he aprendido en estos años.

También quiero agradecer a Marisa y Mónica su tiempo conmigo. Os echo de menos. Os echamos de menos. Echo de menos escucharos durante horas sin parar de sentir fascinación. Cada palabra en vosotras era humana, era bella, era enseñanza. También, a Laurel, a Bruce y a Ben. Jamás pensé el día que recordaba con Cris antes que podría hablar en otro idioma de lo que toca a las emociones, de lo que me preocupa, de lo que desconozco y deseo, de lo que vivo y trato de cambiar. Me reafirma en sentir que no hay barreras para los humanos más allá de las que nosotros mismos hemos construidos. Somos parte y esencia de lo mismo. Gracias por abrirme todas las puertas y por creer en mí. En nuestro tiempo presente, las experiencias se suceden una tras otra casi sin tregua. Pero al margen de todo ese frenesí, existe en todas las personas un rincón muy pequeño de momentos que son puntos de inflexión. Los hitos fundacionales de la historia de cada uno. Gracias por regalarme uno de los puntos de inflexión más importantes.

Y, por último, quiero agradecérselo todo a muchas personas que me han acompañado en la intrahistoria de esta tesis. Muchas de ellas no son parte del mundo académico, pero me han recordado día a día la relevancia social de lo que hago y, más allá, de lo que podríamos cambiar con nuestra voz como científicos. Hablo de Patri, Rafa, Ju, Ángel, Andrés, Fran, Vio, Paco, Antonio, Agus, Aurora, Carmen, Rocío, Elena, Eli… Me he sentido plenamente feliz a vuestro lado. Simplemente nos lo hemos confiado todo y hemos exprimido cada tarde, cada plazuela, cada café. A Tere por *estar*. Por enseñarme la belleza que encierra ese verbo. A vosotros, mamá y papá, porque sois la raíz y mi suerte. En cada trabajo, firmo orgulloso con vuestros dos apellidos. Con el recuerdo del cariño que me regaláis, sin acuse de recibo. Con la humildad de reconocer día a día, paso a paso, que nada de lo que tengo sería mío si no fuera por vuestro regalo.

TABLE OF CONTENTS

ABSTRACTS

Abstract

There is currently a growing interest in ways to enhance and preserve our cognitive skills through changes in lifestyle. Extensive scientific evidence links several behavioral and environmental factors, such as smoking, alcohol and drug abuse, a sedentary lifestyle, and inadequate nutrition, to an increased risk of cognitive impairment, dementia, and accelerated aging. On the other side, education, physical exercise, and cognitively stimulating occupations and leisure activities have all been associated with neurocognitive benefits and the prevention of the pervasive consequences of neural aging. Among them, a wealth of studies has associated musical training, and particularly learning to play an instrument, with differences in auditory and sensorimotor skills, as well as in multiple non-musical cognitive capacities: intelligence, visuospatial abilities, processing speed, executive control, attention and vigilance, episodic and working memory, and language. In addition, anatomical and functional changes have been documented in several brain networks, some of them related to higher-order cognitive processing or non-musical skills.

A priori, the characteristics of playing a musical instrument make it a promising candidate for producing a transfer effect. It involves multiple sensory and motor systems, and requires a wide variety of higher-level cognitive processes. Moreover, a regular and motivated practice of progressive difficulty is necessary to master the technique of an instrument. The wide range of observed differences between musicians and non-musicians suggests that musical practice might produce *near* and *far transfer*. However, some voices have argued against the causal role of musical training and hypothesized that the advantages are the consequence of the

lack of control of cross-sectional studies. Skeptic authors rather propose that high-functioning children, with higher musical aptitude, higher socioeconomic status, and high openness to experience are more likely to be interested in music. Therefore, the idea that learning to play a musical instrument is the *cause* of a broad cognitive enhancement is still controversial. The research program in the present thesis dissertation aimed to contribute with answers to the debate.

First, in a comprehensive meta-analysis of intervention studies (i.e., with a pre-posttest assessment), we showed that the available evidence of randomized controlled trials with children and adolescents supports a small benefit of musical training (d = 0.26). Interestingly, a small advantage at baseline was observed in studies with self-selection (d = 0.28), indicating that participants who had the opportunity to select the activity consistently showed a slightly superior performance prior to the beginning of the intervention. However, baseline performance did not fully explain the differences between children/adolescents with and without musical training, which rules out the effect being a methodological artifact (e.g., regression toward the mean). In addition, some moderators of the effect were observed: (a) the larger the baseline difference, the smaller the observed effect of musical training; (b) participants with lower socioeconomic status showed greater improvements compared to those with middle-high socioeconomic status; (c) the earlier the age of commencement, the larger the effect.

Second, we conducted a meta-analysis regardless of the age of the participants to examine the impact of learning to play an instrument on music-related skills. The available intervention studies also suggested near transfer, but they are still scarce to reach firm conclusions. One explanation for the potential broad benefits of musical training might be its impact on attention and executive functions, as they are necessary functions for many cognitive tasks and daily activities. Indeed, in a well-controlled cross-sectional study with a preregistered design, we found superior vigilance and psychomotor speed for musicians than non-musicians. Importantly, our extensive control of confounders led to smaller effects in contrast to the previous literature. These results are consistent with a *nature and nurture hypothesis*, in which expert musicians might have preexisting advantages (cognitive, personality, and/or musical aptitudes) that would promote the acquisition of musical skills and motivation to practice, while at the same time, this long-term engagement would also result in multiple neural and cognitive changes.

Finally, we meta-analyzed the literature on musical training in healthy aging. We included both cross-sectional and experimental studies as they are complementary: experimental methodology involves randomization and thus allows the establishment of causal relationships, while correlational designs analyze samples with longer musical training. We observed benefits in both types of designs, although the experimental evidence is less abundant. Taken all together, it seems that musical training might have a protective effect in some functions and, mostly, an enhancing effect throughout life. Thus, musicians would present a superior cognitive performance at all stages of life.

I proposed here several non-exclusive mechanisms to explain cognitive benefits of musical training. Given the high demands that musical practice places on multiple cognitive functions (e.g., memory), learning to play an instrument could specifically enhance cognitive abilities through neuroplasticity as a consequence of the increased use of those abilities. However, it might promote the use of more efficient strategies (e.g., improved rehearsal mechanism and semantic organization). As it is a multisensory activity, it might lead to multimodal representations of real-life events (e.g., spatial or visual representation of auditory words), enriching them with complementary inputs. Also, the characteristics of musical training might build a greater propensity for effort (i.e., learned industriousness), making effortful tasks less aversive and more engaging. Finally, the enhancements on domain-general cognitive functions, especially attention and executive control, might spread their benefits on other cognitive tasks, such as preventing the interference of irrelevant events in working memory.

Overall, the contribution of musical training to cognitive skills seems to be rather small and probably makes very little difference in daily life, so it might be not one of the first-choice interventions if the only purpose is cognitive enhancement. However, learning to play an instrument is an enriching activity in itself and can become an important source of pleasure in the player's life. In addition to the social and emotional benefits of playing, practicing this activity for long periods (several decades) could also have significant implications for the development of basic cognitive skills, especially in samples with lower cognitive performance, low socioeconomic status or suffering from neurological conditions.

Resumen

El interés por las formas de mejorar y preservar nuestras capacidades cognitivas a través de los estilos de vida ha crecido en los últimos años. Una abundante evidencia científica vincula ciertos factores ambientales y ciertos hábitos, como el tabaquismo, el abuso de alcohol y drogas, el sedentarismo y una nutrición inadecuada, con un mayor riesgo de deterioro cognitivo, una mayor prevalencia de demencias y un envejecimiento acelerado. En el lado contrario, la educación, el ejercicio físico, y las profesiones y actividades de ocio mentalmente estimulantes se han asociado a beneficios neurocognitivos y a la prevención de las consecuencias del envejecimiento cerebral. Una de esas actividades ha sido la práctica musical, y en particular aprender a tocar un instrumento, la cual se ha relacionado con diferencias en las habilidades auditivas y sensoriomotoras, así como en múltiples habilidades cognitivas que no son específicas de la música: la inteligencia, las habilidades visuoespaciales, la velocidad de procesamiento, el control ejecutivo, la atención, la capacidad de vigilancia, la memoria episódica, la memoria de trabajo y el lenguaje. También se han documentado cambios anatómicos y funcionales en varias redes cerebrales, algunas de ellas involucradas en procesos cognitivos de orden superior o capacidades no musicales.

Tocar un instrumento musical es una actividad con unas características que, a priori, la convierten en una candidata prometedora para producir efectos de transferencia. Tocar un instrumento implica múltiples sistemas sensoriales y motores, y requiere una gran variedad de procesos cognitivos de nivel superior. Además, dominar la técnica de un instrumento conlleva una práctica regular y motivada con una dificultad

progresiva. La amplia gama de aspectos cognitivos que se ven mejorados en las personas con formación musical sugiere que la práctica musical podría producir una transferencia cercana y lejana. Sin embargo, algunas voces han argumentado en contra del papel causal de la formación musical y plantean que todas las ventajas son consecuencia de la falta de control de los estudios transversales. Esas voces escépticas han propuesto que ciertas variables predisponen a que las personas se interesan y se impliquen en la práctica musical: un mayor rendimiento cognitivo previo al comienzo de la formación musical, mayores capacidades musicales, un mayor estatus socioeconómico y una mayor apertura a la experiencia como rasgo de personalidad. Por lo tanto, aún existe controversia en torno a la idea de que aprender a tocar un instrumento musical cause beneficios cognitivos. El conjunto de estudios que conforman esta tesis pretende aportar respuestas a este debate.

En primer lugar, en un metaanálisis exhaustivo de los estudios de intervención (es decir, aquellos con un diseño pre-postest), encontramos que la evidencia disponible de los ensayos controlados aleatorizados con niños y adolescentes respaldan la existencia de un beneficio cognitivo pequeño de la práctica musical (d = 0,26). También observamos una pequeña ventaja al inicio del estudio en los estudios sin aleatorización (d = 0,28), lo que confirma que las personas que seleccionaron la práctica musical en base a sus propias motivaciones tenían un rendimiento superior antes del comienzo de la intervención. Sin embargo, el rendimiento inicial de los participantes no explicaba totalmente las diferencias entre los niños/adolescentes con y sin formación musical, lo que descarta que el efecto sea un artefacto metodológico (por ejemplo, la regresión a la media). Además, el efecto de la práctica musical estaba moderado por algunas variables: (a) el beneficio de la práctica musical disminuía cuanto mayor era la diferencia entre los dos grupos al principio del estudio (antes de la intervención); (b) los participantes con un estatus socioeconómico más bajo mostraban mayores mejoras en comparación con aquellos con un estatus socioeconómico medio-alto; y (c) cuanto más temprana era la edad de inicio, mayor era el efecto.

En segundo lugar, realizamos un metaanálisis en todas las edades sobre el impacto de aprender a tocar un instrumento en las capacidades auditivas relacionadas con la música. Los estudios de intervención disponibles sugirieron una transferencia cercana, pero su número era escaso para conducir a conclusiones firmes. Una explicación de los amplios beneficios de la práctica musical podría ser a través de los beneficios que produciría en la atención y las funciones ejecutivas, ya que son funciones esenciales en muchas tareas cognitivas y actividades cotidianas. De esta forma, en un estudio transversal con un diseño prerregistrado y en el que controlamos una lista extensa de variables de confusión, un grupo de músicos adultos mostraron ventajas en la capacidad de vigilancia y la velocidad psicomotora en comparación a un grupo de personas sin formación musical. Destaca que los efectos observados tras el exhaustivo control de variables de confusión fueron menores que los encontrados en múltiples estudios transversales anteriores. Estos resultados son coherentes con una explicación de las diferencias cognitivas basada tanto en factores innatos como en la experiencia, es decir, las ventajas encontradas en los músicos expertos pueden ser consecuencia de factores anteriores a la práctica musical (ventajas cognitivas previas, rasgos de personalidad y/o aptitudes musicales anteriores a la formación musical) que promoverían la adquisición de las habilidades musicales y la motivación para practicar, mientras que la práctica musical a lo largo del tiempo también daría lugar, por su parte, a múltiples cambios neuronales y cognitivos.

Por último, se realizó un metaanálisis de los estudios en el envejecimiento saludable. Incluimos tanto estudios transversales como experimentales, ya que son dos metodologías complementarias: los diseños experimentales implican la aleatorización de los participantes y, por tanto, permiten establecer relaciones causales, mientras que los diseños correlacionales analizan muestras con un entrenamiento musical más prolongado. Nuestro metaanálisis mostró beneficios en ambos tipos de diseño, aunque la evidencia experimental fue menos abundante. En conjunto, parece que la práctica musical podría tener un efecto protector en algunas funciones cognitivas, pero sobre todo tendría un efecto potenciador a lo largo de la vida. Por tanto, las ventajas en el rendimiento cognitivo de los músicos estarían presentes en todas las etapas de la vida.

Propongo la existencia de varios mecanismos no excluyentes para explicar los beneficios cognitivos del entrenamiento musical. Dadas las demandas elevadas de la práctica musical sobre múltiples funciones cognitivas (por ejemplo, la memoria), aprender a tocar un instrumento podría mejorar específicamente las capacidades mentales a través de la neuroplasticidad desencadena por un mayor uso de esas capacidades. Sin embargo, podría promover el uso de estrategias más eficientes (por ejemplo, mejoras en el mecanismo de ensayo y la organización semántica). También, al tratarse de una actividad multisensorial, podría dar lugar a representaciones multimodales de los acontecimientos de la vida real (por ejemplo, representando espacial o visualmente las palabras auditivas), enriqueciéndolas con una información complementaria. Además, las características del entrenamiento musical podrían convertir a quienes la practican en personas con una mayor propensión al esfuerzo (es decir, con una mayor *laboriosidad aprendida*), por lo que las tareas que requieren esfuerzo podrían ser menos aversivas y más atractivas. Por último, las mejoras en funciones cognitivas generales, especialmente la atención y el control ejecutivo, podrían extender sus beneficios a otras tareas cognitivas, como la prevención de la interferencia de eventos irrelevantes en la memoria de trabajo.

En general, la contribución del entrenamiento musical a las habilidades cognitivas parece ser bastante pequeña y probablemente marque una diferencia reducida en la vida diaria, por lo que podría no ser una de las intervenciones de primera elección si el único propósito es la mejora cognitiva. Sin embargo, aprender a tocar un instrumento es una actividad enriquecedora en sí misma y puede convertirse una fuente importante de placer en la vida de quien lo toca. Lo interesante es que, además de los beneficios sociales y emocionales de tocar, podría tener además implicaciones significativas en el desarrollo de habilidades cognitivas básicas tras largos periodos de práctica (de varias décadas) y en muestras con un menor rendimiento cognitivo, un bajo nivel socioeconómico o que sufren alguna afección neurológica.

INTRODUCTION

Cognitive training: in search of the boost

We live in a society that is becoming more and more demanding in terms of the productive use of time and working hours. Many people would like to engage in interesting activities in their free time, travel and visit many corners of the globe, and spend a lot of time with people close to them. While listening to our street conversations, anyone would say that we are also competing to be the most productive in our leisure time. "This month I have managed to read four books. I am really proud". "I haven't had time. With the painting course, the film club, and yoga, I can't keep up". In addition, parents want their children to develop their cognitive skills optimally and achieve academic success, and older adults, for their part, would like to live as many years as possible in the fullness of their physical and mental capacities.

Given the *zeitgeist* of our time, there is a growing interest in ways to enhance and preserve our cognitive skills, especially those that have to do with modifiable factors such as lifestyles. Extensive scientific evidence links several behavioral and environmental factors to an increased risk of cognitive impairment, dementia, and accelerated aging (Cesari et al., 2021). For example, smoking, alcohol and drug abuse, a sedentary lifestyle, and inadequate nutrition were associated with a negative cognitive trajectory (Baumgart et al., 2015). Other factors such as air pollution or persistent stress might also have a similar impact (Cesari et al., 2021). On the other side, engaging in certain stimulating activities throughout life might improve our capacities and help to prevent the pervasive consequences of neural aging. Education, physical exercise, and cognitively stimulating occupations and leisure activities have all been associated with neurocognitive benefits (Arenaza-Urquijo et al., 2013; Kim et al., 2015; Ludyga et al., 2020; Ritchie et al., 2018; Smith et al., 2010) and a reduced risk of dementia (Verghese et al., 2003).

A classic example in the literature was the studies of London taxi drivers by Eleanor Maguire and her collaborators. Using magnetic resonance imaging (MRI), they showed that these professionals had larger posterior hippocampus than a group of intelligence-matched control adults (Maguire et al., 2000), which is a brain structure with an important role in spatial navigation and topographical memory. In particular, the right posterior hippocampus was observed to be more active during driving route recall, but not during the recall of world-famous landmarks that the participants had never visited (Maguire et al., 1997). Consistent with this, a 65-year-old taxi driver who suffered bilateral damage of the hippocampi retained a broad landmark, relational and orientation knowledge about central London, but not detailed spatial representations (Maguire et al., 2006). He was therefore able to navigate using main artery roads, but his navigation across secondary roads, which required access to the complex road matrix of the city, was generally impaired. Could it be that people with better spatial memory (and larger posterior hippocampus) are more prone to choose to be taxi drivers? Or would the observed differences in taxi drivers rather be the long-term consequence of their occupation as taxi drivers? Maguire and her collaborators (2000) found that the amount of time spent as a taxi driver positively correlated with the volume of the posterior hippocampus, suggesting that this region may expand with usage and argue against a predisposition. Although a more compelling answer arose with a longitudinal study from the same research group (Woollett & Maguire, 2011), in which trainees seeking to qualify as licensed London taxi drivers (n = 59) were compared with a group of control adults (n = 31) at the start of their training and three to four years later, just after qualification. Importantly, 39 trainees went on to qualify while 20 did not. The three groups did not statistically differ on a range of initial background measures, such as age, education, intelligence quotient (IQ), and memory measures, nor in their brain gray matter volume (analyzed with voxel-based morphometry). After three to four years of training, however, the group of qualified participants showed an increase in gray matter volume in the posterior hippocampi bilaterally, a change that did not emerge in the control participants or in the group that failed to qualify. Despite challenges such as lack of time, economic imperatives, or family obligations, those trainees who persevere by spending more hours per week training and taking the license exam more times were more likely to succeed in the qualification; and that successful learning was accompanied by increases in hippocampal size. The finding mirrored the results of hippocampal neurogenesis in rodents (Curlik & Shors, 2011), which also exhibited a learning rate whereby the animals that learned best had more new neurons after training than those who did not learn efficiently.

Although these studies were relevant to understand neural plasticity at a theoretical level, their practical implications were as surprising. Practicing the same thing thousands of hours, in their case driving along the London area, correlates with higher proficiency in that skill and brain areas underlying neural implementation of that function. In the same vein, people inexperienced in juggling presented a transient increase in areas associated with the processing of complex visual motion (bilateral hMT+/V5 and left posterior intraparietal sulcus) after practicing a three-ball cascade juggling routine for three months (Draganski et al., 2004). The structural expansion was related to the achieved juggling performance as it decreased after a subsequent period of three months, while the participants stopped practicing and most subjects were no longer fluent in three-ball cascade juggling. Moreover, subsequent cross-sectional studies found a positive correlation between gray matter density in the right hMT+/V5 region and performance in expert jugglers (Gerber et al., 2014).

However, the growing attention devoted to cognitively stimulating activities is not precisely due to their impact on the trained skills themselves. The interest in companies such as Lumosity (https://www.lumosity.com/en/), as well as commercial products such as Cogmed (https://www.cogmed.com) and Brain Training by Nintendo is rather based on their potential benefits over cognition in general. Therefore, training on one or more cognitive tasks could be interesting not only because it leads to improvements in the skills involved in those activities, but also because it could generalize, or *transfer*, its benefits to skills that are loosely related (Simons et al., 2016). It means that, by engaging in certain activities, people might improve their performance on other untrained tasks, both in the laboratory and in everyday life. At the core of cognitive training programs is the purpose of making people "smarter", better at learning or solving problems, as well as improving school and work outcomes and, ultimately, people's lives. A large body of research has examined the extent to which training interventions can enhance cognitive skills, evidenced by the exponential growth of scientific publications on this topic (**Figure 1A**). The number of mentions of concepts such as *cognitive training* and *brain training* has also increased in the literature for general audiences (**Figure 1B**), which is a sign of the widespread interest in this topic.

The Lumosity or Cogmed programs, as instances, were deliberately designed with the purpose of enhancing general cognitive skills such as attention, memory, processing speed, and executive functions. Using sets of computerized games or tasks similar to many tests used in the laboratory (e.g., Stroop tasks, go/no-go, visual search, etc.), multiple studies found benefits on trained cognitive skills (Ball et al., 2002; Etherton et al., 2019; Thorell et al., 2009), and sometimes those benefits generalized to other functions and intelligence as well (Bergman et al., 2011; Holmes et al., 2009; Jaeggi et al., 2008, 2011; Karbach & Kray, 2009; Richmond et al., 2011; Rueda et al., 2005; Thorell et al., 2009). Those benefits have been

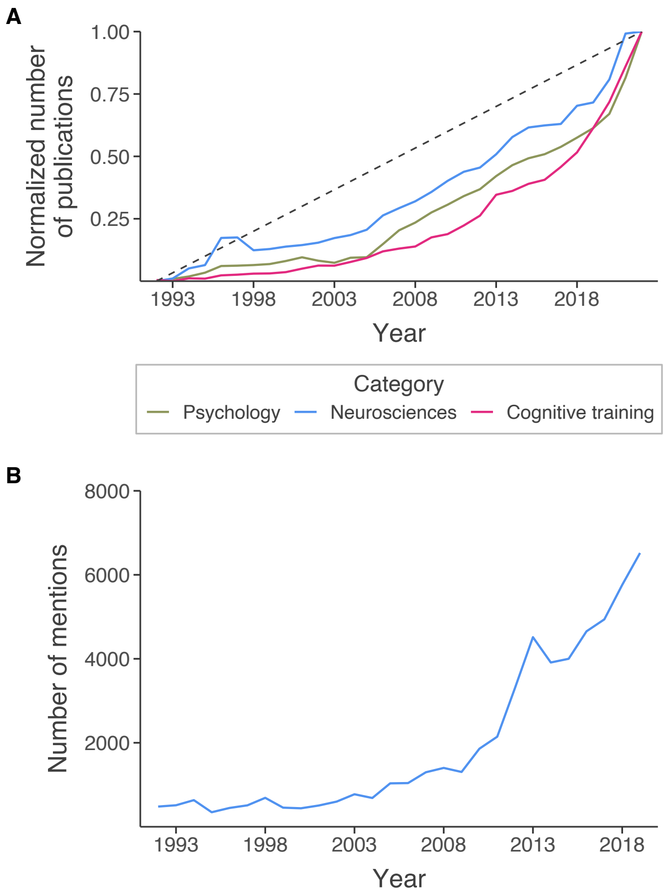


Figure 1. Evolution of the literature on cognitive training and the use of the term.
(A) Number of articles indexed in Scopus per year in the areas of psychology (green), neurosciences (blue), and cognitive training (magenta) [using the terms "cognitive training", "brain training", and "working memory training"]. The number of publications per year was normalized to express the values of all the categories in a common scale from 0 to 1. Whereas grey dashed line expresses a linear growth, the growth of all the categories followed an exponential trend, especially pronounced in the case of cognitive training. (B) Number of mentions of the terms "cognitive training", "brain training", and "working memory training" in printed sources published between 1500 and 2019 in Google's text corpora in English (Google Ngram Viewer; https://books.google.com/ngrams/).

observed at all stages of life, including adulthood (Jaeggi et al., 2008, 2011; Karbach & Kray, 2009) and aging (Ball et al., 2002; Richmond et al., 2011). Some trials showed long-lasting effects when follow-up assessments were conducted several months after the end of the intervention (Ball et al., 2002; Klingberg et al., 2005). Interestingly, the impact of this type of program has been observed to be greater in populations with neurological or psychiatric conditions (e.g., attention-deficit/hyperactivity disorder, ADHD: Klingberg et al., 2002) or lower cognitive performance at baseline due to age or individual differences (e.g., lower cognitive maturation: Rueda et al., 2005; cognitive aging: Bugos & Wang, 2022; Karbach & Kray, 2009; individual differences: Holmes et al., 2009;Jaeggi et al., 2011). Finally, other key aspects in cognitive training programs are the duration of the intervention, as there is evidence that the benefits are dosage-dependent (Jaeggi et al., 2008), and how challenging the training tasks are, as too easy or too effortful interventions might fail to produce optimal engagement and interest (Jaeggi et al., 2011). Therefore, the use of adaptive programs that matched the task difficulty to the level of performance of the trainees is encouraged (Diamond, 2013; Holmes et al., 2009). The progression in task demands seems to be crucial maintaining trainees' motivation and to keep pushing themselves to do better (Diamond, 2013).

However, another stream of this literature has examined the impact of ordinary activities that are cognitively demanding, such as physical exercise (Erickson et al., 2011), chess (Sala et al., 2015), video games (Green & Bavelier, 2003), meditation and yoga (Tang et al., 2007). Although they are activities that a considerable proportion of the population practices for multiple reasons (e.g., joy, well-being, fitness, socialization), a growing set of evidence emphasizes their potential cognitive applications. Musical training is one of these activities that could act as a cognitive enhancer. Like physical exercise and meditation, *musical training* is an umbrella term that includes many forms of musical interventions. It is used to refer to structured programs of learning to read music notation and to play a musical instrument or singing such as those in conservatories, programs of music education such as Kindermusik, Orff, or Kodály methods, computerized training of musical skills, phonological training with music support, and listening programs. These programs have proven to improve the skills they train, so they are effective as program of skill acquisition. For example, Herrera et al. (2011) showed that preschool children who undertook programs of phonological awareness with and without music (based on children's songs and single words, respectively) performed significantly better in tasks of naming and phonological processing, with group with music showing the greatest change in some phonological outcomes.

Importantly for this thesis, the characteristics of playing a musical instrument make it a priori a promising candidate for producing a transfer effect. Playing an instrument involves multiple sensory and motor systems, and requires a wide variety of higher-level cognitive processes (Herholz & Zatorre, 2012). Musical performance involves high sensorimotor integration, promoting strong associations between sensory inputs (audio-visual-tactile integration), as well as coupling of visual stimuli and motor commands (e.g., notes on the staff; Landry & Champoux, 2017), together with coordinated interhemispheric connectivity (Bartolomeo, 2022). Moreover, it also seems to be an optimal cognitive activity since it involves regular and motivated practice of progressive difficulty. Musical training and practice may also pose a unique type of ongoing challenge that might facilitate *far transfer*. No matter what level of technical and artistic mastery a musician achieves, there is always room for improvement. Furthermore, there are always new pieces, interpretations, styles, and genres of music to learn. And different musicians and ensembles to play with, adjust to, and learn from. Thus, improvement through the application of effortful control can remain a rewarding challenge throughout the lifespan. As a representative anecdote, when the virtuoso cellist Pau Casals was asked why he continued to practice four and five hours a day when he was eighty years old, he answered: "Because I think I am making progress" (Lyons, 1958). For all these reasons, and given the practical and theoretical relevance of the topic, I decided to focus the present doctoral dissertation on the role of playing an instrument as a potential enhancing activity of brain function and cognition.

Music and musicality: why are we musical beings?*

Now we can really understand what the meaning of music is. It's the way it makes you feel when you hear it. […] We don't have to know a lot of stuff about sharps and flats and chords and all that business in order to understand music. If it tells us something, not a story or a picture, but a feeling. If it makes us change inside and has all those different good feelings that music make you have, then you're understanding it.

Leonard Bernstein
Young People's Concerts: What does music means?, 1958

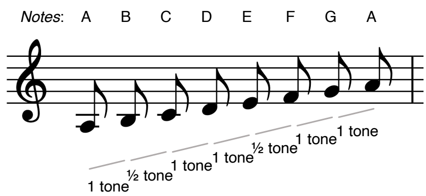
Music is an ancient activity present in all human cultures (Mehr et al., 2019). However, *music* is a broad concept that has been object of debate (Savage et al., 2015). On the one hand, our continuous experience with it gives us a sense of knowing what we mean by music. But the Western modern intuition does not match the concept of music in other languages. For example, Sanskrit *sangıta*, Thai *wai khruu*, and *nkwa* of the Igbo of Nigeria encompass music and dance as facets of the same activity (Trehub et al., 2015). The very origin of the Western word, from the Greek *mousiké* ('art of the Muses'), referred to a diverse set of activities including dance, poetry, and gymnastics. Dictionary definitions such as "a pattern of sounds made

* The content of this section has been covered by **Appendices B1 and B4**.

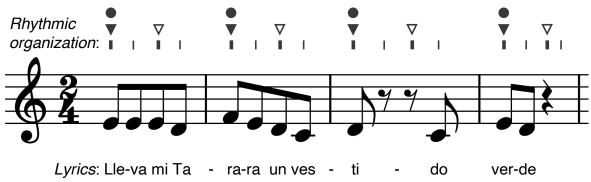
by musical instruments, voices, or computers, or a combination of these, intended to give pleasure to people listening to it" (Cambridge Dictionary) include main aspects of the general concept of music: "instrumental and vocal sounds", "intentionality", "organization", "pleasure", and "emotions". However, there are documented musical expressions that do not have a tonal or rhythmic organization such as some examples from Papua New Guinea compounded of percussion sounds and moaning voices containing neither discrete pitches nor an isochronous beat (Savage et al., 2015). Reversely, some forms of language, such as the recitation of a poem and the oratory from preachers, are undoubtedly speech as the meaning of the words is essential although their pitch variation and the kind of rhythmic organization bring them closer to music (Montagu, 2017).

Whereas the analysis of one of the most diverse global music collections, the *Garland Encyclopedia of World Music*, has revealed no absolute universal feature of music, there are many statistical universals that are consistent across cultures (**Table 1**; Savage et al., 2015). In addition, some musical features are highly prevalent together. The use of percussion instruments is usually combined with phrase repetition, motivic patterns, few durational values, and syllabic singing (i.e., enunciating a new syllable for each note), as all together facilitate group coordination and help to create predictable rhythms that can be easily danced to (Savage et al., 2015). The existence of traits common to all cultures suggests that the biological mechanisms that enable the perception and production of music are universal, varying only in their adaptation to the conventions of each culture and historical time. Therefore, we can distinguish between *music* and *musicality*. *Musicality* is the natural set of biological traits underlying our capacities to perceive and produce music, which would be a universal aspect of human biology. On the other hand, *music* is the diverse cultural products generated from those abilities humans inherit: songs, instruments, dance styles, etc. (Honing, 2018). At the same time that music is based on all capacities that form musicality, music universals could be a consequence of biological and cognitive constraints of how music is implemented in our brain, especially the characteristics related to the structure and the content of music (pitch, rhythm, and form). In addition, other aspects, such as the predominance of group musical performance, may instead be a manifestation of why we are endowed with music. For example, the use of scales with a small set of notes might be the product of constraints on short-term memory and categorization (McDermott & Hauser, 2005). Moreover, the sense of octave equivalence and the distinction between consonant and dissonant intervals come from the acoustic processing of our auditory system (Tramo et al., 2001). Musical notes produced by instruments or the voice are perceived to have a pitch, typically having energy at a fundamental frequency (f_0) and at harmonics whose frequencies are integer multiples of f_0. In the case of the note A_4 with f_0 = 440 Hz (the standard tuning frequency according to the International Standards Organization), the harmonic frequencies will be 880 Hz (A_5), 1320 Hz (E_6), 1760 Hz (A_6), 2200 Hz ($C\sharp_7$), and so on. Indeed, the relative intensity levels of the different harmonics are the base for the perception of timbre (i.e., the tone quality that allows distinguishing different sound sources, such as different voices or musical instruments). When two tones are combined in a musical interval, their adjacent harmonics may be close enough to interact on the basilar membrane so that they are not cleanly encoded in different tonotopic channels (i.e., they differ by less than a critical band). Whereas two tones that are perceived as consonant, such as the octave or a perfect fifth (e.g., A_4–A_5 and A_4–E_5), have few harmonics between them that fall within critical bands, the opposite is true for tones that are perceived to sound dissonant together (e.g., intervals such as the tritone and the minor second, as in the famous *Maria* from *West Side Story*: "Ma-ri", tritone; "ri-a", minor second) and that create the perception of beating and roughness (Trainor, 2015). In the case

Table 1. Cross-culturally statistical universals of music.
Table adapted from the results in Savage et al., 2015.

<table>
<tr><td>Pitch
1. Discrete pitches
2. Unequal scales (e.g., non-equidistant steps of tones and semitones)
3. Seven or fewer steps per octave
4. Descending or arched melodic contours
5. Small intervals (a perfect fifth or smaller)</td><td>Music tends to use sets of discrete notes (A, B, C, D…) to form scales with seven or fewer non-equidistant steps (e.g., some steps comprise a whole tone and others a semitone), such as the A major scale.


This set of sounds are used to build melodies usually with descending or arched contours (i.e., pitch trajectories) composed of small intervals.

</td></tr>
<tr><td>Rhythm
6. Isochronous beat
7. Metric hierarchy
8. Two- or three-beat subdivisions (especially multiple of two beats)
9. Motivic rhythms
10. Few durational values</td><td>Music tends to use isochronous beats with a periodic alternation between strong and weak beats. Those beats are periodically organized in groups of two or three beats (i.e., forming bars) with a constant meter (i.e., the strongest beat at the beginning of rhythmic bar that generally correspond to the spontaneous tapping of the foot).


This beat serves the skeleton to construct motivic patterns based on fewer than five durational values.</td></tr>
<tr><td>Form
11. Short phrases (less than 9 s)</td><td>Music tends to consist of short phrases less than 9 s long.</td></tr>
<tr><td>Instrumentation
12. Voice use
13. Instrument use</td><td>Music tends to use both the voice and instruments, often together in the form of accompanied vocal songs.</td></tr>
<tr><td>Performance style
14. Modal register (chest voice)
15. Word use</td><td>Music tends to use the chest voice to sing real words, rather than vocables (non-lexical syllables).</td></tr>
<tr><td>Social context
16. Group performance</td><td>Music tends to be performed predominantly in groups.</td></tr>
</table>

of the octave, the f_0 of the second tone (e.g., A_5, 880 Hz) actually has the same frequency as the first harmonic of the lower note (A_4, 440 Hz). The idea that consonance is a consequence of the functioning of the cochlea was advanced centuries before by Helmholtz (1885/1954).

Neuropsychological reports have been crucial to unraveling music-dedicated architecture in the human brain (Peretz & Coltheart, 2003; **Figure 2**). People with *amusia* have normal IQ, working memory capacity, auditory skills, and speech comprehension, but marked impairments in music skills as a result of brain damage (*acquired amusia*) or due to a neurodevelopmental disorder (*congenital amusia*). While *congenital amusia* is a developmental deficit in acquiring musical syntax and tonal representations that hampers the early development of the neural music processing network, *acquired amusia* represents a shift from a previously normal to a deficient music processing system caused by a brain lesion (e.g., stroke; Sihvonen et al., 2019). Cases of acquired amusia showed that selective brain lesions can impair the discrimination of pitch relations while sparing the perception of time relations, or, conversely, rhythmic discrimination can be disrupted while extraction of pitch content is spared (Ayotte et al., 2000; Peretz, 1990; Peretz & Zatorre, 2005). This double dissociation between melodic and temporal processing suggests the involvement of separate neural subsystems. The right secondary auditory cortex seems to have a key role in processing relationships between pitch elements, especially if the pitch changes are small. Furthermore, both the extraction of the melodic contour and the analysis of the precise pitch intervals are relevant stages for the perception and recognition of melodies that are can be selectively impaired (Ayotte et al., 2000). The evidence converges to show that the right superior temporal gyrus (STG) plays a critical role in contour analysis, while interval information involves the cooperation of both the right and left temporal structures (Ayotte et al., 2000; Liégeois-Chauvel et al. 1998 et al.; Peretz, 1990). Coherently, absolute pitch (i.e., the rare ability to be able to identify any pitch by its musical note name without reference to any other sound) has been associated with an enlarged asymmetry between the plana temporalis of both hemispheres. That difference was mainly accounted for by a reduction in the volume of right-hemisphere structures (Keenan et al. 2001).

In the same vein, brain damage can alter the tonal encoding of musical pieces, leaving intact other spectral functions. For example, the case of GL, a man who had lesions in the left temporal and right inferior frontal gyrus (IFG; **Figure 3**) as a consequence of two consecutive aneurysms, was no longer able to distinguish tonal from atonal music nor to judge melodic closure properly, in contrast to normal discrimination of melodic contours and pitch intervals, and temporal processing (Peretz, 1993). Therefore, the IFG has a special role in detecting deviations from harmonic expectancies (Peretz & Zatorre, 2005).

On the other hand, the temporal organization involves the segmentation of the sequence of musical sounds into rhythmic groups and the extraction of an underlying regular beat. Several neuropsychological studies support that these two components are implemented in the brain by separate neural subsystems: selective lesions in the anterior part of the STG (such as those produced in cortectomy for refractory epilepsy) produced a decline in the perception of the meter and tempo (Kester et al., 1991; Liégeois-Chauvel et al. 1998), in contrast to the impairment in rhythmic discrimination with lesions left temporoparietal regions (Robin et al., 1990) that sometimes spares low-level temporal processing (i.e., discriminating sound duration and gap length) and meter evaluation (Di Pietro et al. 2004). Along with the regions of the brain cortex, the cerebellum and basal ganglia also contribute to temporal organization controlling motor and perceptual timing (Peretz & Zatorre, 2005).

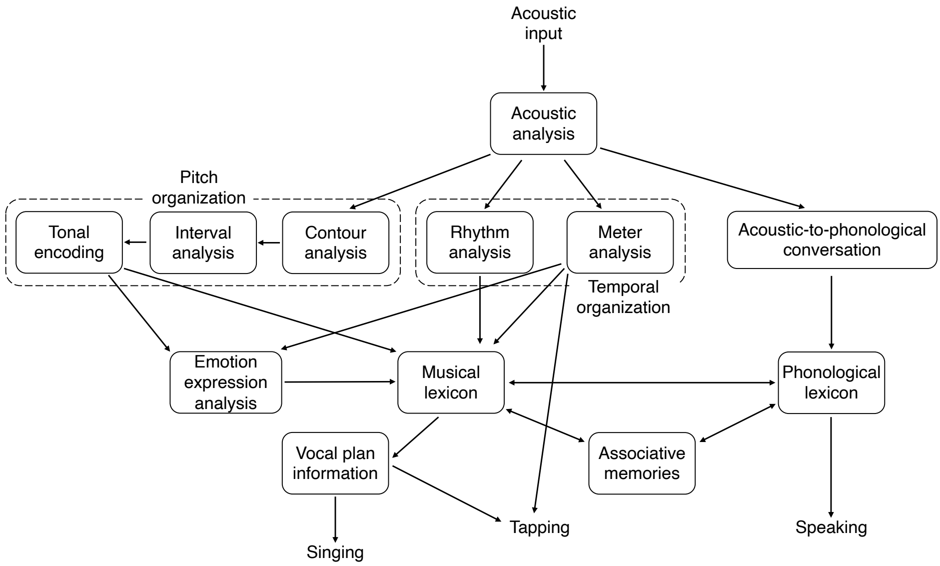


Figure 2. Modular model of music processing by Peretz & Coltheart (2003).
Boxes are the multiple processing components in music and speech perception, whereas arrows represent their communication pathways. A neurological disorder may either alter a processing component (box) or interfere with the flow of information between two boxes. According to the model, music and speech have both shared and unique components. Adapted from Peretz and Coltheart (2003).

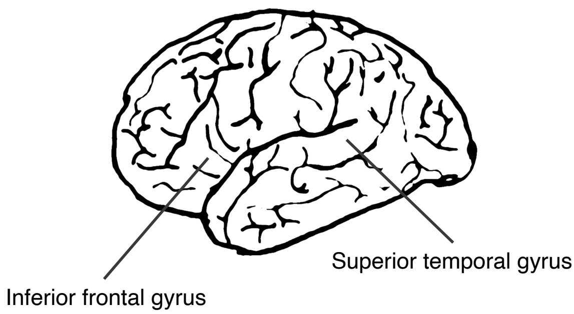


Figure 3. Inferior frontal and superior temporal gyri.
Lateral view of a left surface of the brain in which the inferior frontal and superior temporal gyri are highlighted.

Other cognitive components of music perception are well instantiated in the human brain. As for words in language, the process of music recognition requires access and selection of potential candidates in a perceptual memory system, although in the case of melodies the stored representations are in essence perceptual (Peretz & Zatorre, 2005). Memories of familiar tunes are relatively abstract to overcome the multiple potential variations in tempo, timbre, instrumentation, etc. Neuropsychological reports showed brain damage, especially those involving anterior STG and insula (Stewart et al., 2006), can impair the recognition of familiar melodies with normal music perception (Eustache et al., 1990; case 1) or intact memory capacity with other materials (e.g., auditory words and environmental sounds; Peretz, 1996). Hence, memory failures may be music-specific and it suggests that memory for music may be segregated from other types of memories.

Finally, music is an intense emotional evoker and one of the most pleasurable stimuli (Mas-Herrero et al., 2013). In Western music, happy and sad emotions are often conveyed with fast tempos and major keys, and slow tempos and minor keys, respectively (McDermott & Hauser, 2005). But to what extent is the response to that musical cues innate? Developmental research shows that the association between mode and mood (i.e., major mode–happy and minor mode–sad) does not appear in children below the age of six years old (Gregory et al., 1996), probably because the emotional connotations of major and minor scales are culturally acquired, and tempo is a crucial cue for affective inferences at that age (Dalla Bella et al., 2001). Consistently, cross-cultural studies found that people can perceive the intended emotions in tunes and melodies even when they are from different cultures. For example, Western people often experienced similar emotions from Indian raga music even when they were not enculturated in that tonal system, but they relied more on tempo and rhythmic features of music in comparison to Indian people in which tonality was one of the main responsible of their emotion (Balkwill & Thompson, 1999; Midya et al., 2019). Emotional responses to music may be altered after lesions in the amygdala and the insula (Gosselin et al., 2005; Griffiths et al., 2004). The activity of those brain structures, along with other regions involved in reward, emotion, and arousal, including the ventral striatum, midbrain, orbitofrontal gyrus (OFG), and ventral medial prefrontal cortex, are modulated during highly pleasurable experience of "*chills*" with music (Blood & Zatorre, 2001). A similar pattern has been observed to the response to other euphoria-inducing stimuli, such as food, sex, and drugs of abuse. In addition, the phenomenon of "*chills*" elicited changes in psychophysiological indicators of emotion and arousal, such as increases in heart rate, respiration depth and rate, and skin conductance, and reductions in the peripheral skin surface temperature and blood volume pulse amplitude (Blood & Zatorre, 2001; Salimpoor et al., 2009). Moreover, it seems that the rewarding experience with music is essentially universal among humans, although the factors that contribute to it may differ between individuals (e.g., the *Barcelona Music Reward Questionnaire* defines five factors: musical seeking, emotion evocation, mood regulation, social reward, and sensory-motor reward; Mas-Herrero et al., 2013). About 5.5% of the people reported difficulty to experience pleasure specifically associated with music, whereas they have normal hedonic responses in the remaining domains, a condition that has been called *musical anhedonia* (Mas-Herrero et al., 2013).

To the universality of music and the existence of specific components in the brain function dedicated to music, we must add evidence that supports that is a unique treat of human beings. *Homo sapiens* appeared in Africa 315,000 years ago and from there they migrated outside the continent to Asia (190,000 years ago) and Oceania (65,000 years ago; Harvati et al., 2019). The earliest archaeological finds reputed to be musical instruments dated to the arrival of anatomically modern *Homo sapiens* in continental Europe (45,000 years ago) in the transition to the Upper Paleolithic (Conard et al., 2009; Higham et al., 2012). They are flutes made of animal bones, mainly large birds such as swans and vultures, that appeared in the caves of two areas, Isturitz, in the French Basque region of the Pyrenees, and the Ach Valley in southern Germany. They were found along with other archaeological finds that indicate that those Paleolithic communities had developed a symbolic and abstract vision of the world (d'Errico, 2003). Beads and pendants evidence a taste for ornamentation, whereas representations such as bone human and animal figurines, and paintings is a proof of the acquisition of symbolism and art. Some of the figurines, such as the Venus of Hohle Fels and the Lion Man, have been even linked with religious thought (Kind et al., 2016). This suite of behaviors is part of what has been called *behavioral modernity* (d'Errico, 2003). Behavioral and cognitive traits that distinguish modern *Homo sapiens* and that include music and dance. However, even when the clearest and most abundant evidence begins to emerge from the arrival in Europe, *Homo sapiens* were already modern at the anatomical level 100,000 years ago when their main populations were concentrated in Africa and the Middle East. There, several objects of a clear "modernity" have also been found, such as the 77,000-year-old engraved ochre pieces found in the Blombos cave in South Africa (Henshilwood et al., 2002). Therefore, the biological changes that were the basis for cognitive and cultural changes of behavioral modernity preceded the expansion of Homo sapiens across Europe. Regarding music, perhaps one of the most enlightening findings is the mammoth ivory flutes of the Ach Valley dated 40,000 years ago. Although its design is essentially identical to the bird bone flutes, the material introduced a remarkable challenge in its manufacture: the piece of ivory must be sawn in half along its length, the core must be removed, and then the two halves of the flute must be refitted and bound together with a bonding substance (Morley, 2013). The technical complexity of the procedure suggests that the original goal of the creator of that artifact was to create a flute, and by 40,000 years ago the production of musical instruments was a honed activity that has probably left no previous trace because of the manufacture in biodegradable matters (e.g., wood; Morley, 2013). Probably, singing and percussion on the body or simple objects such as stones preceded other forms of music with no unambiguous archaeological trace.

But are we the only species with musical abilities (i.e., *musicality*)? And the subsequent question: why did *Homo sapiens* develop a such repertoire of cognitive traits? The first question has been easier to answer as it involves a present phenomenon: the current cognitive differences between humans and other animals. Ethological and experimental observations have shown that most of our musical abilities are present in other species to some extent. For example, our relatives the primates distinguish between consonant and dissonant intervals (McDermott & Hauser, 2004), although only some species such as chimpanzees share our preference for consonance (Sugimoto et al., 2010), experience octave equivalence and some form of melodic contour (Wright et al., 2000). Our nearest relatives, the great apes, have been observed drumming their chests (e.g., gorillas; Redshaw & Locke, 1976), or on hollow trees and resonant objects (Arcadi et al., 1998), displaying some forms of vocal communication such as chimpanzees' pant-hoots or gibbons' coordinated vocal duets (Geissmann, 2000), and chimpanzees perform "rain dances" and "waterfall dances" as a collective response to the sound of heavy rain (Whiten et al., 1999). As an example of "tool use" which blurs the line between vocal and instrumental displays, orangutans have been reported to use leaves placed in front of the mouth to lower the frequency of their vocalizations in situations of danger and convey the predator a larger body size (Hardus et al., 2009).

Outside of the primate order, wood-peckers produce drumming displays by striking hollow trees with the bill for territorial defense and advertisement purposes (Dodenhoff et al., 2001), and kangaroo rats pound the ground in a seismic-like manner with their feet to scare predators away their burrows (Randall & Stevens, 1987). Among the percussive abilities in the animal kingdom, it is notable the case of palm cockatoos, in which the male palm cockatoo uses a stick, held in the foot, to strike on resonant hollow branches as part of their courtship (Wood, 1984). Moreover, songbirds, parrots, whales, and seals have the perceptual skills and the capacity for vocal learning that allow them to produce songs, understood as complex learned vocalizations (Fitch, 2015). In contrast, some primate vocalizations such as those of gibbon duets, although complex and beautiful, are not learned in the same way that songbirds, whales, and humans themselves learn songs. Finally, several parrot species and a sea lion have convincingly been shown capable of audiomotor entrainment (Kotz et al., 2018). A sulfur-crested cockatoo, Snowball, became famous through videos on YouTube showing its striking abilities to synchronize to the beat of songs of different styles (from Queen, the Backstreet Boys, Guns N' Roses, to Lady Gaga; Patel et al., 2009). A California sea lion specimen, Ronan, has shown similar audiomotor entrainment (Cook et al., 2013). Equally impressive are the choruses of plain-tailed wrens, in which males and females alternate their part precisely with little or no overlap between them, individuals within the same sex sing the same phrase in synchrony, and during the song individuals do not have to contribute the entire time, they can drop out and join in later without losing synchronization (Mann et al., 2005).

Altogether, it seems likely that most of the basic capacities comprising human musicality are shared with at least some other animal species, but at the same time, no other non-human species seems to possess "music" in the fullness of the human form. Therefore, what is unusual about humans may simply be that we combine all of these abilities (Fitch, 2015).

In addition, the fact that some animal songs sound musical to our ears does not imply that they are endowed with the wholeness of musicality. Unlike humans, who constantly use music for pure enjoyment, animals sing almost exclusively in the context of territorial defense or courtship, so their survival and reproduction depend on that behavior. Even when they sing aiming to alter the other animals' emotions, as far as we know, the purpose of such action is primarily subsistence (McDermott & Hauser, 2005).

So why that uniqueness and universality in music? What has it brought us? Since Alfred Russel Wallace and Charles Darwin presented their theory of evolution, many authors have supported the idea that music is an adaptative origin due to the benefits it confers to humans. Darwin himself argued by analogy with birds and other animals that the primitive proto-songs of humans "would have been especially exerted during the courtship of the sexes, —would have expressed various emotions, such as love, jealousy, triumph, —and would have served as a challenge to rivals" (Darwin, 1871). On the other side, some authors have stood the opposite view, according to which the music is a byproduct of the evolution of other traits that were the actual targets of natural selection. To Herbert Spencer (1857), animals express their emotions through their bodies. Thus, just as dogs wag their tails as an expression of joy or cats purr in pleasure, musical vocalizations, which for Spencer were primordial music, are the muscular consequence of emotion. Spencer believed that the most sophisticated music of his time, the music composed by Beethoven, Mendelssohn, and Chopin, was the expression of a progression of the civilization to reach finer feelings (Spencer, 1857). William James, in his monumental *The Principles of Psychology* (1890), also believed that music has no "zoological utility" and was developed as an accidental trait of our auditory system. For James, the love of music is comparable to seasickness and the effects of intoxicants as human reactions that would be "incidental to others evolved for utility's sake" (James, 1890, p. 1097). But, among the non-adaptationist arguments, the best known was Steven Pinker's (1997) comparison of music to a strawberry cheesecake:

> We enjoy strawberry cheesecake, but not because we evolved a taste for it. We evolved circuits that gave us trickles of enjoyment from the sweet taste of ripe fruit, the creamy mouth feel of fats and oils from nuts and meat, and the coolness of fresh water. Cheesecake packs a sensual wallop unlike anything in the natural world because it is a brew of megadoses of agreeable stimuli which we concocted for the express purpose of pressing our pleasure buttons. (p. 525)

According to Pinker, music is an “auditory cheesecake”, a byproduct of the evolution of other cognitive capacities that are actual adaptations, such as language and auditory scene analysis (Pinker, 1997). However, music is a loud activity that attracts attention (also of predators or enemies) and is energetically expensive (sometimes to the point of exhaustion) that if it had no value whatsoever, one might expect a strong selection against musical behavior (Fitch, 2006). On the contrary, facts such as the antiquity and the universality of music, and the separate neural implementation of some aspects of music cognition as evidenced by cases of amusia (Peretz & Zatorre, 2005) have inspired a wealth of adaptationist theories about the original functions for music.

One possibility is that human musical abilities could be *exaptations* rather than proper adaptations. That is, they could appear as byproducts of other cognitive adaptations, such as auditory scene analysis, but once they were acquired, they could take on new beneficial effects that create new selective pressures (Trainor, 2015). For instance, contour feathers were first adapted in reptiles for thermoregulation and then exapted for flight (Sumida & Brochu, 2000), or two of the ossicles in the middle ear, the malleus and the incus, were exaptations of two reptilian bones implicated in jaw joint (the articular and quadrate bones; Allin, 1975; **Figure 4**). Therefore, some aspects of music might have emerged as byproducts of the development of the auditory system, such as basic spectral and temporal processing, octave equivalence, or consonance/dissonance perception, while there is the possibility that other musical capacities, such as tonal pitch perception, beat-based timing, audiomotor synchronization, and the assignment of emotional meaning could evolve for music (Trainor, 2015).

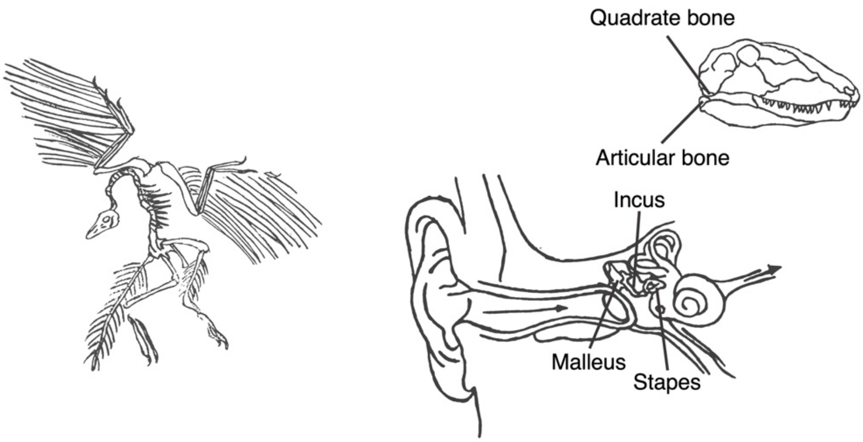


Figure 4. Archaeopteryx fossil and middle ear ossicles.
On the left, a fossil of Archaeopteryx, an animal genus of feathered dinosaurs that could potentially fly or glide. On the right, the three bones that form a transmission chain between the tympanic membrane and the cochlea, in comparison to the articular and quadrate bones of a reptile.

Among the adaptationist theories, the function of music in human courtship has received considerable attention (see Miller, 2000). Darwin (1871) believed that human proto-songs were part of the wide list of curious sexually selected traits that animals use to attract potential mates, from to peacocks' tails to deer antlers to birdsong. However, in practice, there is still no clear evidence of a relationship between having exceptional musical skills or being a virtuoso musician and having greater reproductive success. Fitch, 2006 argues:

> For every Bach with many children there may be a Beethoven who died childless, and for every popular conductor or lead guitarist there may be a lonely oboist or bassist.

In addition, music might have played a role in emotional regulation throughout human existence, especially regarding soothing infants (Mehr & Krasnow, 2017), and in social bonding, in a broad sense ranging from dyads (e.g., parent and infant, mate bonding) to bands of small coalitions and large groups of unrelated individuals (Savage et al., 2021). As Savage and collaborators stated in their *music and social bonding hypothesis* (Savage et al., 2021), group living comes with benefits (e.g., greater safety in numbers, and greater success with cooperative hunting and defense), but also costs (e.g., increased local competition for food and mates). The increase in group size during hominin evolution made inefficient many ancestral forms of social bonding (such as grooming in other primates), so music may have provided a novel system that allowed for bonding with a larger group (Dunbar, 2012; Savage et al., 2021). Thus, music-based activities have been associated with social cohesion effects. For example, adults singing in regular choir sessions develop feelings of social closeness toward co-participants more quickly than people engaged in other non-musical activities (e.g., crafts or creative writing), corresponding with an "*ice-breaker effect*" (Pearce et al., 2015). Feelings of inclusion, connectivity, positive affect, and pain threshold increased in small and large singing groups, with participants in large choirs (more than 80 participants) experiencing greater changes compared to smaller choirs (Weinstein et al., 2016). In addition, adults and infants who move together to a shared musical beat are subsequently more likely to display prosocial behaviors toward each other, suggesting that interpersonal motor synchrony might be one key component of musical engagement that encourages social bonds (Cirelli et al., 2014, 2016).

The *music and social bonding hypothesis* (Savage et al., 2021) additionally proposed neural model underlying the bonding effects of music (**Figure 5**). According to it, music involves predictable combinations of rhythms and pitches that activate neural systems for auditory perception (e.g., STG) that are tightly coupled with the motor system (i.e., *perception–action coupling*). Rhythm perception activates regions commonly thought to belong to the motor system (e.g., premotor area, supplementary motor area, and basal ganglia; Grahn & Brett, 2007) and whose functioning is strongly coupled with the auditory system (Fujioka et al., 2015; Grahn & Rowe, 2009). Learning to form predictions about musical features activates the dopaminergic reward system (i.e., ventral striatum, midbrain, OFG, and ventral medial prefrontal cortex; Blood & Zatorre, 2001) and supports across-individual synchronization facilitating social bonding and prosociality through the production of oxytocin (Grape et al., 2003; Keeler et al., 2015) and endogenous opioids (Weinstein et al., 2016). Finally, group musical experiences can be themselves rewarding and, as a consequence, people seek to participate more in musical activities and learn more musical features/knowledge, forming a cyclic model (**Figure 5**).

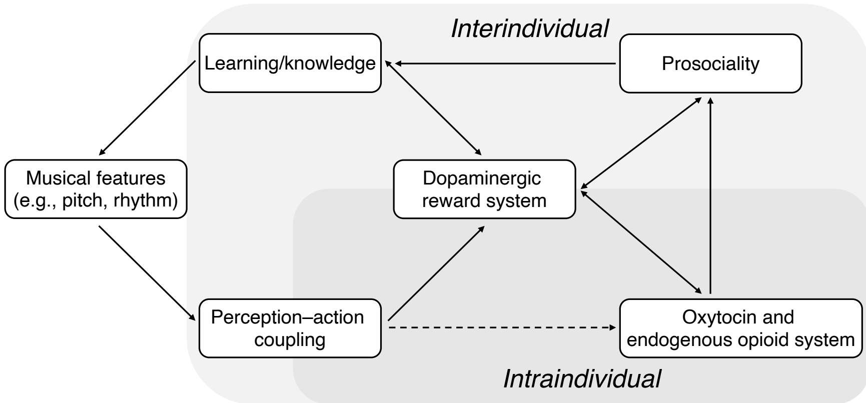


Figure 5. Neural model by Savage et al. (2021).
Proposed neural model underlying the social bonding effects of music by Savage et al. (2021). The model proposes intraindividual and interindividual levels, as well as the dopaminergic reward system interacts with the release of oxytocin and endogenous opioids in the synchronization of people's actions, perspectives, and emotions through musical engagement (dashed arrow indicates need for more evidence of that pathway). Adapted from Savage et al. (2021).

Musical training as a cognitive enhancer*

Any man could, if he were so inclined, be the sculptor of his own brain

Santiago Ramón y Cajal

Consistent with adaptationist hypotheses linking music origin with social and emotional advantages, several studies suggested benefits of musical training in empathy (Kawase et al., 2018; Rabinowitch et al., 2012), prosocial skills (Schellenberg et al., 2015), social closeness to the members of the group (Weinstein et al., 2016), and mood (Grape et al., 2003; Seinfeld et al., 2013). However, the benefits of music can be extended to loosely related domains. For example, in the 1990s, Rauscher, Shaw, and colleagues reported in a series of studies that listening to 10 minutes of the first movement of Mozart's two-piano sonatas improved scores on a test of spatial-temporal reasoning performed immediately after (Rauscher et al., 1993, 1995). Their studies showed that the so-called *Mozart effect* appeared in comparison to silence or other auditory stimuli (e.g., relaxation tapes; Rauscher et al., 1993) and the benefit was especially prominent in tasks that involve spatial imagery and temporal ordering of spatial components, such as the *Paper Folding and Cutting task* from the Stanford Binet's Intelligence Scale (Rauscher & Shaw, 1998). The authors suggested that listening to

* Part of the content of this section has been covered by **Appendix B1**.

complexly structured music excites cortical firing patterns similar to those used in spatial-temporal reasoning. Therefore, music such as Mozart's sonata "acts as an 'exercise' for exciting and priming the common repertoire and sequential flow of the cortical firing patterns responsible for higher brain functions" (Rauscher et al., 1995, p. 47).

Although Mozart effect was replicated in multiple independent laboratories (Pietschnig et al., 2010), subsequent studies have observed it with a wide range of musical styles, from other pieces of classical music (Ivanov & Geake, 2003; Nantais & Schellenberg, 1999) to the contemporary compositions by Yanni (Rideout et al., 1998). Furthermore, the evidence accumulated since the seminal paper on the Mozart effect fits better with a later alternative explanation (Nantais & Schellenberg, 1999; Thompson et al., 2001): music would enhance cognitive performance by promoting positive mood and higher levels of arousal. Nantais and Schellenberg (1999) observed similar enhancements after listening to the Mozart excerpt and after 10 minutes of Stephen King's short story. However, when the listeners' preferences were taken into account, the effect was larger in the Mozart than in the story condition with participants who preferred Mozart's music, while the opposite pattern was found for those who preferred the story. Further studies from Schellenberg's research group showed that the preference effect could be explained by changes in mood and arousal, as the Mozart effect disappeared when the changes in these variables were controlled for (Thompson et al., 2001) or reduced when the sonata for two pianos was manipulated to have musical features that generally evoke sad emotions or low levels of arousal (Husain et al., 2002).

In the same vein, background music can positively affect performance on multiple cognitive tasks. There are reports of benefits of listening to background music in processing speed (Angel et al., 2010), intelligence tests (Cockerton et al., 1997), vigilance (Fontaine & Schwalm, 1979), arithmetic (Hallam et al., 2002), long-term (Hallam et al., 2002) and working memory (Mammarella et al., 2007), and verbal fluency (Mammarella et al., 2007). These transient improvements may be due to temporal increases in arousal during monotonous or unstimulating tasks (Ünal et al., 2013), promoting task-focus states and reducing mind-wandering (Kiss et al., 2021), or producing a calming effect (Hallam & Price, 1998). But this is not always the case. Under some circumstances, background music could interfere instead of improving performance, especially with challenging tasks (Furnham & Strbac, 2002; Miskovic et al., 2008; Shih et al., 2012) and disrupting the rehearsal of verbal information during reading or memory tasks (Logie et al., 1990; Salamé & Baddeley, 1989).

Beyond the effects of music through emotional changes, taking music lessons and making music have been linked with improvements in cognitive skills themselves as a result of brain plasticity (Benz et al., 2016; Herholz & Zatorre, 2012). As one would expect, playing a musical instrument is associated with superior auditory skills (for a review, see Herholz & Zatorre, 2012). Many cross-sectional studies that compare groups of musicians with non-musicians have observed enlarged auditory cortical evoked potentials to tones (Pantev et al., 1998) and to the specific timbre of the instrument of training (e.g., enhanced cortical response in violinists to violin sounds compared to trumpet sounds, whereas the reversed was true for trumpetists; Pantev et al., 2001). Adults with musical training are better than untrained participants at recognizing melodies presented in transposition (Halpern et al., 1995) or with an unusually fast or slow tempo (Andrews et al., 1998), detecting differences in pitch between two tones (Schellenberg & Moreno, 2010), and on tasks measuring temporal discrimination (Rammsayer & Altenmüller, 2006) and timbre discrimination (Chartrand & Belin, 2006). Consistently, several studies found differences between musicians and non-musicians at the anatomical level, with greater volume, concentration, and thickness of auditory cortices in musicians (Bermudez et al., 2009; Gaser & Schlaug, 2003; James et al., 2014; Schneider et al., 2002), and the structural changes were linked to behavioral performance in musical tests (Foster & Zatorre, 2010; Schneider et al., 2002).

Similarly, parts of the sensorimotor network differed between trained musicians and non-musicians, such as larger anterior corpus callosum (Schlaug et al., 1995) and higher gray matter volume in the primary motor and premotor cortex (Amunts et al., 1997; Bailey et al., 2014; Bermudez et al., 2009; Gaser & Schlaug, 2003), the postcentral gyrus (Criscuolo et al., 2022), and the cerebellum (Gaser & Schlaug, 2003; Hutchinson et al., 2003). Musicians also showed higher axonal integrity (i.e., fractional anisotropy) in the posterior internal capsule, which contains descending fibers from the primary sensorimotor and premotor cortices that are of critical importance for independent finger movements in humans (Bengtsson et al., 2005; Criscuolo et al., 2022; Han et al., 2009). The structural differences in the motor cortex between musicians and non-musicians could be distinguished even at the macroscopic level, and between violinists and pianists (Bangert & Schlaug, 2006). While violinists presented a right-hemispheric enlargement coherent with the higher fine motor demands on the left hand for violin performance, the opposite pattern was observed for pianists, whose left hand may have more an accompaniment function (Bangert & Schlaug, 2006). Elbert et al. (1995) showed greater somatosensory cortical representations of the fingers of violinists' left hands compared to their right hands' representations or to controls, but the effect was smallest for the left thumb, which is involved in grasping the neck of the instrument instead of fingering the strings. In general, auditory and motor changes become more pronounced with earlier age of commencement of training (Amunts et al., 1997; Bailey et al., 2014;

Foster & Zatorre, 2010; Pantev et al., 1998, 2001; Schlaug et al., 1995) and longer training duration (Foster & Zatorre, 2010).

Over the past three decades, the literature has accumulated evidence associating musical training with benefits in non-musical cognitive capacities: intelligence (Bugos, 2014; Schellenberg, 2006; Swaminathan et al., 2017), visuospatial abilities (Brochard et al., 2004; Sluming et al., 2007), processing speed (Bugos, 2014; Jentzsch et al., 2014), executive control (Bialystok & DePape, 2009; Jentzsch et al., 2014; Medina & Barraza, 2019; Travis et al., 2011), attention and vigilance (Kaganovich et al., 2013; Rodrigues et al., 2013; Strait et al., 2010), episodic and working memory (Chan et al., 1998; Talamini et al., 2017), and language (Bidelman et al., 2014; Parbery-Clark et al., 2009). Musical training has related to a lower risk for developing mild cognitive impairment and dementia (Balbag et al., 2014; Merten et al., 2021; Verghese et al., 2003). In addition, anatomical and functional changes have been documented in brain networks involved in higher-order cognitive processing or non-musical skills. For example, increase in grey matter volume of bilateral inferior temporal gyrus, right fusiform gyrus, right medial orbital, left IFG, left intraparietal sulcus, right superior parietal cortex, left anterior hippocampus, bilateral posterior cerebellar Crus II, bilateral putamen, right middle and posterior cingulate gyrus, right calcarine sulcus, and right lingual gyrus (Fauvel et al., 2014a; Gaser & Schlaug, 2003; Groussard et al., 2010; James et al., 2014; Vaquero et al., 2016). In the same vein, musicians also present differences in the structural connectivity of the brain (i.e., higher fractional anisotropy in the posterior corpus callosum, the arcuate fasciculus; Bengtsson et al., 2005; Halwani et al., 2011) and strengthened connectivity within resting-state functional networks (salience network: cingulate gyrus, temporal pole, and IFG; control network: inferior OFG and the claustrum; default mode network, DMN: posterior cingulate gyrus and inferior OFG; Fauvel et al., 2014a), and between networks (between perceptual and motor networks:

auditory–visual, visual–sensorimotor, auditory–sensorimotor; Luo et al., 2012; salience–auditory, salience–visual, and salience–somatosensory; Tanaka et al., 2018; Zamorano et al., 2017; DMN–salience, DMN–control, DMN–auditory; and DMN–visual; Tanaka et al., 2018; Zamorano et al., 2017).

All these differences suggest that the type of training that musicians undertake benefits a wide range of cognitive skills, both closely and loosely related to the musical activity (i.e., *near* and *far transfer*). However, most of the studies in the field are correlational, which does not allow for establishing firm conclusions about the causal role of musical training in those advantages (Schellenberg, 2020). A plausible alternative explanation for these results is that high-functioning children, with higher musical aptitude, higher socioeconomic status (SES), and/or personality traits associated with cognitive improvements (e.g., openness to experience) are more likely to be interested in music and take music lessons (Corrigall et al., 2013; Swaminathan et al., 2017). Or perhaps individuals with better executive functions are more prepared to resist the temptation to abandon the continued effort that mastering an instrument entails. From this point of view, most of the cognitive and academic advantages observed in correlational studies and interventions without random assignment (where participants and their families chose musical activities) could be due to preexisting differences in children's intelligence, temperament, and environment. For example, Swaminathan and collaborators (2017) reported that the association between musical training and intelligence disappear after controlling for music aptitude. In addition, it has been argued that far transfer (i.e., the generalization of training in one domain to skills in a loosely related domain) rarely occurs with most types of cognitive training, because of the small overlap between domain-specific and domain-general abilities (Melby-Lervåg et al., 2016; Sala & Gobet, 2019a).

Extending this logic, it would be unlikely that musical training could enhance general cognitive abilities.

Other theoretical proposals have tried to reconcile both positions, arguing that expert musicians might have preexisting advantages (cognitive, personality, and/or musical aptitudes) that would promote the acquisition of musical skills and motivation to practice, while at the same time this long-term engagement would also result in multiple neural and cognitive changes (e.g., *nature and nurture hypothesis*, Wan & Schlaug, 2010). In this vein, the difference in magnitude between the effects observed in correlational studies (often Cohen's *d* around 0.80–1) and in experimental designs with random allocation ($d \approx 0.20$; Corrigall et al., 2013; for a classic example, see Schellenberg, 2004) might be the consequence of the fact that musicians in correlational studies present both preexisting cognitive advantages *and* benefits due to musical training. One design that can be helpful for disentangling the musical training–cognition relationship has been experimental studies with random allocation of the participants to the groups, the inclusion of an active control group (i.e., randomized controlled trials, RCTs), and blinded assessment. Several RCTs have confirmed the benefits of learning to play a musical instrument on a wide range of cognitive skills, such as intelligence (Costa-Giomi, 1999; Schellenberg, 2004), processing speed (Bugos et al., 2007; James et al., 2020), attention (Bugos et al., 2007; Frischen et al., 2021; Hallberg et al., 2017; James et al., 2020), episodic and working memory (Bugos & Wang, 2022; Frischen et al., 2021; Thorne, 2015), executive control (Frischen et al., 2021), switching (Bugos, 2019; Bugos & Wang, 2022), and reasoning (Thorne, 2015). Moreover, evidence from RCTs has documented brain changes with short instrumental tuition programs, such as an increase in cortical thickness in auditory regions (Worschech et al., 2022) and preventing an age-related decline in the fiber density of the fornix, a relevant structure for episodic memory (Jünemann et al., 2022).

However, given RCT designs are costly and suffer from attrition, RCTs with musical training are scarce in comparison to cross-sectional studies, and with short interventions (≈ 6–12 months long) and small samples (≈ 25 participants per group). Note that for a medium effect [around $d = 0.50$ according to Cohen's (1992) benchmarks], 51 participants per group would be needed to reach an acceptable power of .80, and even larger sample sizes for a small effect (i.e., for a $d = 0.20$, 351 participants per group) and higher statistical power (i.e., for a $d = 0.20$ and power of .95, 542 participants per group)[1]. Participants and trainers cannot be also blinded to the type of training they are taking/training (i.e., musical training or the control activity). Under those conditions, it is perhaps unsurprising that the results have been inconsistent across RCTs and some of them have reported null effects (D'Souza & Wiseheart, 2018; Haywood et al., 2015).

Indeed, some meta-analytic evidence of RCTs suggested that cognitive benefits of musical training, even if small, are not supported by studies with high-quality design (i.e., active control group and random assignment; Sala & Gobet, 2017a, 2020). Based on their meta-analytic null effect, Sala and Gobet have concluded that "researchers' optimism about the benefits of music training is empirically unjustified and stems from misinterpretation of the empirical data and, possibly, confirmation bias" (Sala & Gobet, 2020, p. 1429), "since there is no phenomenon, there is nothing to explain" (Sala & Gobet, 2020, p. 1437), and "researchers and policymakers should seriously consider stopping spending resources for this type of research" (Sala & Gobet, 2017b, p. 519). "Music is over" (Sala & Gobet, 2017a, title) and "Elvis has left the building" (Sala & Gobet, 2019b, title), they summarized. However, their findings are still under debate (Bigand & Tillmann, 2022). One of the reasons for the lower impact of

[1] Power analyses were conducted using G*Power 3.1 (Faul et al., 2009) for a one-tailed *t*-test and an alpha of .05.

musical training in random assignment studies is that participants might not be self-motivated to practice the activity and it can compromise the extent of the benefits. Also, choosing by chance one leisure activity that participants have to engage in for long periods, such as in the case of musicians (i.e., for decades), would be simply unethical (Habibi et al., 2018; Tervaniemi et al., 2018).

As motivated practice might be one key factor for far transfer, other types of designs would be helpful to shed light on the debate. For example, well-controlled cross-sectional studies cannot address differences before the training commencement but, with proper control of confounding variables, allow better isolation of neurocognitive differences due to the practice of a particular activity. Moreover, they investigate the musical training–cognition relationship under more ecological conditions, with groups of self-motivated participants. In a cross-sectional study with a large worldwide sample (6664 participants), Nichols and collaborators (2020) observed that people who reported playing an instrument outperformed non-instrumentalists in computerized tasks of executive control, planning, working memory, attention, and visuospatial abilities. However, after controlling for multiple confounders (i.e., age, SES, country of origin, handedness, gender, and education), the differences between both groups were small (all *d*s = 0.20 or smaller). Among nine pairs of monozygotic twins who were discordantly engaged in musical practice (i.e., nine individuals played a musical instrument whereas their corresponding siblings did not), de Manzano and Ullén (2018) found greater cortical thickness in the auditory-motor network of the left hemisphere and more developed white matter microstructure in tracts of both hemispheres (i.e., corticospinal tract, arcuate fasciculus, inferior longitudinal fasciculus, and uncinate fasciculus) and the corpus callosum. Those neuroanatomical differences were presented even when controlling for genes and early shared environment. On the contrary, several twin studies from the same cohort observed that the associations between the amount of practice and musical abilities, and between practice and intelligence disappeared when controlling for genetic and shared environmental influences using a co-twin control method (Mosing et al., 2014, 2016). Sample differences could explain the discrepancies within the same cohort of participants. Thus, Mosing et al. (2014, 2016) used a larger sample of monozygotic pairs (1211 pairs), most of them formed by two siblings with musical training and only in a small subsample of pairs one of the siblings played an instrument with a within-pair difference in total hours of practice higher than 1000 h (< 100 pairs; de Manzano & Ullén, 2018). While the comparison in the neuroanatomical study by de Manzano and Ullén (2018) resemblances classic cross-sectional comparisons between expert musicians and non-musicians, the findings in Mosing et al. (2014, 2016) may have led to conclusions mostly related to differences between people with different levels of musical training.

A second type of design is longitudinal studies, in which it is possible to control for confounders and, in addition, to follow up subsequent changes after the first measurement. In a study that employed population-level educational records for over 110000 students of British Columbia, Guhn and collaborators (2020) showed that music participation was related to higher scores in math science, and English subjects in Grades 10 and 12, especially instrumental music. That advantage arose even after adjusting for students' previous achievement (Grade 7), sex, cultural background, and SES. A longitudinal twin study (n = 1684; Gustavson et al., 2021) revealed that playing a musical instrument from age 12 to 16 years was associated with an increase in verbal abilities during that four-year period. Given that instrument engagement was highly heritable (78%) and it was genetically correlated with verbal intelligence at 12 years, the study suggested that a common set of genetic influences predisposes individuals to have high IQ and engage with musical instrument in early adolescence, but musical training may also have small direct benefits on later language abilities. The findings of these behavioral studies are in line with longitudinal evidence of brain plasticity with musical training (Hyde et al., 2009).

Taken together, the wealth of evidence in this literature suggests that learning to play a musical instrument could enhance cognitive abilities and promote neural plasticity, and those changes are independent of the existence of factors that increase the propensity of individuals to engage in this activity (e.g., higher pretraining cognitive skills, better pretraining musical skills, etc.). However, that hypothesis is still controversial and many authors dispute that musical training can be the *cause* of cognitive benefits (Mosing et al., 2014, 2016; Sala & Gobet, 2020; Schellenberg, 2020). The research program exposed in the present thesis dissertation was born aiming to contribute with answers to the debate.

MOTIVATION AND AIMS

Research, open science, and dissemination

It is well-established that doctoral theses are mainly devoted to the endeavor of furthering scientific knowledge on a particular topic. Mine arose with the aim of bringing new evidence to a controversial literature that is still of great public interest. From a scientific view, this is a good field to develop a doctoral thesis, as any further step might help to answer the debate and come with practical implications. Part of my work during these years had to be with this classic sense of a *thesis*, reviewing previous findings, thinking hypotheses, conducting studies, and publishing our results in scientific journals. The fruits of that research work are exposed in **Appendices A1–A5**.

Robert Merton (1942) proposed four values that represent the ethos of modern science: (1) *communism* (i.e., in an academic sense, the results and discoveries of researchers should be the common property of the whole scientific community), (2) *universalism* (i.e., scientists should apply impersonal and objective criteria in judging the validity of knowledge, independent of their sociopolitical and personal characteristics), (3) *disinterestedness* (i.e., scientists should have no emotional or financial attachments to their work, they should be instead motivated by finding out the truth), and (4) *organized skepticism* (i.e., scientists should remain skeptical about the results of research and continually challenge them until all the facts are established). Those values are in consonance with the practices proposed by the *open science movement*, which has gained popularity in the face of growing concern about the *reproducibility crisis* (Baker, 2015; Open Science Collaboration, 2015). Sharing data, materials, and analysis code in public repositories, preregistration of the hypotheses and analysis plan, registered reports, and publishing peer review history are some examples of practices that facilitate the access and the scrutiny of scientific discoveries (Nosek et al., 2015). Therefore, the studies conducted during the thesis adhered to open science philosophy and incorporates as many of the aforementioned elements as possible. In all cases, data and R scripts for the analyses were made publicly available via Open Science Framework (https://osf.io/) and the design and hypotheses of one of the studies were preregistered (https://osf.io/ktd2q).

Given the broad interest in the topic of the thesis and the need to bridge the gap between scientific knowledge and society, I decided to extend the objectives of the thesis beyond research work. Thus, the aims of this thesis are twofold, adding to the classic research objective a purpose of scientific dissemination to the general public. The findings of our studies and their background have been disseminated in different formats and to different audiences trying to effectively convey the scientific answers on this subject. That outreach work ranges from articles in lay journals and newspapers, radio and television interviews, to a proposal and draft for a dissemination book about the broad psychological and social benefits of music. The products of the dissemination of the thesis are exposed in **Appendices B1–B7**.

Meta-analysis in childhood and adolescence

The controversy surrounding the causal role of learning to play an instrument and music making is an ideal context for the application of a meta-analysis, as it allows a quantitative review of the literature and enables drawing firmer conclusions given an increased statistical power. Also, meta-analysis offers numerical estimators of the magnitude of the effect and between-studies consistency, which provide the opportunity to assess the relevance of interventions (and not only their statistical significance) and to identify potential moderators. Given the initial skepticism of some authors with the evidence coming from cross-sectional studies, assessing the impact of instrumental learning in RCTs could be a cautious starting point (considered as a gold standard design for proving causality). The most recent and comprehensive meta-analysis in the literature (i.e., Sala & Gobet, 2020) found a positive small effect of musical training ($d = 0.18$, $p < .001$) that was reduced to null when characteristics of design quality, random allocation and active control, were taken into account ($d \approx 0$). However, the interpretation of their results seems problematic for several reasons. First, only a third of the studies included in Sala and Gobet's meta-analysis had instrumental programs (19 out of 54) and that underrepresentation was even more pronounced among studies with random assignment and/or an active control group (i.e., only 27% of the randomized studies, 6 out of 22; 36% of those using an active control group, 9 out of 25; and 31% of those using both randomization and an active control group, 4 out of 13). Given that non-instrumental interventions (e.g., music education such as Kodály method, computerized training of musical skills, phonological training with music, etc.) likely have a smaller impact on cognitive skills and academic achievement compared to instrumental ones, the greater representation of the former in Sala and Gobet's meta-analysis may have led to conclusions mostly related to non-instrumental musical training. Second, some outcomes included in Sala and Gobet's meta-analysis were measures of skills trained with active control activities (e.g., phonological training purportedly enhances phonological abilities), and therefore should not be analyzed in a far-transfer meta-analysis (Bigand & Tillmann, 2022). Finally, some analytical decisions in Sala and Gobet's meta-analysis might have influenced their findings (e.g., partial exclusion of outliers; Bigand & Tillmann, 2022).

Thus, the overall impact of formal instrumental learning remains uninvestigated with a comprehensive and updated meta-analysis. The research work presented in **Appendix A1** (Román-Caballero et al., 2022b) aimed to fill that gap and shed light on the causal role of musical training. We restricted our meta-analysis to samples of school-age children and adolescents as a first step given it has been suggested that early musical training, especially during the sensitive period before the age of 12, may result in stronger and longer-lasting effects (Penhune, 2011; Vaquero et al., 2016). In addition, we additionally incorporated quasi-experimental pre-posttest studies for comparative purposes with experimental studies.

Near transfer of musical training

The idea that musical training, as any other program of skill acquisition, might have an impact on musical skills has been supported by cross-sectional studies (for a review, see Herholz & Zatorre, 2012) and some RCTs with older adults that observed benefits on auditory skills and their associated brain regions (Thorne, 2015; Worschech et al., 2021, 2022). However, there is also inconsistent evidence (Kragness et al., 2021; Mosing et al., 2014) suggesting the opposite, that is, that the malleability of musical skills is limited even for interventions with high overlap (i.e., *near transfer*). The historical propensity towards skepticism in the literature of musical training regarding near and far transfer contrasts with the optimism with other leisure activities (e.g., physical exercise, Ciria et al., 2023; Román-Caballero et al., 2023a). The inconsistencies might be the consequence of some studies using musical programs with different demands than instrumental training and samples in which most of the participants had some degree of musical training (i.e., few participants without training). Therefore, a comprehensive meta-analysis of RCTs with instrumental learning programs could provide relevant answers to the debate. Such a meta-analysis is presented in **Appendix A2** (Román-Caballero et al., 2022a).

Attentional advantages in adulthood

Beyond confirming the existence of far transfer with musical training, another relevant question is regarding the explanatory mechanism behind cognitive benefits. The cognitive and academic benefits of musical training across a wide range of areas may be in part a consequence of its purported impact on attention and executive functions. Attention and executive functions are engaged in many daily activities as well as in many measurement tasks used in the laboratory. Therefore, any benefit in attention and executive functions might indirectly influence performance in those activities (i.e., acting as a mediator factor between musical training and non-musical skills; Hannon & Trainor, 2007; Moreno & Farzan, 2015).

In particular, as with sport training and physical exercise (Ciria et al., 2023), musical training usually involves prolonged performances (in concerts and rehearsals) and the detection of stimuli needing a response (Rodrigues et al., 2013). For example, classical musicians have to play continuously for more than an hour in the interpretation of symphonies or operas, while conductor's movements (among other relevant stimuli) express crucial changes in rhythm, volume, or the beginning of a melody, which the orchestra must consider to accomplish a synchronized performance. In this vein, there is evidence that musicians show better performance in tasks of selective, divided, and sustained visual attention compared to non-musicians (Rodrigues et al., 2013), besides less auditory distraction (Kaganovich et al., 2013). Similarly, several studies have indicated better executive control in musicians than in their counterparts (Bialystok & DePape, 2009; Jentzsch et al., 2014; Medina & Barraza, 2019; Travis et al., 2011).

By contrast, other studies have not shown such advantages for musicians as compared to non-musicians in selective attention (Clayton et al., 2016; Roden et al., 2014), vigilance (Carey et al., 2015; Roden et al., 2014; Wang et al., 2015), or executive control (Clayton et al., 2016; Yeşil & Ünal, 2017; D'Souza & Wiseheart, 2018). Furthermore, Lim and Sinnett (2011) showed no differences between musicians and non-musicians in either exogenous or endogenous attentional orienting. Other mixed results were reported by Strait et al. (2010), wherein musical training was associated with faster responses in an auditory alertness task, but not when the warning signals were visual.

Taking all the above-mentioned literature into account, although some studies have shown attentional advantages for musicians as compared to non-musicians, others have not. Thus, a cross-sectional study with extensive control of confounding variables and appropriate statistical power could provide relevant evidence of the relationship between musicianship and attentional components. That study is presented in **Appendix A3** (Román-Caballero et al., 2021), in which we used a task developed in our group to measure simultaneously the functioning of the three attentional networks (alertness, orienting, and executive control), together with two independent measures of vigilance (arousal and executive vigilance): *ANT for Interactions and Vigilance—executive and arousal components* (ANTI-Vea; Luna et al., 2018). In addition, further advances in the analyses of vigilance tasks as the one used in our cross-sectional study were developed and are presented in **Appendix A4** (Román-Caballero et al., 2023b). Continuing this work would be a promising avenue for disentangling fine-grained differences between expert musicians and non-musicians, as described in the **General Discussion** section.

Meta-analysis in healthy aging

Although it has been hypothesized that cognitively stimulating activities have a greater impact when they are practiced at an early age, the studies with taxi drivers (Woollett & Maguire, 2011) and juggling (Draganski et al., 2004) suggest that neural plasticity can still occur at late stages of life. Indeed, some RCTs with older adults showed that benefits can still emerge out of childhood and adolescence (Thorne, 2015; Worschech et al., 2021, 2022). The world's population is currently experiencing a progressive aging process (United Nations Department of Economic and Social Affairs, 2020). This demographic change poses new challenges for today's societies, which must address the difficulties of aging (e.g., age-related neurocognitive decline) and identify the factors that can offer protection against these problems. The existence of age-related cognitive and brain declines, which become more marked around the age of 60, is well established today (Borella et al., 2008; Hedman et al., 2012; Salthouse, 2010). However, there is high heterogeneity in cognitive trajectories, as some individuals exhibit cognitive decline while others remain cognitively healthy across older age (Borghesani et al., 2012; Wilson et al., 2002). It appears that age-related cognitive decline is neither inevitable nor irreversible. Some of these differences may be due to protective genetic factors, such as engaging in certain stimulating activities throughout life including musical practice (Verghese et al., 2003). On the contrary, cognitive enhancements produced by musical training may remain in later life (Alain et al., 2014). However, to our knowledge, no systematic reviews had been conducted so far in the field of aging when the thesis was started. The work exposed in **Appendix A5** (Román-Caballero et al., 2018) aims to fill that gap in the literature. To this end, we decided to include studies with both experimental and cross-sectional designs, given their complementarity: experimental methodology involves randomization and thus allows establishing causal relationships; by contrast, correlational designs offer the possibility of analyzing samples with a higher and more extensive level of musical practice over longer periods of time.

In the **General Discussion** section, all the new evidence from cross-sectional and experimental designs, as well as from all life stages, will be brought together to reach a broad picture of conclusions on the discussion of near and far transfer of musical training.

GENERAL DISCUSSION

Transfer: suggestive but not conclusive

The research program exposed in the present thesis dissertation aimed to contribute new evidence to the debate on the existence of cognitive benefits as a consequence of learning to play a musical instrument and musical practice. The works conducted in this thesis examined whether musical training has an impact on both near-trained skills (i.e., auditory skills) and loosely related, more domain-general functions (e.g., attention). Furthermore, it is critical to the thesis to investigate whether benefits occur across the lifespan or are limited to the early stages of life. We, therefore, conducted several meta-analyses of evidence from RCTs (as a gold standard design for testing causality; see Román-Caballero et al., 2018, 2022a, b) and complementary, well-controlled cross-sectional studies (see Román-Caballero et al., 2021, 2023b). Given society's growing interest in enhancing and preserving our cognitive abilities, the answers to these questions may have relevant theoretical and practical implications.

The results described in the present doctoral thesis suggested that, overall, instrumental musical training *causes* benefits on cognitive skills and other related outcomes, such as academic achievement. The enhancement seems to occur both in skills closed to trained abilities and skills with little overlap (i.e., near and far transfer). The observed effects are small in both cases, which at some point seem paradoxical. One would expect larger improvements on trained abilities than in less related ones (Gathercole et al., 2019), but our findings are not consistent with that hypothesis. One explanation for that could be the design of classic tasks used to measure musical skills, which involve holding in memory a reference auditory fragment and making a same/different judgment with a subsequent target melody or tone. There is a vast literature of cross-sectional studies pointing out that musical training could affect short-term memory (Talamini et al., 2017), a result we consistently replicated with RCTs with short programs in children and adolescents (Román-Caballero et al., 2022a). In fact, a multi-laboratory registered report study, in which I am participating (Grassi et al., in principle acceptance), is underway to provide a worldwide reliable estimate of the musicians' memory advantage. Therefore, tasks of auditory skills that rely on short-term memory might offer mixed measures of such skills. Previous twin studies found moderate heritability of performance on tests based on same/different judgments (Mosing et al., 2014). In contrast, the genetic influence on auditory tasks that do not involve memory demands seems to be reduced, whereas shared and non-shared environmental factors explain a large part of the individual differences (Seesjärvi et al., 2015). The reduced heritability in tasks such as the Out-of-key and the Off-beat tests from the Online Test of Amusia (Peretz et al., 2008), which entail the perception of key and rhythm violations in single melodies with no memory-based comparison, suggests that tasks with fewer memory demands might be more sensitive to the changes purely produced in musical skills by music-making experiences. Further research with tasks such as the Online Test of Amusia would present larger enhancement, but the evidence with them is very scarce.

Furthermore, the results are the fruit of comprehensive and updated meta-analyses (Román-Caballero et al., 2018, 2022a, b) and one cross-sectional study in which an extensive list of confounders was controlled for (Román-Caballero et al., 2021). The most compelling evidence come from studies with random assignment of participants and active control groups. To my knowledge, six studies, with a total of 809 participants (D'Souza & Wiseheart, 2018; Frischen et al., 2021; Haywood et al., 2015; James et al., 2020; Schellenberg, 2004; Thorne, 2015) followed such a gold standard design, and their meta-analytic outcomes are coherent with near and far transfer of musical training. In addition, the findings are consistent with the existence of differences prior to the commencement of musical training. In the meta-analysis with intervention studies in childhood and adolescence, children who self-selected learning to play an instrument showed higher cognitive performance at baseline (d = 0.29; Román-Caballero et al., 2022b), and, in our cross-sectional study, before matching musicians presented higher levels of education, physical exercise, use of a second language, and engagement in cognitive activities than non-musicians (Román-Caballero et al., 2021). Similar findings emerged in cross-sectional (Corrigall et al., 2013; Swaminathan et al., 2017) and twin studies (Gustavson et al., 2021). In a longitudinal investigation of children from infancy to school age, Zuk and colleagues (2022) observed that fractional anisotropy of the right corticospinal tract and the posterior corpus callosum in infancy predicted subsequent musical abilities at school age. Therefore, the literature is in accordance with the existence of a set of common genetic and environmental influences that predisposes individuals to have high cognitive functioning and engage with musical instrument in early adolescence: heritability of intelligence and musical aptitudes, personality traits, SES, etc. When the research design accounts for all of them, it allows isolating the effects of musical training on cognition. Accordingly, evidence from both RCTs and well-controlled longitudinal and cross-sectional studies converged to a small effect ($d \approx 0.20$; Guhn et al., 2020; Gustavson et al., 2021; Román-Caballero et al., 2018, 2021, 2022b).

However, Medina and Barraza (2019) observed an extremely large advantage in executive control for professional pianists (d = 1.51) using a visuospatial attentional task (i.e., the *Attentional Networks Test*, ANT; Fan et al., 2002), which correlated with the number of years of musical practice. This exceptionally large effect was likely inflated by the lack of control over several variables potentially enhancing attention. Indeed, in a similar study with an ANT-like task (i.e., the ANTI-Vea), we observed a smaller difference in executive control ($d = 0.25$) when the effect of musical training was measured while controlling for a wide list of confounders (Román-Caballero et al., 2021). All in all, our findings are in line with the *nature and nurture hypothesis* (Wan & Schlaug, 2010). According to this view, preexisting cognitive advantages would facilitate the learning of musical skills, but the engagement itself in the complex activity of learning to play a musical instrument for a long period would lead to neurocognitive adaptations.

Interestingly, we observed three variables moderating the effects of musical training in childhood and adolescence: pretest cognitive performance, SES, and age of the participants (Román-Caballero et al., 2022b). Thus, the larger the baseline difference, the smaller the benefit. This could be due to children with a lower initial level of performance having a greater window of opportunity, and vice versa. An alternative explanation for the pretest effect is a regression toward the mean of those samples of children who showed remarkably disparate scores at baseline (higher or lower). This is a key aspect in RCTs with small samples, which would need to discard the possibility of a regression toward the mean before inferring an enhancing effect (especially, when there is no between-group difference in the posttest performance and the larger improvement is mainly driven by a pretest difference). In the same vein, participants with lower SES showed greater improvements compared to those with middle-to-high SES, which might be also the consequence of a large margin for improvement for individuals whose development of cognitive skills and academic achievement is limited by their socioeconomic environments (Diamond, 2013). Although higher-functioning individuals are more likely to select and maintain musical practice for many years, children with a less favorable background can also benefit from musical training as long as they engage in it for enough time (Fasano et al., 2019; Portowitz et al., 2009; Tierney et al., 2015). If this finding is confirmed by future research, musical training can become an excellent candidate to contribute to reducing cognitive and academic differences due to social disparities.

Finally, our results were consistent with previous cross-sectional studies that show greater neural and cognitive advantages for earlier commencement of the training (Penhune, 2011). It suggests the existence of a sensitive period during which instrumental learning is likely to have stronger and more permanent effects on non-musical skills, perhaps as a consequence of greater neural plasticity earlier in development, and because those early neurocognitive changes might serve as a scaffold for future training (Vaquero et al., 2016). For example, White-Schwoch and collaborators (2013) found that older adults with a moderate amount (4 −14 years) of music training early in life showed faster neural timing in response to speech compared to untrained older adults. The key finding in the study was that the difference in neural response was still observable several decades after cessation of the practice. A similar result has been observed in young adults, who seem to retain neural changes accompanying musical training during childhood (Skoe & Kraus, 2012).

Alain and colleagues (2014) proposed that the cognitive benefits of music training might vary in an age-dependent manner. Their model posits that musical training during early stages of life enhances perceptual and cognitive functioning via structural changes in the brain. After a sensitive period, musical training is thought to enhance performance via functional changes and promoting the strategic use of cognitive skills (e.g., new cognitive routines; **Figure 6**). Therefore, learning to play an instrument might improve performance in tasks of memory, attention, executive control, etc., as a consequence of changes at different levels, structural or functional, depending on the age of onset.

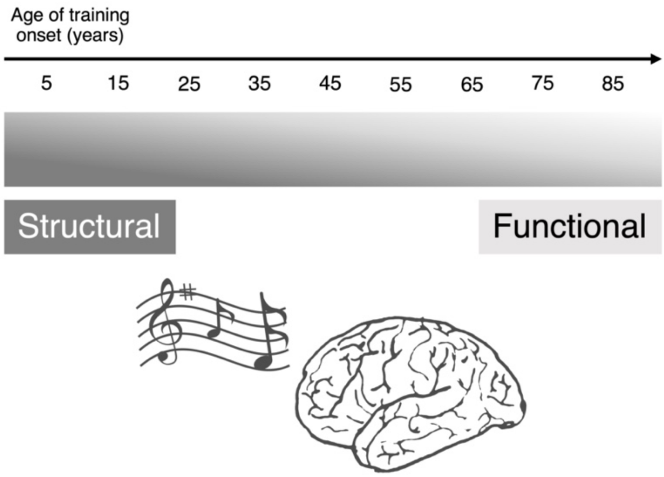


Figure 6. Alain et al. (2014) model of neural changes with musical training. Schematic representation of the neural changes produced by musical training, in which there is an age-dependent shift from structural to functional changes. While the earlier the onset of musical training the greater the perceptual and cognitive improvements via anatomical changes, after a sensitive period musical training is thought to enhance performance via functional changes. Adapted from Alain et al. (2014).

In addition, Alain and colleagues (2014) conceived two different patterns for the potential benefit of musical training in mitigating age-related decline on cognitive and perceptual skills (**Figure 7**). The first is a scenario in which musical training might enhance certain skill that tends to decline through age with the same rate in trained and untrained people (i.e., main effect of training without interactions with age). They called it *preserved differentiation.* The second pattern, called *differential preservation*, is characterized by an interaction between age and the amount of training, with a slower rate of age-related decline in expert musicians. Whereas people with musical training would show better performance at late age in both scenarios, only *differential preservation* is indicative of a *protective effect* (*preserved differentiation* would be linked with an *enhancing effect* across lifespan). For example,

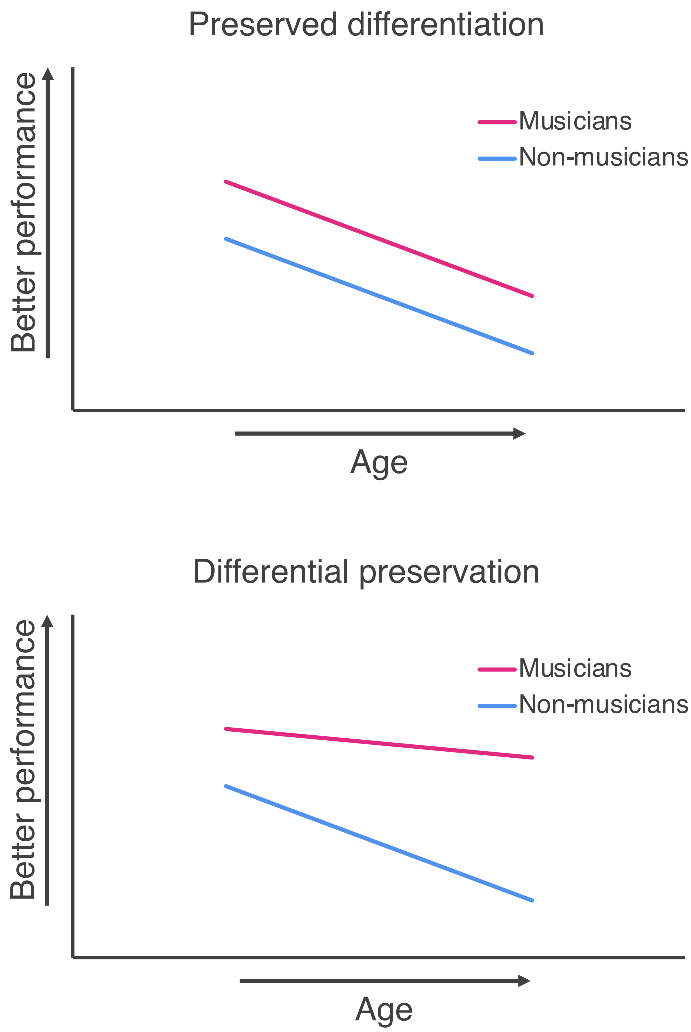


Figure 7. Two patterns of aging differences according to Alain et al. (2014). Differences between older musicians and non-musicians could be hypothetically due to a pattern of preserved differentiation or differential preservation. Only differential preservation is indicative of a protective effect of expertise because it represents a modulation of experience on the age-related decline.

Zendel and Alain (2012) found that musicians experienced less age-related decline for both gap-detection and speech-in-noise thresholds (i.e., *differential preservation pattern*) and a lifelong advantage in detecting a mistuned harmonic compared to non-musicians (i.e., *preserved differentiation pattern*), even when musicianship had no influence on the age-related decline in pure-tone threshold. It suggests that aging can differentially influence central and peripheral stages of auditory processing, where musical training can delay some of the age-related changes in central auditory processing (e.g., gap-detection and speech-in-noise thresholds) and enhance other central-auditory abilities (e.g., mistuned harmonic detection).

In the case of other cognitive skills, our meta-analysis in aging (Román-Caballero et al., 2018) suggests that playing a musical instrument throughout life seems to be associated with benefits beyond childhood and even if training began later. The available evidence is particularly insufficient to draw any firm conclusions in this regard, but some early evidence pointed to different patterns depending on the type of cognitive ability. In a cross-sectional study, Fauvel et al. (2014b) found a similar rate of decline for some attentional tasks (e.g., d2 test), whereas no decline was observed in other tasks (e.g., verbal fluency tasks). Interestingly, several studies with large samples have been published after our meta-analysis showing patterns of results more coherent with a *preserved differentiation*. For example, Merten and collaborators (2021) assessed in five moments the ability to perceive speech under adverse conditions (i.e., speech comprehension in competition with another distracting message) in a large sample of adults raging 48–92 years at baseline (n = 2938). The sample of musicians presented less decline in speech perception, consistent with a protective effect of musical training (*differential preservation pattern*). However, it was not the case of other less related capacities, for which there was only a trend of better cognitive performance at every age (i.e., *preserved differentiation pattern*). Other recent cross-sectional studies with large samples have found a similar *enhancement-without-protection pattern* in domain-general abilities (e.g., executive functions: Nichols et al., 2020; Tremblay & Perron, 2023; episodic memory: Romeiser et al., 2021; Rouse et al., 2021). These results are consistent with longitudinal and cross-sectional studies investigating education (Zahodne et al., 2011; Zarantonello et al., 2020), which showed a positive effect on cognitive functions but the effects of education did not interact with age. Altogether, the available literature suggests that the role of music training fits better as an enhancer than a protector of domain-general cognitive capacities in healthy aging.

Toward a mechanism of neurocognitive changes

The findings presented in this thesis suggest that instrumental learning could be beneficial for cognitive tasks and contexts quite distinct from musical performance. Computerized psychological tasks (e.g., go/no-go), and standardized tests of intelligence or academic achievement have little in common with playing a musical instrument at a concert or rehearsal. Thus, our results are in accordance with the idea that, besides improving domain-specific abilities, involvement in the stimulating activity of playing a musical instrument enhances distant functions. Nevertheless, not all cognitive domains and academic achievement appear to be equally sensitive to instrumental training. For example, executive functions showed the most robust benefits in our meta-analysis in childhood and adolescence ($d = 0.40$; Román-Caballero et al., 2022b, Table 3), and, in our cross-sectional study, the differences in attentional aspects such as vigilance and psychomotor speed were larger than in other outcomes ($d \approx 0.40$; e.g., flanker conflict, $d = 0.25$; Román-Caballero et al., 2021). A more recent reanalysis of the same data with the psychometric-curve approach (Román-Caballero et al., 2023c) showed that the smaller vigilance decrement in musicians was mainly due to a reduced increase in attentional lapses (see **Figure 8**). Our reanalysis shows that, across task, participants adopted a more conservative response criterion (i.e., horizontal shift of the psychometric curve) and tended to make overall fewer hits, even in cases where the distinction of the target from distractors is evident (i.e., increase in lapse rate). However, expert musicians were distinguished from non-musicians in terms of a less prominent increase in attentional lapses. These attentional differences are not surprising, as music-making places high demands on the abilities of control and self-regulation, monitoring, planning, and focused and sustained attention, among others, which are important for mastering an instrument and also for life in general.

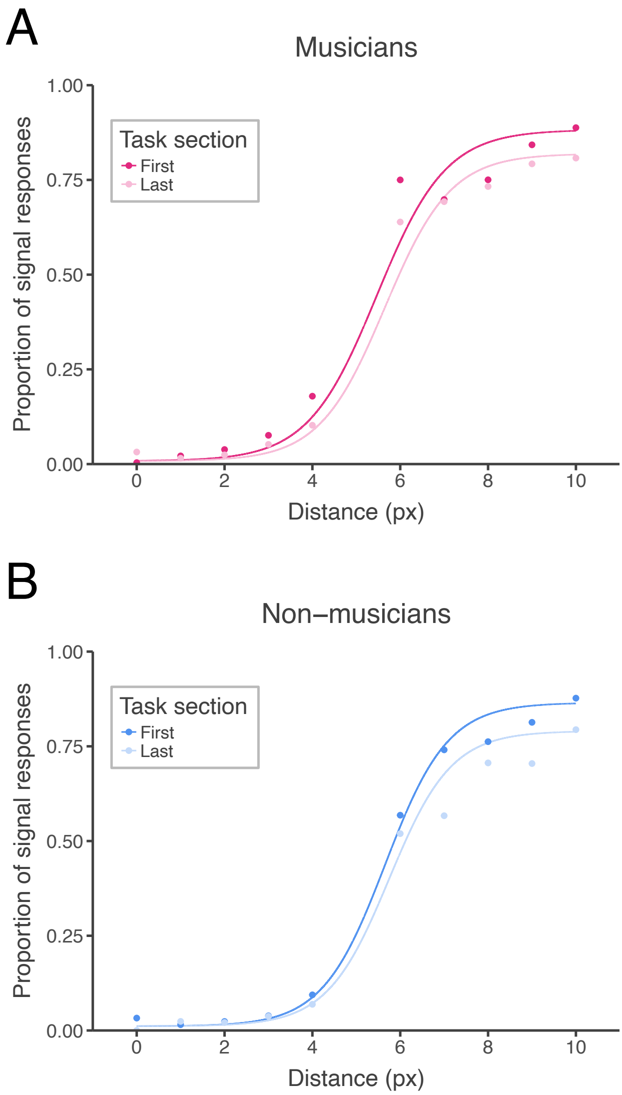


Figure 8. Psychometric curves of musicians and non-musicians.
Performance of (A) musicians and (B) non-musicians on the first and last sets of blocks of the ANTI-Vea task (i.e., first and second blocks vs. fifth and sixth blocks). While noise trials comprised distances between the target and the two most proximal flankers from 0 to 4 pixels, signal trials involve target–flanker distances from 6 to 10 pixels.

Some authors have expressed skepticism about far transfer (Roediger, 2013; Sala & Gobet, 2019a; Thorndike, 1906). Specifically, Thorndike (1906) proposed that transfer only occurs when trained and untrained processes share features in common. Under this approach, he concluded that "the most common and surest source of general improvement of a capacity is to train it in many particular connections" (Thorndike, 1906, p. 248). Unlike many other cognitive activities involving highly specific contexts and tasks, music-making requires the coordination of several skills and sensory modalities and involves a wide and constantly augmented variety of stimuli, social situations, and types of performance. Therefore, musical training has singular characteristics that made it a plausible cognitive enhancer, even from a skeptical perspective.

One explanation for far transfer is that regular training in a particular basic cognitive process fosters the process itself and, as a consequence, affords advantages to any daily task that also hinges on the same skill. This hypothesis is supported by several studies showing hippocampal neurogenesis in rodents throughout life (Curlik & Shors, 2011; Shors et al., 2012). According to that literature, engaging in new and difficult tasks leads to retaining many of the new neurons in the hippocampus (Shors et al., 2012). In rodents, the number of new cells decreases with factors such as age (decreasing by more than a half from puberty to adulthood), stressful experiences, drug abuse, and sleep deprivation, and, reversely, it increases in response to exercise and other healthy activities. Most of the new neurons do not survive, although learning experiences occurring during multiple forms of training increase their survival, in a "use it or lose it" fashion (Shors et al., 2012). However, this explanation is undoubtedly simplistic, as evoking a "brain as a muscle" metaphor fails to explain why cognitive training programs sometimes fail to extend their benefits to other activities or contexts (Gathercole et al., 2019; Owen et al., 2010; Roediger, 2013; Simons et al., 2016; Stojanoski et al., 2021; Taatgen, 2013). In addition, the evidence with rodent neuroplasticity is consistent with the idea that the benefits of early musical training are driven mostly by structural changes, whereas the improvements of late training interventions would be the result of functional changes and the strategic use of available resources. Similar reasoning has appeared in studies of cognitive training through physical activity (Pesce, 2012; Tomporowski & Pesce, 2019), in which most research has adhered to a quantitative approach manipulating variables such as the frequency, intensity, and the duration to improve cardiovascular fitness. However, improved physical fitness alone does not seem to explain the cognitive benefits, as shown by a recent umbrella review of published meta-analysis in which I participate (Ciria et al., 2023).

An alternative proposal conceptualizes transfer as the consequence of acquiring complex cognitive skills that can be applied to untrained tasks with some overlap, regardless of the age at which it takes place (Gathercole et al., 2019; Taatgen, 2013). The *cognitive routine framework* (Gathercole et al., 2019) posits that training on unfamiliar or highly demanding tasks, such as learning to play an instrument, leads to the development of new complex cognitive skills. Transfer then occurs when one of these new skills can be applied to a novel activity. In the case of musical training, several studies have reported superior memory scores for adult musicians when they were compared to non-musician counterparts (Franklin et al., 2008; Jakobson et al., 2008; for longitudinal studies, see Portowitz et al., 2009; Roden et al., 2012), but the evidence suggests that the advantage is largely due to more robust and efficient coding (via improved rehearsal mechanism, Franklin et al., 2008; and increased use of semantic information for organization strategies, Jakobson et al., 2008). In line with these results, musical training could stimulate the development of singular strategies, such as mental rehearsal and semantic organization, that can be applied to several non-musical tasks. Accordingly, the expansion of cognitive capacities along with the development of new complex skills could explain the broad benefits observed with musical instrumental learning.

Another potential mechanism might come from the multisensory nature of playing an instrument. For example, Lappe and colleagues (2008, 2011) found that learning to play a musical sequence on the piano over two weeks, compared to only listening to that music, produced greater enhancements in detecting incorrect pitch or timing, as well as larger responses of the auditory cortex (i.e., larger mismatch negativity to musical deviations). These group differences indicate that not only are sensorimotor and auditory systems connected but also sensorimotor-auditory training causes plastic reorganizational changes in the auditory cortex over and above changes introduced by auditory training alone (Lappe et al., 2008). In the same vein, a wealth of cross-sectional studies has documented that instrumentalists exhibit involuntary motor activity when they just listen to well-trained pieces (Baumann et al., 2005; to the point that notes that are preferably played by the thumb and the little finger could be clearly distinguished from the evoked motor activity; Haueisen & Knösche, 2001), and, reversely, auditory activity when they moved their fingers simulating a musical performance (Baumann et al., 2005). Consistently, multiple MRI studies revealed strengthened structural and functional connections between auditory and sensorimotor brain networks (Criscuolo et al., 2022; Luo et al., 2012).

Similar findings have been observed regarding auditory-visual and visuomotor coupling. For example, Che and collaborators (2022) observed in an RCT that piano training (over eleven weeks) improved the detection of audio-visual temporal discrepancies compared to a group that only listened to the same practiced excerpts or an as-usual control group. Moreover, musicians are less susceptible to audiovisual illusions, such as the double-flash illusion (Bidelman, 2016), whereby the presentation of two auditory beeps concurrent with a single visual flash induces an illusory perception of two flashes, and the Colavita effect (Wang et al., 2022), in which the simultaneous presentation of visual and auditory stimuli makes more likely that the participants respond only or preferentially to visual stimuli. The repeated experience with combining auditory and visual cues (e.g., instrument sound with music notation) during musical training might therefore improve the integration of inputs from multiple sensory systems (audition and vision). People with musical training are more likely than untrained individuals to map musical dimensions (e.g., pitch, amplitude, and duration) onto visual metaphors (height, size, and length of visual figures, respectively; Walker, 1987). On the basis that the representation of a perceptual effect (e.g., a musical note) can trigger the movement necessary to produce the effect itself, Novembre and Keller (2014) suggested that the enhanced coupling of perception and actions in musical training might facilitate the representation of complex actions and the coordination with other agents. The enhanced perception–action coupling might explain the overall faster response of musicians in cognitive tasks (e.g., Román-Caballero et al., 2021). The coupling between several sensory modalities would similarly produce enriched representations of the events of the environment and facilitate the response to them. For example, Huang et al. (2010) found visual cortex activation during verbal memory retrieval in musicians, but not in participants without systematic musical training, who also showed lower recall. Therefore, the activity of visual areas in the retrieval of verbal information could be related to singular representations of words auditorily presented to accomplish the task, such as visual imagery.

Cognitive advantages in musicians might not only come from differences in cognitive capacity and skills. Interestingly, musical training as a continuously rewarding activity with multiple feedback sources (teachers, audience, colleagues, the accuracy of produced sounds, etc.) might promote that effort itself can become a secondary reinforcer and be rewarding by itself (i.e., *learned industriousness*; Inzlicht et al., 2018). Furthermore, learning to play an instrument constitutes prolonged successful experience that is worth investing effort in, as it leads to successful mastery the instrument. As a result, people with musical training might become more willing to exert effort and approach any demanding tasks, such as cognitive tests, with a different motivational state. In this sense, musical training would improve performance by altering the effort willingness of the musicians, not their capacities themselves. For example, in the cross-sectional study that forms part of the thesis (Román-Caballero et al., 2021), expert musicians exhibited a lower general disengagement of the task (measured as a lower increase in attentional lapses) and external cues (i.e., auditory warning signals) had a smaller effect over performance (i.e., *phasic alertness effect*), both indices suggesting a greater capacity of musicians for endogenously sustaining high preparation levels over time-on-task. Thus, the evidence supports the hypothesis that people with long-term musical training were more vigilant due to a greater willingness to exert effort.

Additionally, as part of a research project (P20-00693) funded by the Junta de Andalucía and FEDER, we are currently carrying out a cross-sectional study about the development of attention and vigilance during childhood and adolescence (using again the ANTI-Vea), and the potential influence of activities such as musical training and structured physical exercise. In that ongoing study, we aim to examine the changes in several mental states (i.e., emotion, task engagement, distress, and worry) related to the completion of the task. Using the Self-Assessment Manikin (Mehrabian & Russell, 1974) and the Dundee Stress State Questionnaire (Matthews et al., 2002) before and after the ANTI-Vea, we are measuring states that can potentially be altered after performing monotonous and demanding activities such as the ANTI-Vea for a prolonged period of time. We hypothesize that the differences between musicians and non-musicians in changes in mental states will reflect differences in decreased vigilance, with a lower tendency to be sadder, distressed, task disengaged, and worried in musicians. Probably, those changes in mental states would mediate the effects on behavioral outcomes, in support of the idea that part of the advantages of musical training is due to motivational and emotional benefits.

Finally, the benefits of musical training on a wide range of cognitive skills could be in part a consequence of its noticeable impact on domain-general functions, such as attention and executive control (Hannon & Trainor, 2007; Moreno & Farzan, 2015). Therefore, the advantages in many other cognitive tasks and daily life activities may be indeed an indirect rather than direct improvement of musical training. In such cases, enhanced attention and executive control would act as a mediator between musical training and non-musical skills. None of these mechanisms are mutually exclusive. On the contrary, all of them might work together and cause musically trained people to show a superior capacity, for example, to recall novel words due to:

a) increased learning ability, via neuroplastic changes driven by the high demands of memory in musical practice (i.e., *domain-specific enhancement*),
b) the use of more efficient coding strategies (improved rehearsal mechanism and semantic organization; i.e., *development of new cognitive routines*),
c) multimodal representations of the events (e.g., spatial or visual representation of auditory words; i.e., *enhanced multisensory and perception–action coupling*),
d) more propensity to exert effort in demanding tasks (i.e., *learned industriousness*), and
e) enhancements on domain-general cognitive functions, especially attention and executive control (i.e., *domain-general enhancement*).

In the case of aging, several models pose that most age-related differences in cognitive measures are associated with changes in a small group of functions. Specifically, there is evidence supporting the role of sensory capacity (Li & Lindenberger, 2002), processing speed (Salthouse, 1996), and executive functions (Hasher & Zacks, 1988; Naveh-Benjamin & Cowan, 2023) as possible mediators of the effects of aging on many other cognitive processes. A decline in sensory capacity seems to affect the early stages of processing, while slower processing seems to lead to incomplete later operations and reduce the amount of information available simultaneously (Salthouse, 1996). In fact, processing speed acts as a mediator of many age-sensitive functions (Salthouse, 1992), including functions that involve both fluid and crystallized abilities, such as phonological fluency (Elgamal et al., 2011) and naming (Verhaegen & Poncelet, 2013). Moreover, inhibitory mechanisms seem to be central to the efficiency of working memory, limiting the entry of irrelevant information or rejecting irrelevant information that has gained access (Hasher & Zacks, 1988). Therefore, executive control could be important for avoiding distractions and also for speech comprehension, memory, and flexibility. In addition, other executive skills, such as coordination of tasks and task switching, monitoring, and updating suffer from an age-related decline (Naveh-Benjamin & Cowan, 2023). Musical training could have an enhancing effect on such domain-general functions thus ameliorating the cognitive consequence of aging.

Whether the demonstration of a causal role of musical training over cognition has been an object of debate, to which the current thesis has contributed showing relevant evidence across the lifespan, the proposed mechanisms are further from being confirmed. Thus, more research is needed not only for the applied knowledge (i.e., musical training could share mechanisms with other training activities) but also for basic interest. Comprehending how learning to play an instrument improves our cognitive abilities could help to understand the fundamental mechanisms of cognitive and brain malleability.

Practical implications and applications

The contributions of the present thesis support that musical practice is an activity with cognitive and academic benefits, although they are fairly small. An overall effect of d = 0.25 indicates a probability of 57% that a randomly selected person with musical training will show a cognitive advantage over a randomly selected person with no training (only 7% above the chance level). One pertinent question is the practical significance of this effect, as musical training is an effortful activity that takes many years. In this regard, Hunter and Schmidt (2015) claimed:

> The question for a treatment is really not whether it had an effect but whether the effect is as large as a theory predicts, whether the effect is large enough to be of practical importance, or whether the effect is larger or smaller than some other treatment or some variation of the treatment. (Hunter & Schmidt, 2015, pp. 246–247)

For example, Schellenberg (2004) found that after 36 weeks of intervention the difference between the IQ gain of the musical training and the passive control groups was only about 2 points. The benefit was even smaller when music participants were compared to children who took drama lessons (a gain difference of 1 IQ point). Similarly, our meta-analysis of studies with children/adolescents and programs lasting 16 months on average (Román-Caballero et al., 2022b) showed a similar overall increase, corresponding to about 3 IQ points. This contribution is rather small and probably makes very little difference in daily life, so, in that case, musical training might be not one of the first-choice interventions if the only purpose is cognitive enhancement. However, 1–1.5 years of musical training and, in some cases, reduced engagement due to random assignment might be not enough to produce substantial benefits on cognition. The few studies that assessed longer training periods have shown a greater impact of playing an instrument (Costa-Giomi, 1999, 2004: 36 months, mean d = 0.43; James et al., 2020: 48 months, mean d = 0.39; Portowitz et al., 2009: 24 months, mean d = 0.73), opening the possibility that the changes have practical relevance in the long run, with years of training.

Furthermore, in contrast to the general population, learning to play an instrument might have significant daily life implications, both in the short and long term, for populations with lower cognitive development and low SES, been in that case even a large effect (fitted $d \approx 1$ in Román-Caballero et al., 2022b; indicating a gain of 15 IQ points and a probability of superiority of 76%). Given unprivileged socioeconomic conditions and poverty have a detrimental effect on cognitive development and access to stimulating activities (Hackman & Farah, 2009), musical training might be an excellent tool to reduce development disparities. However, it is an expensive activity that makes it inaccessible to the low-SES population. On the other hand, access to conservatories (one of the main educational institutions of music) seems to be a competitive selection process. In Spain, eight-year-olds are given preferential access over older children and choose their instrument specialty based on their scores in tests of musical skills. Nevertheless, the cognitive development of children born in the first months of the year at the age of eight might be substantially higher than children born in the last months of the same year. The consequence of grouping candidate children by their year of birth instead of the month-by-month adjusted cognitive development could lead to an overrepresentation of children born closer to the beginning of the selection year compared to those born later (i.e., the first and second birth quarters vs. the third and fourth). That pattern is called the *relative age effect* and has been previously documented in sports teams (Huertas et al., 2019). In the aforementioned cross-sectional study that we are currently conducting with children and adolescents, a *relative age effect* has been observed in our sample of children with musical training (n = 222; **Figure 9A**) as well as the complete censuses of students from six Andalusian conservatories [$\chi^2(3, n = 1431) = 9.65, p = .022$; **Figure 9B**]. In addition to factors such as low SES, these birth asymmetries suggest that access to musical training may be hindered by the selection procedure of the educational system itself.

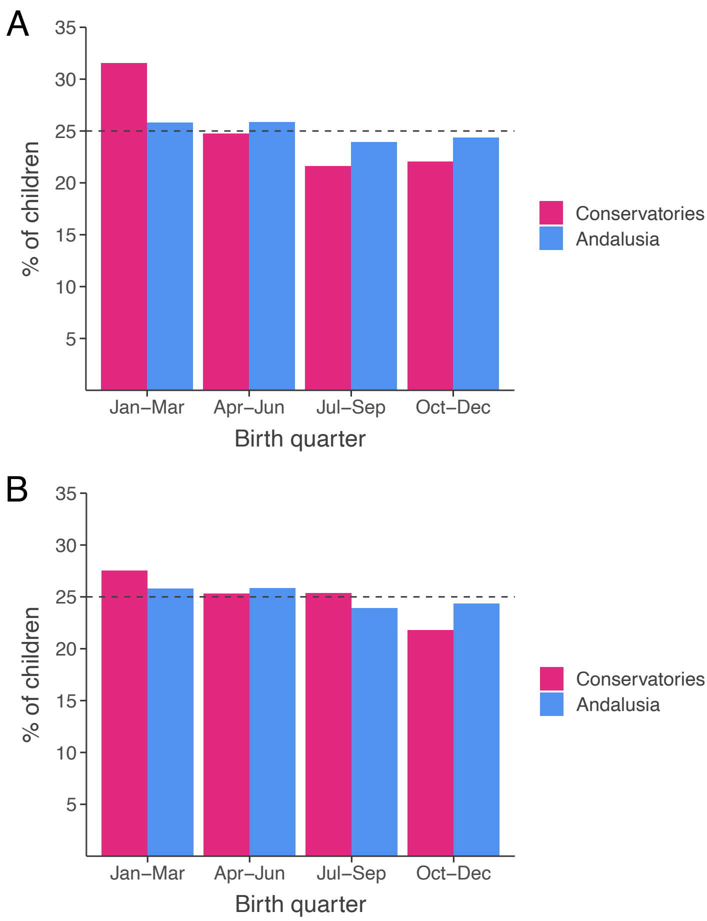


Figure 9. Relative age effect on conservatory musical training.
Distribution of children with musical training in (A) an ongoing cross-sectional study (n = 222) and (B) the complete censuses of students from six Andalusian conservatories (n = 1338; both in magenta). A *relative age effect* is apparent in both samples compared to an equal distribution of births in each quarter (dashed line) and the actual distribution of births in Andalusia between 2005 and 2014 (in blue).

In the event that new research confirms a greater impact of musical training on populations with low SES and cognitive development, policymakers should not "seriously consider stopping spending resources for this type of research", as Sala and Gobet (2017b) proposed. On the contrary, politicians should rethink educational models and look for ways to make such activities more accessible to low-income families and children with lower cognitive development. It is very likely that these children could benefit from multiple stimulating activities, so musical training should not be the only option that educational systems offer to them. Ideally, children and their families should be able to make a choice based on their own motivation thus maximizing the likelihood that they get the most out of the activity. Furthermore, instead of having strict selection criteria linked to the year of birth to give access to these activities, the individual growth curve of children should be taken into account to give access to those stimulating activities.

Another area where the implications of musical training might be greater is aging and age-related neurological conditions (e.g., stroke and mild cognitive impairment). The effects observed in older adults were larger than in children (*d*s > 0.40; Román-Caballero et al., 2018), even with short-term programs. Performance of older adults seems to be especially affected by adverse conditions (e.g., noisy environments) and tasks with a high degree of complexity, given the decline in high-level processes (e.g., working memory; Salthouse, 1992). Musical training could be a remarkable impact on this population by increasing high-level capacities and reducing the dampening of such *complexity effect*. In addition to the role of musical training in ameliorating cognitive aging, it can improve performance by improving quality of life, depression and anxiety feeling, physical and mental health, bringing enjoyment, and increasing social interaction (among others; Särkämö, 2018). These changes would be not restricted to later stages of life. Therefore, the cognitive benefits that could appear with musical training should be not taken as the principal value or goal of playing an instrument in most contexts, but as a precious supplementary effect that adds value to an ancient human facet with many other functions.

Finally, music-based activities can be an effective tool for neurological rehabilitation. Some music interventions engage specific regions associated with musical rhythm, movement, singing, or memory that are not directly affected by the disease (Sihvonen et al., 2017). In neurological conditions in which the internal sequencing of actions is impaired due to motor system dysfunction, rhythmic entrainment can act as an external timer cueing the execution of movements. Therefore, patients with impaired muscle coordination or with Parkinson's disease might find it easier to execute motor tasks with rhythmic support provided by music listening or dancing. Melodic intonation therapy is a singing-based intervention developed for the rehabilitation of people with non-fluent aphasia after damage in the left hemisphere. Singing engages bilateral brain regions, wider than speaking does, which enables the training of speech via both spared left hemisphere regions and homologous right hemisphere regions. Moreover, in the cases of language and attention disorders after a stroke, music might promote inter- and intra-hemispheric connectivity. The reconnection would allow the development of compensatory mechanisms and be a good prognostic sign (Bartolomeo, 2022). In people with Alzheimer's disease, the regions that encode musical memory also show minimal atrophy (i.e., the anterior cingulate and medial prefrontal cortex), which potentially explains why patients with Alzheimer's disease are able to recognize familiar songs. In addition, music making and music listening can produce benefits over well-being and mood that indirectly affect the cognitive performance of patients (Sihvonen et al., 2017).

Taken all together, the smallest cognitive effects of musical training might be those in populations from which expert musicians usually come:

middle-to-high SES, pretraining high musical and cognitive aptitudes, engaged in a wealth of stimulating activities apart from musical practice, and with high openness to experience. In addition, most of the existing studies were conducted with this sample (i.e., Western middle-to-high-SES children, university students, and older adults). Nevertheless, the benefits of musical training are presumably larger in other disadvantaged conditions, which makes it an extremely pleasurable activity that, in addition, can be an interesting tool for cognitive enhancement.

CONCLUSIONS

Despite the existence of skeptical voices, the available literature is suggestive of the benefits of musical training in a wide range of cognitive skills, both closely and loosely related to musical activity. It seems to occur regardless of the life stage in which the training takes place, although an earlier commencement is associated with structural and more permanent brain changes. In the case of late musical training, the improvement in cognitive skills is presumably a consequence of the acquisition of new strategies and the potentiation of domain-general capacities (i.e., attention and executive control), consistent with a more functional than structural change. Unlike many other cognitive activities involving highly specific contexts and tasks, playing an instrument involves multiple sensory and motor systems, and requires a wide variety of higher-level cognitive processes. Therefore, even from a skeptical perspective (i.e., "the most common and surest source of general improvement of a capacity is to train it in many particular connections" (Thorndike, 1906, p. 248), musical training has singular characteristics that makes it a plausible cognitive enhancer. Among its idiosyncrasies, the continuous multi-sensory integration in music-making might lead to a different representation of real-world events and the development of new cognitive routines fruit of enriched representations. Moreover, the benefits of musical training extend into aging, following in most cases a *preserved differentiation pattern* rather than a protective role of musical training. Strictly speaking, musical practice would act as a cognitive enhancer in most loosely related skills. Finally, the cognitive advantages of short-term musical training seem to be small and with little practical implications in healthy and middle-to-high-SES (e.g., a gain of 3 IQ points) samples. In such cases, we should not overlook the pleasure of making music in itself. The impact of this activity on our mental skills should be not taken as their principal goal, but as a supplementary effect that adds value to an ancient human facet with many other functions. The evidence is not large enough to be conclusive, so more studies are needed with high-quality designs and practices that allow for broad and transparent scrutiny. However, the evidence is sufficiently abundant to raise the questions that have been investigated the least: what are the explanatory mechanisms of the observed cognitive benefits? Which variables can moderate neurocognitive changes? In which contexts might musical training be particularly valuable for its practical significance? The historical propensity towards skepticism in the literature of musical training stands in contrasts with the optimism with other leisure activities (e.g., physical exercise, Ciria et al., 2023). Future research will shed light into the actual role of this promising cognitive enhancer.

ABBREVIATIONS

ADHD: attention-deficit/hyperactivity disorder

DMN: default mode network

IFG: inferior frontal gyrus

IQ: intelligence quotient

MRI: magnetic resonance imaging

OFG: orbitofrontal gyrus

RCT: randomized controlled trials

SES: socioeconomic status

STG: superior temporal gyrus

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APPENDICES

Appendix A1

Román-Caballero, R., Vadillo, M. A., Trainor, L. J., & Lupiáñez, J. (2022). Please don't stop the music: A meta-analysis of the cognitive and academic benefits of instrumental musical training in childhood and adolescence. *Educational Research Review, 35*, 100436.

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Please don't stop the music: A meta-analysis of the cognitive and academic benefits of instrumental musical training in childhood and adolescence

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ABSTRACT

An extensive literature has investigated the impact of musical training on cognitive skills and academic achievement in children and adolescents. However, most of the studies have relied on cross-sectional designs, which makes it impossible to elucidate whether the observed differences are a consequence of the engagement in musical activities. Previous meta-analyses with longitudinal studies have also found inconsistent results, possibly due to their reliance on vague definitions of musical training. In addition, more evidence has appeared in recent years. The current meta-analysis investigates the impact of early programs that involve learning to play musical instruments on cognitive skills and academic achievement, as previous meta-analyses have not focused on this form of musical training. Following a systematic search, 34 independent samples of children and adolescents were included, with a total of 176 effect sizes and 5998 participants. All the studies had pre-post designs and, at least, one control group. Overall, we found a small but significant benefit ($\bar{g}_{\Delta} = 0.26$) with short-term programs, regardless of whether they were randomized or not. In addition, a small advantage at baseline was observed in studies with self-selection ($\bar{g}_{\text{pre}} = 0.28$), indicating that participants who had the opportunity to select the activity consistently showed a slightly superior performance prior to the beginning of the intervention. Our findings support a *nature and nurture* approach to the relationship between instrumental training and cognitive skills. Nevertheless, evidence from well-conducted studies is still scarce and more studies are necessary to reach firmer conclusions.

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1. Introduction

The literature about the effects of musical training on cognitive and brain function is growing rapidly. Multiple studies have documented that involvement in musical activities enhances auditory and sensorimotor processes (James et al., 2020; Kraus et al., 2014; Slater et al., 2015; for a review, see; Herholz & Zatorre, 2012). However, whether musical training impacts general cognitive abilities (e.g., memory or attention) and academic achievement (especially, in literacy and mathematics) is still debated. Playing an instrument is a complex task involving several perceptual modalities, sensorimotor integration, and higher-order cognitive processes. Moreover, structured instrumental learning is an effortful activity that needs to be maintained across long periods of time; it requires regular and motivated practice, learning of new and progressively more difficult material, and adapting to new contexts. Those characteristics have led some to propose that musical training is an optimal general cognitive training strategy that might have an impact beyond music performance itself, benefiting performance in daily life activities (e.g., Bugos et al., 2007). Extensive evidence has associated musicianship with advantages in general cognitive functions, often loosely related to musical skills, such as intelligence (Bugos, 2014; Schellenberg, 2006; Swaminathan et al., 2017), visuospatial abilities (Sluming et al., 2007), processing speed (Bugos, 2014; Jentzsch et al., 2014), executive control (Jentzsch et al., 2014; Medina & Barraza, 2019), attention and vigilance (Kaganovich et al., 2013; Rodrigues et al., 2013; Román-Caballero et al., 2021), and episodic and working memory (Talamini et al., 2017). Also, it might protect against the cognitive decline associated with aging (Román-Caballero et al., 2018). Unfortunately, most of the studies in the field are correlational, which does not allow establishing firm conclusions about the causal role of musical training in those advantages (Schellenberg, 2020).

A plausible alternative explanation for these results is that high-functioning children, with higher musical aptitude, higher socioeconomic status, and/or personality traits associated with cognitive improvements (e.g., openness to experience), are more likely to be interested in music and take music lessons (Corrigall et al., 2013; Swaminathan et al., 2017). Or perhaps individuals with better executive functions are more prepared to resist the temptation to abandon the continued effort that mastering an instrument entails. From this point of view, most of the cognitive and academic advantages observed in correlational studies and interventions without random assignment (where participants and their families chose musical activities) could be due to preexisting differences in children's intelligence, temperament, and environment. In addition, it has been argued that far transfer (i.e., the generalization of training in one domain to skills in a loosely related domain) rarely occurs with most types of cognitive training, because of the small overlap between domain-specific and domain-general abilities (Melby-Lervåg et al., 2016; Sala & Gobet, 2019). Extending this logic, it would be unlikely that musical training could enhance general cognitive abilities.

Other theoretical proposals have tried to reconcile both positions, arguing that expert musicians might have preexisting advantages (cognitive, personality, and/or musical aptitudes) that would promote the acquisition of musical skills and motivation to practice, while at the same time this long-term engagement would also result in multiple neural and cognitive changes (e.g., *nature and nurture hypothesis*, Wan & Schlaug, 2010). In this vein, the difference in magnitude between the effects observed in correlational studies (often Cohen's d around 0.8–1.0) and in experimental designs with random allocation ($d \approx 0.2$; Corrigall et al., 2013; for a classic example, see Schellenberg, 2004) might be the consequence of musicians' in correlational studies benefitting from both preexisting cognitive advantages *and* musical training itself. Only a small number of experimental studies comply with basic methodological standards, such as randomization, the inclusion of an active control group, and blinding of the assessment, and, in practice, most of them involve short interventions (1–1.5 years long) and relatively small samples (≈ 25 participants per group), with the subsequent lack of statistical power to detect small-to-medium effect sizes.[1] Under those conditions, it is perhaps unsurprising that the results have been inconsistent across studies, with some studies providing evidence of a positive impact of instrumental learning (Frischen et al., 2021; James et al., 2020; Schellenberg, 2004), while other studies have shown null effects (D'Souza & Wiseheart, 2018; Haywood et al., 2015).

This is an ideal context for the application of a meta-analysis, as it allows a quantitative review of the literature and enables drawing firmer conclusions given an increased statistical power. Also, meta-analysis offers numerical estimators of the summary effect and between-studies consistency, which provide the opportunity to assess the relevance of interventions (and not only their statistical significance) and to identify potential moderators. Unfortunately, even at the meta-analytic level, there are inconsistent results concerning the impact of musical training in experimental and quasi-experimental studies (Butzlaff, 2000; Cooper, 2020; Gordon et al., 2015; Hetland, 2000; Jaschke et al., 2013; Sala & Gobet, 2017, 2020; Standley, 2008; Vaughn, 2000). Probably, one of the greatest sources of variability is the vague and inconsistent definition of musical training across meta-analyses (Jaschke et al., 2013), which usually combine highly heterogeneous musical interventions, including instrumental tuition, programs of music education such as Kindermusik, Orff, or Kodály methods, computerized training of musical skills, phonological training with music support, and listening programs, among others.

Although in the past some authors have called for analyzing each type of training program separately to reach reliable results (Jaschke et al., 2013), subsequent meta-analyses have continued to include and pool multiple types of interventions in the same analysis (Cooper, 2020; Gordon et al., 2015; Sala & Gobet, 2017; 2020). Arguably, studies examining the effects of formal programs in instrumental training are ideal for investigating the causal role of musical training on cognitive skills and academic achievement. Most correlational studies reporting effects of musical training have compared expert instrumentalists with non-musicians, suggesting that instrumental programs might be advantageous. Formal programs in which the participants learn to play a complex musical instrument

[1] A power analysis using G*Power 3.1 (Faul, Erdfelder, Buchner, & Lang, Georg, 2009) for a one-tailed t-test and an alpha of .05 indicated that around 310 participants per group would be necessary to achieve an acceptable power of .80 with a Cohen's d of 0.20 (small effect), and 51 participants per group for a d of 0.50 (medium). Required sample sizes are larger when two-tailed contrast statistics or higher power values are used.

and to read music notation are the most similar to the type of training that such expert musicians follow.[2] Additionally, although all types of musical training aim to promote musical skills (e.g., rhythm, pitch and timbre discrimination, singing, basic music notation, etc.), learning to play an instrument seems to pose greater cognitive demands than other musical activities, as it requires particularly intensive practice entailing hand dexterity, bimanual coordination, and core cognitive functions such as working memory and attention. For that reason, far transfer might be more probable with instrumental learning. Although some studies have reported cognitive improvements with non-instrumental interventions (for Kindermusik, Orff, Kodály or related methods, see Kaviani et al., 2014; Patscheke et al., 2016; for listening programs, see Bugos, 2010; Hole, 2013), there is evidence of greater benefits with instrumental programs, to such an extent that non-instrumental music programs have even been used as control conditions in some studies (see Bugos, 2010; James et al., 2020). Nevertheless, to the best of our knowledge, the impact of instrumental interventions has not been investigated separately in any previous meta-analysis, nor has it been tested as a moderator.

On the other hand, the most recent and comprehensive meta-analysis (i.e., Sala & Gobet, 2020), which included different musical interventions, found a positive small effect of musical training ($\overline{g} = 0.18$, $p < .001$) that was reduced to null when characteristics of design quality (i.e., random allocation and active control) were taken into account ($\overline{g} \approx 0$). However, the difficulty of implementing methodologically rigorous designs adds to the inherent cost of instrumental interventions that require highly specialized material and professionals. This might explain why only a third of the studies included in Sala and Gobet's meta-analysis had instrumental programs (19 out of 54) and why many studies with instrumental programs have not used optimal experimental designs. Indeed, studies involving instrumental training were underrepresented among Sala and Gobet's studies with random assignment and/or with an active control group. More precisely, only 27% of the randomized studies (6 out of 22), 36% of those using an active control group (9 out of 25), and 31% of those using both randomization and an active control group (4 out of 13), had instrumental training. Given that non-instrumental interventions likely have a smaller impact on cognitive skills and academic achievement compared to instrumental ones, the greater representation of the former in Sala and Gobet's study may have led to conclusions mostly related to non-instrumental musical training. Thus, despite all the previous meta-analyses, the overall impact of formal instrumental learning remains uninvestigated. In addition, some outcomes included in the meta-analyses by Sala and Gobet (2017, 2020) were measures of skills trained with active control activities (e.g., phonological abilities with phonological training), and therefore should not be analyzed in a far-transfer meta-analysis (Bigand & Tillmann, 2021). Finally, new studies have appeared since the publication of the most recent meta-analysis (Sala & Gobet, 2020) and we additionally found some studies that have never been included in any previous meta-analysis, including some from unpublished doctoral theses (such as Nering, 2002; Pelletier, 1963).

Considering all the above, it seems crucial to carry out a new comprehensive meta-analysis that separately investigates the impact of instrumental learning programs on cognitive skills and academic achievement. The present work aims to address this issue by shedding light on the debate about the causal role of musical training in school-age children and adolescents. Accordingly, we analyzed the pre-posttest cognitive and academic changes in the available experimental and quasi-experimental studies that used formal training programs involving learning to play a musical instrument. While experimental studies with random assignment of the participants allow drawing causal inferences about the effects of musical training (and, therefore, representing the main source for the causal conclusions in the present meta-analysis), non-randomized longitudinal studies were also included for comparison purposes.

2. Method

2.1. Literature search

A systematic search strategy was used following the recommendations of PRISMA (Moher et al., 2009). Firstly, we consulted PubMed, ProQuest, Scopus, Web of Science, and ProQuest Dissertation & Theses using the search syntax *"music*" AND ("training" OR "instruction" OR "educati*" OR "practice") AND ("child*" OR "adolescen*")*. Also, references from previous empirical studies, reviews, and meta-analyses on this subject were examined. The latest search was carried out in February 2021, without any time restriction. In total, 8560 potentially relevant results were found, among which 32 met the inclusion criteria described below and were included in our meta-analysis (Fig. 1). These studies included 34 independent samples, 179 effect sizes, and a total of 5998 participants.

[2] Structured singing training, such as that received by lyrical singers, is also comparable to the training of expert musicians. Nevertheless, in the literature, is it often difficult to distinguish between formal singing programs (intensive in terms of technique, music theory, and out-of-class practice) and interventions directed at a more diverse population with more informal approaches. It is also the case that singing interventions build on a capacity for singing already present in individuals without training, whereas learning an instrument entails learning completely new skills. Some studies have found smaller effects for vocal training in comparison to instrumental training (Guhn et al., 2020; Kinney, 2008; for a null difference, see Schellenberg, 2004). Although the comparison of formal instrumental and vocal training remains an open question that needs confirmation from studies with experimental designs, the most notable evidence to date is from the study of Guhn et al., who showed advantages for both instrumental and vocal musical training in a remarkably large sample of students ($N \approx 110{,}000$) who chose to take part in music courses or not. This result held even after controlling for several confounding variables (cultural background, SES, sex, and prior academic achievement). Crucially, instrumental learning led to larger differences in comparison to vocal training (*ds* ranging from 0.12 to 0.31), a result that the authors attributed, among other factors, to the complexity involved in learning to play an instrument. They suggested that this complexity might have a particularly positive impact on executive functions and, through them, on other cognitive domains. Because for much of this literature it is very difficult to determine whether studies used formal or informal vocal training, and considering the evidence from Guhn et al. that cognitive benefits for instrumental training are likely larger than for vocal training, we decided to constrain the scope of our meta-analysis to studies with formal learning of musical instruments.

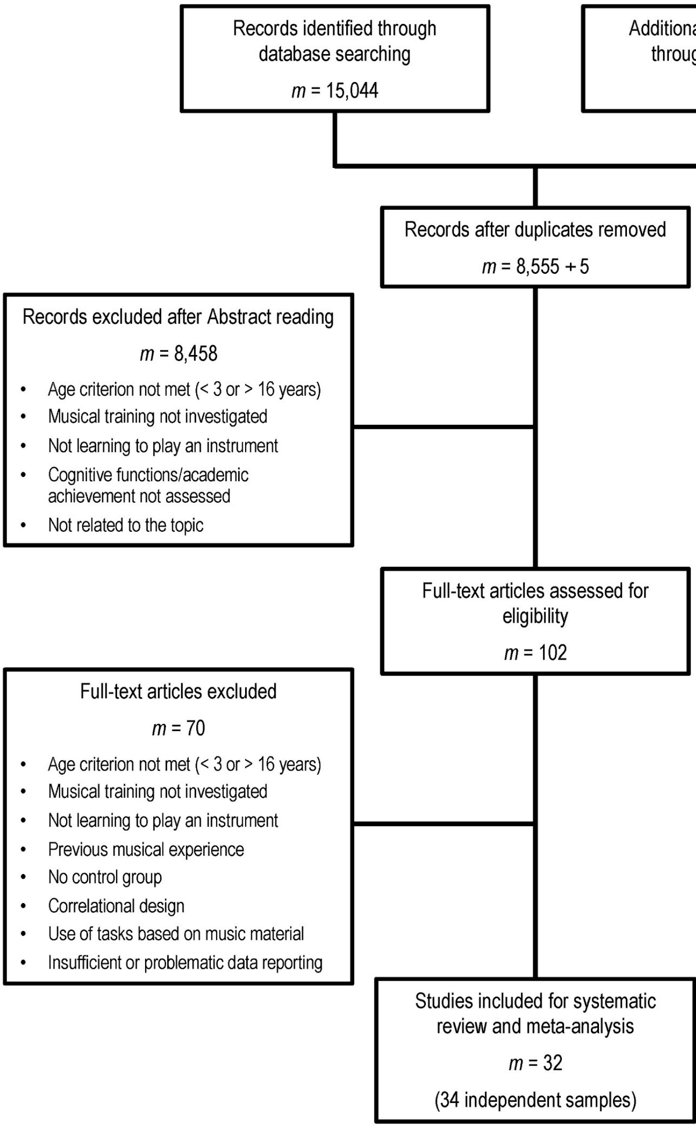

Fig. 1. Flowchart of the studies included in the systematic review and meta-analysis.

2.2. Selection criteria

The studies selected in the review had to meet the following criteria:

1. Published articles or theses that included musical training programs involving at least learning to play an instrument;
2. The design of the studies included pretest and posttest measures, regardless of whether there was a random assignment of children/adolescents to conditions or they themselves (or their parents or their teachers) selected the activity;
3. The studies included a comparison between a music-treated group and, at least, one control group (active or passive);
4. The participants had no previous formal musical training or instrumental learning prior to the program;

5. The studies contained sufficient information to calculate at least one effect size (mainly, means and standard deviations, *t* value, *F* value, and the standardized effect size itself; otherwise, authors were contacted and the studies were included if the information was provided);
6. The studies included at least one non-musical measure of academic and/or cognitive skills (note that near-transfer effects were not included);
7. At the moment of starting the training, participants were between 3 and 16 years old;
8. The participants of the study did not suffer from neurological or psychiatric conditions.

As the included studies used different instruments to assess the outcomes (with different scales) from study to study, we used a standardized estimator of the effect size: Hedges' *g*. There are multiple ways of estimating Hedges' *g* in pre-posttest designs with two groups (see below, *Effect Size*), the most common being the standardized mean difference with posttest measures only, which we will refer to as g_{post}. An alternative index, proposed by Morris (2008), which we will refer to as g_{Δ}, is the standardized mean change difference (i.e., the difference between the two groups in the change of the outcomes between pretest and posttest moments). An advantage of this index over g_{post} is that it controls for preexisting differences at baseline. Collating both types of effect sizes, g_{post} and g_{Δ}, in a single meta-analysis requires making some assumptions. For instance, the variance of the pretest score is assumed to be equal to the variance of the posttest score. Similarly, both groups are assumed to be equivalent in baseline performance. However, it is arguable that these assumptions are not met in most circumstances. Previous research suggests that there are cognitive and personality differences in individuals who choose and continue with musical training as an activity (Corrigall et al., 2013). For that reason, and unlike previous reviews (Sala & Gobet, 2017; 2020; Vaughn, 2000), we constrained our review only to pre-posttest studies.

We included studies with random assignment (***randomized studies***), studies in which the children or their parents or their teachers selected the training group (***self-selection studies***), and studies with other allocation strategies that can not be consider random (such as quasi-randomization; ***non-randomized studies***), as all of them can offer valuable information for the debate. On the one hand, randomized studies allow the establishment of more conclusive causal inferences about the effects of training, as randomization of the individuals reduces bias due to preexisting differences in cognitive, academic or musical skills, or other confounds (e.g., personality traits; Corrigall et al., 2013). On the other hand, studies that allowed the participants to choose the program has higher risk of selection effects, which might be observable in the overall difference in the pretest performance. Whereas we based the main inferences about causality, moderating variables and publication bias on randomized and non-randomized studies, the inclusion of self-selection studies was restricted to the assessment of baseline differences and the overall analysis for comparison purpose.

2.3. Statistical analysis

2.3.1. Effect size

We used the formula proposed by Morris (2008) for g_{Δ} as an estimator of the effect size in the main analyses,

$$g_{\Delta} = c_p \times \left(\frac{\left(M_{post,\,T} - M_{pre,\,T}\right) - \left(M_{post,\,C} - M_{pre,\,C}\right)}{SD_{pooled,\,pre}} \right), \tag{1}$$

where M_{pos} and M_{pre} represent the scores at pretest and posttest, respectively, for the treatment group (T) and the control group (C), and $SD_{pooled,\ pre}$ is the pooled standard deviation for the pretest scores of both groups. Moreover, c_p is a correction factor of the small sample bias, given by

$$c_p = 1 - \frac{3}{4 \times (N_T + N_C) - 9}, \tag{2}$$

where N_T and N_C are the number of participants in the treatment group and the control group. Positive values of g_{Δ} represent greater benefits in favor of treatment group, and negative values index the contrary. We multiplied by −1 those effects in which it was necessary to keep the mentioned direction. The *g* values were interpreted according to Cohen's criteria (Cohen, 1992): values close to 0.2, 0.5, and 0.8 or higher are interpreted as small, medium, and large effects, respectively. The variance of g_{Δ} was calculated following the formula by Morris (2008).

$$V_{g_{\Delta}} = 2 \times c_p^2 \times (1 - r) \times \left(\frac{N_T + N_C}{N_T \times N_C}\right) \times \left(\frac{N_T + N_C - 2}{N_T + N_C - 4}\right) \times \left(1 + \frac{g_{\Delta}^2}{2 \times (1 - r) \times \left(\frac{N_T + N_C}{N_T \times N_C}\right)}\right) - g_{\Delta}^2, \tag{3}$$

where *r* is the correlation between pretest and posttest scores. We directly estimated *r* from raw data when they were available or used the following formula when other reported statistics made it possible:

$$r = \frac{SD_{pre}^2 + SD_{post}^2 - SD_{Diff}^2}{2 \times SD_{pre} \times SD_{post}}, \tag{4}$$

$$V_r = \frac{(1 - r^2)^2}{N - 1}. \quad (5)$$

Using these equations, we could extract 75 correlation coefficients and their respective variances from 14 studies, with a meta-analytic mean r of 0.71 (see Data S2 in https://osf.io/9y5tp/). This final value of r is close to 0.70 that Rosenthal (1991) proposed as a conservative assumption when pre-posttest correlations were not available. Considering that, we conducted our analyses assuming $r = 0.70$.

Furthermore, as previous literature pointed to the existence of baseline differences between individuals who chose to take musical training and individuals who did not (Corrigall et al., 2013; Swaminathan et al., 2017), we were also interested in comparing the performance of both groups just at baseline. For that purpose, we calculated the traditional Hedges' g only with pretest scores (called here g_{pre})

$$g_{pre} = c_p \times \left(\frac{M_{pre,\,T} - M_{pre,\,C}}{SD_{pooled,\,pre}} \right), \quad (6)$$

$$V_{g_{pre}} = c_p^2 \times \left(\frac{N_T + N_C}{N_T \times N_C} + \frac{g_{pre}^2}{2 \times (N_T + N_C)} \right). \quad (7)$$

2.3.2. Meta-analysis, heterogeneity and moderator analysis

As is often in psychology meta-analyses, most of the included studies contributed with more than one effect size from the same sample, which rendered the outcomes not independent. Most of the conventional meta-analytic procedures, however, assume independence between effect sizes. The robust variance estimation approach (RVE; Hedges et al., 2010) has been developed to deal with correlated structure of outcomes. This method estimates the correlation matrix and sets the weights according to a correlated or a hierarchical structure. Simulation studies show that RVE is remarkably accurate in estimating the mean effect and the confidence interval, even with a small number of studies ($m = 10$) and when they include a large number of dependent estimates per study ($k = 10$; Hedges et al., 2010). We used the ***robumeta*** package for R (Fisher et al., 2017) for implementation of RVE conducted in the main analyses (all the data and R script for the analyses are fully available in the Supplementary Material). We chose a correlated dependence model with small-sample corrections (Tipton, 2015).

First, we studied the overall impact of musical training, fitting an overall meta-analytic model with randomized and non-randomized studies, and then for each group of studies separately. For comparison, we repeated the analysis with self-selection studies (combined with the rest of studies and separately). The usual heterogeneity indexes, τ^2 and I^2, were computed. To identify studies with outlying outcomes, we fitted a multilevel model with the *rma.mv*() function of *metafor* (Viechtbauer, 2010) and estimated the Studentized residuals (>2) and Cook's distance (>4/n). For the analysis of differences at baseline, we fitted separate RVE models for randomized, non-randomized and self-selection studies using the g_{pre} as effect size estimate.

Then, we assessed the influence of the following moderating variables on effect sizes: (1) randomization (randomized vs. non-randomized studies, note that self-selection studies were not included in moderator analyses); (2) type of control group (active vs. passive); (3) whether there was blinding of assessors or the measure was computerized (yes/no); (4) age of the participants at the baseline (in years); (5) duration of the training program (in months); (6) between-groups baseline difference, measured as g_{pre}; (7) low socioeconomic status (SES) of the sample (yes vs. no/not reported); and (8) the type of cognitive or academic outcome (mathematics, literacy,[3] intelligence, processing speed, short-term memory, long-term memory, visuospatial abilities, phonological processing, and executive functions). Regarding the type of control, we conducted the analyses with the effects corresponding to the two comparisons (experimental vs. active control group, and experimental vs. passive control group) in those studies in which both were available in the same study.

2.3.3. Publication bias

Several lines of evidence indicate that multiple factors of the reporting and the publication procedure can drastically affect the results of a meta-analysis. Studies reporting significant and large effect sizes are more likely to be published or made available than statistically non-significant results or results that contradict an accepted theory (Carter et al., 2019). This phenomenon (called *publication bias*) leads to studies with null or negative estimates being less accessible and underrepresented in meta-analyses. Several methods have been developed to detect publication bias and correct for its adverse consequences over the final effect.

One popular approach is the visual inspection of small-study effects in a funnel plot and the use of the trim-and-fill method to correct the final estimate. The funnel plot is a display of the individual effect sizes on the x-axis against the corresponding standard errors on the y-axis. An asymmetric distribution can be a sign of publication bias, with missing studies in non-significant regions of the plot (Egger et al., 1997). The trim-and-fill method (Duval & Tweedie, 2000) detects (and removes) studies causing funnel plot asymmetry and then imputes missing studies to estimate a bias-corrected effect size. Alternatively, the precision-effect test and the precision-effect estimate with standard error procedures (PET and PEESE; Stanley & Doucouliagos, 2014) are based on a

[3] The academic measures included in the present meta-analysis were standardized tests of achievement in literacy (reading, vocabulary, language, etc.) and math proficiency, including national academic assessments. The names of the tests used in each of the studies are available in the supplementary data file (https://osf.io/9y5tp/).

meta-regression approach to test for selective reporting and adjust for small-study effects. Both methods use a measure of precision as a covariate in the meta-analytic model (the standard error of the effect size in the case of PET, and sampling variance for PEESE), where the significance of the regression coefficient tests for publication bias, and the intercept of the model is taken as the true underlying effect. Thirdly, selection models (Vevea & Hedges, 1995) assume that the probability of publication depends on the *p* value. In our meta-analysis we use a selection model with a single cut point at $p_{\text{one-tailed}} = .025$, which divides the range of possible *p* values into significant and non-significant values.

The previous methods assume independent effect sizes in their original formulation. A way to account for dependence is to combine all the effect sizes coming from the same sample generating an average estimate for each study, and conduct the classic methods on these aggregated estimates (Rodgers & Pustejovsky, 2020). In addition, some recent approaches directly handle the issue of dependence. For instance, the logic of PET-PEESE and other regression-based methods can be extended to multilevel models and RVE (Fernández-Castilla et al., 2021; Friese et al., 2017; Rodgers & Pustejovsky, 2020). Mathur and VanderWeele (2020) also proposed a sensitivity analysis that can be fitted with RVE. Assuming that positive results are more likely to be published than null or negative results by an unknown ratio (η, which is > 1 under publication bias), it is possible to estimate how strong this ratio would need to be to make the final effect negligible. Values of 1.5 are frequent in psychology literature, whereas values over 5 are rare (the 95th quantile of the estimated selection ratios, Mathur & VanderWeele, 2020).

Simulation studies show that ignoring dependence results in inflated Type I error (Rodgers & Pustejovsky, 2020). Although the methods that handle correlated effect sizes exhibit better performance, none of them stands as superior in terms of performance. Their performance depends on many parameters, such as the number of studies, heterogeneity, the degree of publication bias, and so on (Carter et al., 2019; Rodgers & Pustejovsky, 2020). A reasonable strategy is to use in combination several of them, and interpret their results taking into account the conditions of the meta-analysis (Carter et al., 2019). In the present meta-analysis we chose four methods to test publication bias and adjust the mean estimate: (i) the trim-and-fill method (with the *L0* and *R0* estimators) and (ii) the selection model, both using aggregates, (iii) the RVE regression-based approaches (RVE PET and RVE PEESE), and (iv) the Mathur and VanderWeele's sensitivity analysis. We used the *MAd* package in R (Del Re & Hoyt, 2014) to generate within-study aggregates, while we carried out the Vevea and Hedges' selection model (1995) with the ***weightr*** package (Coburn & Vevea, 2019) and the Mathur and VanderWeele's sensitivity analysis with the *PublicationBias* package (Mathur & VanderWeele, 2020). For the RVE meta-regression test, we chose a modified formula of the sampling variance and, in parallel, a variance-stabilizing transformation for the standardized mean difference to prevent the artifactual dependence between the effect size and its precision estimate (Pustejovsky & Rodgers, 2019; see Appendix A).

Regarding the conditions of the present meta-analysis, previous comprehensive meta-analyses of the literature (Sala & Gobet, 2017a, 2020) revealed moderate heterogeneity (τ ≈ 0.2), a small sample of studies using instrumental programs (*m* ≈ 20), some evidence of publication bias, and a small uncorrected effect (g ≈ 0.20). Under similar conditions, trim-and-fill, selection model and the RVE meta-regression show acceptable Type I error rates when there is no publication bias (below a nominal level of 0.1, and RVE meta-regression below 0.05; Rodgers & Pustejovsky, 2020). When there is selective reporting, the three methods have low power, especially trim-and-fill, although selection model can detect publication bias more often. The limited power of RVE meta-regression was especially sensitive to heterogeneity and the size of the true effect, becoming lower with higher heterogeneity and smaller effects. Regarding the adjustment of the effect, the original PET-PEESE (which assumes independence) performed worse with smaller true effects and higher heterogeneity, consistently underestimating the true effect. Furthermore, its estimate should be interpreted with caution in small meta-analyses (with 20 studies or less; Stanley, 2017). Additionally, we conducted a simulation analysis with the software developed by Carter et al. (2019; http://www.shinyapps.org/apps/metaExplorer/) comparing the performance of the standard versions (not accounting for dependence) of trim-and-fill, PET-PEESE, and selection model under conditions similar to those in previous comprehensive meta-analyses (Sala & Gobet, 2017a, 2020; for further details, see Appendix B). Under the predefined conditions, the selection model achieved the best performance correcting the estimate (in terms of root square mean error and coverage) and trim-and-fill the worst, systematically overestimating the effect. The performance of PET-PEESE fell between both extremes. Finally, the Mathur and VanderWeele's sensitivity analysis seems to be relatively unbiased with values of η below 20 (i.e., a publication probability 20 times higher for positive than null or negative results; Mathur & VanderWeele, 2020).

2.4. Sensitivity analyses

Only a subset of the studies reported sufficient information to compute the pre-posttest correlation with Equations (6) and (7). To confirm that the results of the meta-analysis do not hinge critically on our decision to assume a correlation of 0.70 for all the studies, we repeated the analyses estimating V_{g_Δ} with $r = 0.50$ and $r = 0.60$. In the same vein, we assumed a within-effects correlation of 0.50 to estimate the sampling variance of the aggregates in the publication bias assessment. We also conducted the analyses with a correlation of 0.80 and 0.30. Moreover, we carried out sensitivity analyses following a multilevel Bayesian approach using the *brms* R package (Bürkner, 2017). The results of all the sensitivity analyses were similar to those reported here, showing far transfer with musical training (Appendices C and D), the modulating role of several variables on this effect (Appendix C), and little evidence of publication bias (Appendix E).

Table 1
Characteristics of the studies included in the meta-analysis.

Study	$N_{music\ group}$	$N_{control\ group}$	Type of publication	Age at baseline (in years)	Duration (in months)	Type of outcome	Blind assessment	Random assignment	Type of control	Low SES
Costa-Giomi (1999)	43	35	Article	9	36	Intelligence	No	Yes	Passive	No
Costa-Giomi (2004)	45	35	Article	9	36	Literacy, and mathematics	No	Yes	Passive	No
D'Souza and Wiseheart (2018)	24	26 & 25	Article	6–9	0.75	Executive functions, intelligence, literacy, processing speed, and short-term memory	Only computerized measures	Yes (stratified randomization; active control and experimental groups) & No (passive group)	Active and passive	No
Degé et al. (2011)	16	18	Article	10	24	Intelligence, and short-term memory	No	No (self-selection)	Passive	Unknown
Fasano et al. (2019)	55	58	Article	8–10	3	Executive functions	No	No (selection by teachers)	Passive	No
Fitzpatrick, 2006; Sample 1	78	1535	Article	9	60	Literacy	Yes	No (self-selection)	Passive	Yes
Fitzpatrick, 2006; Sample 2	158	1167	Article	9	60	Literacy	Yes	No (self-selection)	Passive	No
Friedman, 1959; Sample 1	76	76	Thesis	10	12	Literacy, and mathematics	No	No (selection by musical skills)	Passive	No
Friedman, 1959; Sample 2	51	51	Thesis	11	12	Literacy, and mathematics	No	No (selection by musical skills)	Passive	No
Frischen et al. (2021)	27	31 & 36	Article	6.6	8.5	Executive functions and short-term memory	Yes	Yes	Active and passive	No
Guo et al. (2018)	20	20	Article	6–8	1.5	Executive functions, literacy, processing speed, and short-term memory	Yes	No (quasi-randomization)	Passive	Unknown
Hallberg et al. (2017)	26	22	Article	5	1.25	Executive functions, and intelligence	Only computerized measures	Yes	Passive	Yes
Haywood et al. (2015)	269	279	Foundation report	11	11	Literacy, and mathematics	Yes	Yes	Active	No
Hennessy et al. (2019)	17	17 & 18	Article	6	48	Intelligence	No	No (self-selection)	Active and passive	Yes
James et al. (2020)	34	35	Article	10.2	48	Executive functions, intelligence, processing speed, short-term memory, and long-term memory	No	Yes (cluster randomization)	Active	Yes
Kinney, 2008; Sample 1	20	85	Article	9	12	Literacy, and mathematics	Yes	No (self-selection)	Passive	Yes
Kinney, 2008; Sample 2	30	97	Article	9	12	Literacy, and mathematics	Yes	No (self-selection)	Passive	No

(*continued on next page*)

Table 1 (*continued*)

Study	$N_{music\ group}$	$N_{control\ group}$	Type of publication	Age at baseline (in years)	Duration (in months)	Type of outcome	Blind assessment	Random assignment	Type of control	Low SES
Legette (1993)	38	47	Thesis	9	8	Literacy, and mathematics	No	No	Passive	Yes
MacCutcheon et al., 2019	26	15	Article	6	12	Short-term memory, and phonological processing	Only computerized measures	No (self-selection)	Active	No
Nan et al. (2018)	30	28 & 16	Article	4–5	6	Intelligence, literacy, and phonological processing	Only computerized measures	No (quasi-randomization)	Active and passive	No
Nering (2002)	10	10	Thesis	3.3–7.3	7	Executive functions, intelligence, literacy, mathematics, processing speed, and short-term memory	No	Yes	Passive	No
Orsmond and Miller (1999)	21	21	Article	5	4	Intelligence, literacy, and visuospatial abilities	No	No (self-selection)	Passive	No
Pelletier (1963)	55	55	Thesis	8	6.25	Literacy	No	No (quasi-randomization)	Passive	Unknown
Portowitz et al. (2009)	45	36	Article	8	24	Intelligence, long-term memory, and visuospatial abilities	No	No	Passive	Yes
Rauscher and Zupan (2000)	34	28	Article	7–9	8	Intelligence, and long-term memory	Yes	No	Passive	No
Rauscher et al. (1997)	34	20 & 14	Article	3–4.8	6	Intelligence	Yes	No	Active and passive	Unknown
Roden et al. (2012)	25	25 & 23	Article	7.7	18	Long-term memory, and short-term memory	Yes	No	Active and passive	No
Roden, Grube, et al., 2014	25	25	Article	7–8	18	Executive functions, and short-term memory	Yes	No	Active	No
Roden, Könen, et al., 2014	192	153	Article	7–8	18	Executive functions, and processing speed	No	No	Active	No
Rose et al. (2019)	19	19	Article	9	12	Executive functions, intelligence, literacy, processing speed, short-term memory, long-term, and visuospatial abilities	No	No (self-selection)	Passive	No
Said and Abramides (2020)	40	40	Article	10.34	6	Literacy, and mathematics	No	No (self-selection)	Passive	No
Schellenberg (2004)	30	34 & 36	Article	6	9	Intelligence	Yes	Yes	Active and passive	No
Schellenberg et al., 2015; Sample 1	20	25	Article	8.7	10	Literacy	No	No	Passive	No
Schellenberg et al., 2015; Sample 2	18	21	Article	8.7	10	Literacy	No	No	Passive	No
Slater et al. (2014)	23	19	Article	6–9	12	Intelligence, literacy, phonological processing, processing speed, and short-term memory	No	No (quasi-randomization)	Passive	Yes
Tierney et al. (2015)	19	21	Article	14.7	36	Phonological processing, processing speed, and short-term memory	No	No (self-selection)	Active	Yes

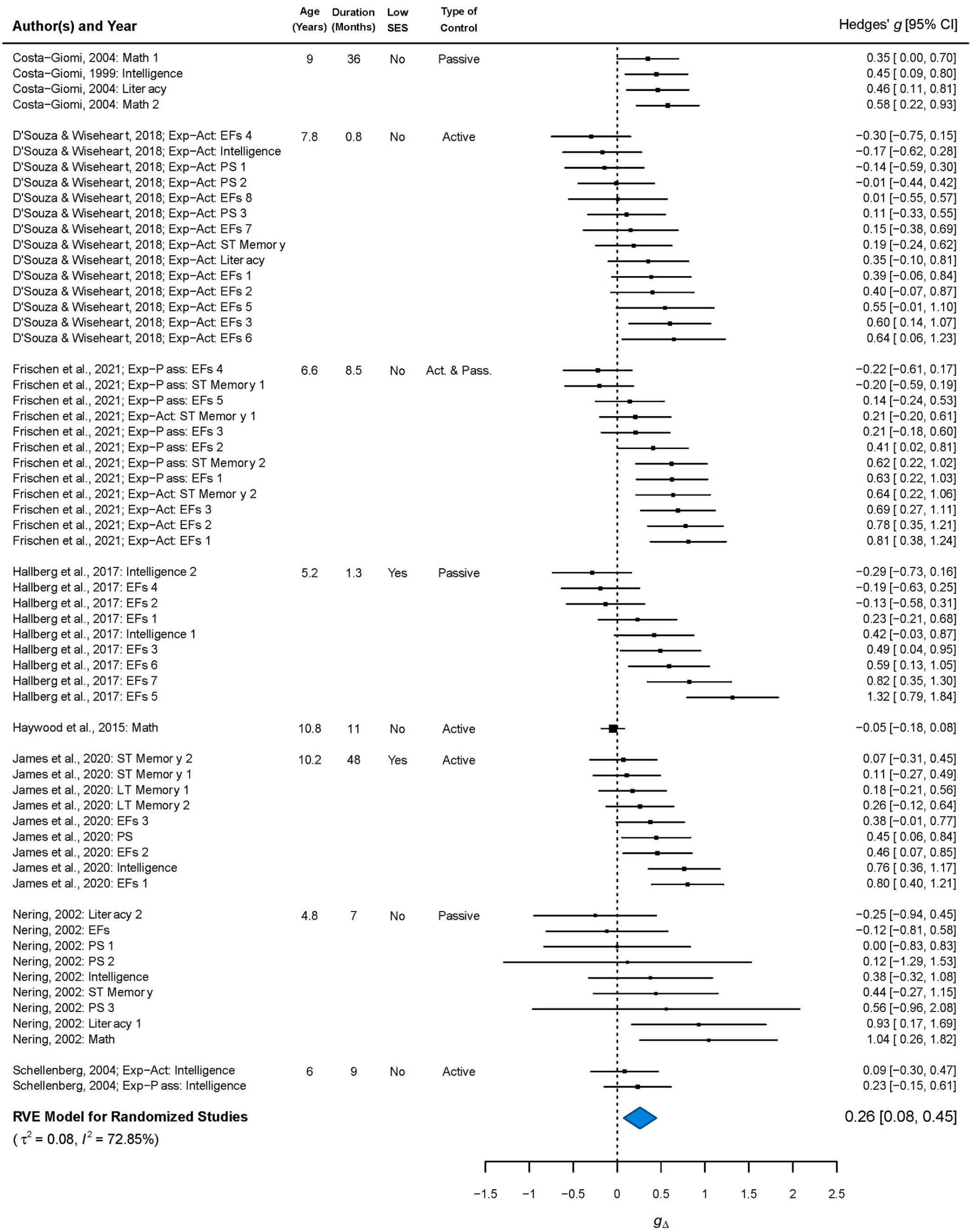

Fig. 2. Forest plot of the standardized difference of mean change (pre-posttest difference) in randomized studies. Vertical diagonal of the blue rhombus represents the summary effect size, horizontal diagonal is the confidence interval for that final estimate. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

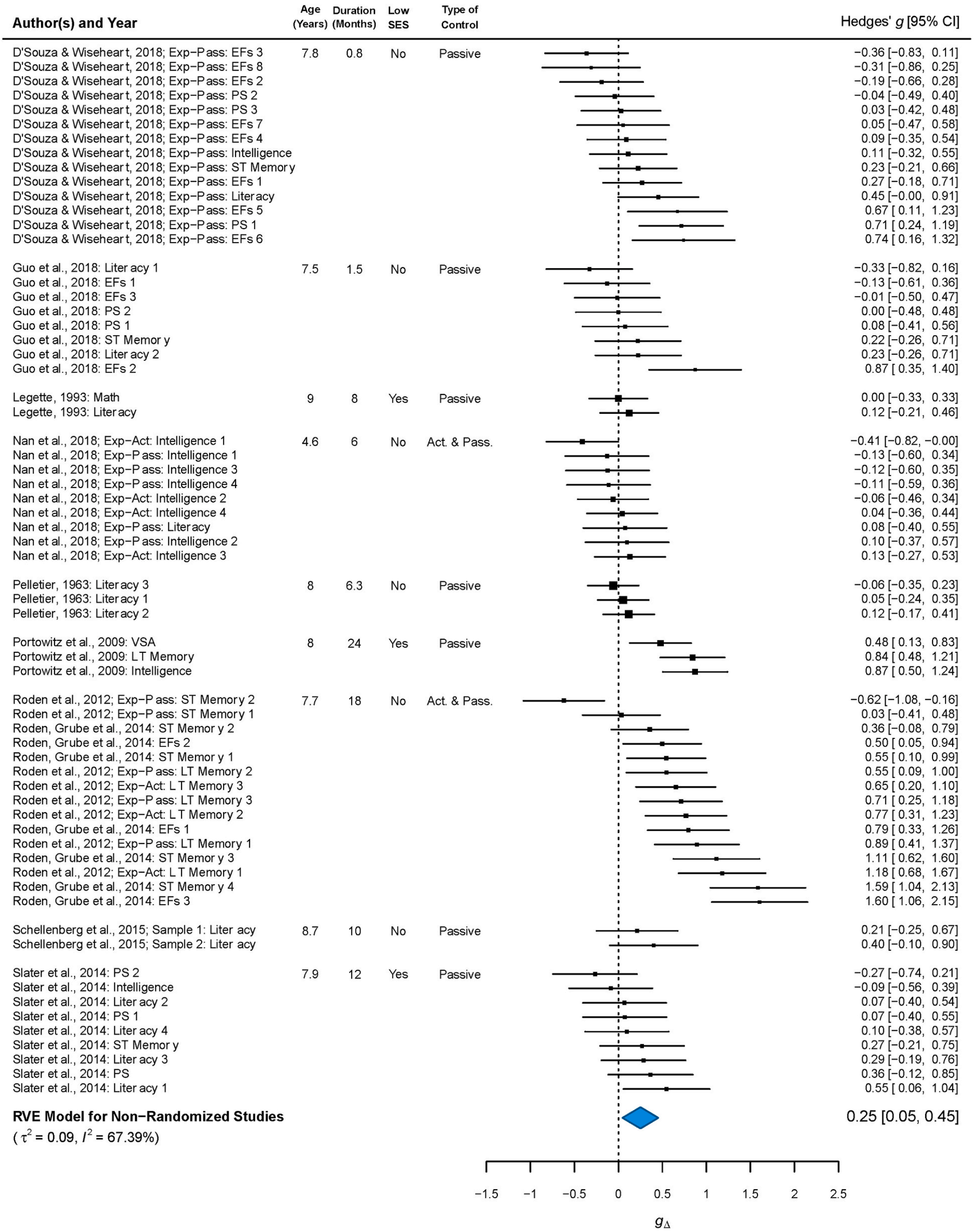

Fig. 3. Forest plot of the standardized difference of mean change (pre-posttest difference) in non-randomized studies. Vertical diagonal of the blue rhombus represents the summary effect size, horizontal diagonal is the confidence interval for that final estimate. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 2
Results of the meta-regressive analyses.

Moderator	F	df	p	
Separate models for each moderator				
Randomization	<0.01	1, 13.4	.952	Randomized: $\bar{g}_{\Delta} = 0.26$ [0.07, 0.44] Non-randomized: $\bar{g}_{\Delta} = 0.25$ [0.05, 0.45]
Active control	<0.01	1, 8.1	.983	Active: $\bar{g}_{\Delta} = 0.28$ [−0.06, 0.61] Passive: $\bar{g}_{\Delta} = 0.25$ [0.13, 0.37]
Blinding	0.02	1, 10.5	.901	Blinded: $\bar{g}_{\Delta} = 0.30$ [0.03, 0.57] Unblinded: $\bar{g}_{\Delta} = 0.24$ [0.08, 0.40]
Age	0.03	1, 5.3	.859	$\beta = -0.008$
Duration	4.07	1, 2.5	.155	$\beta = 0.009$
Baseline difference	2.43	1, 10.6	.148	$\beta = -0.25$
Low SES	0.74	1, 7.6	.415	Low SES: $\bar{g}_{\Delta} = 0.34$ [0.00, 0.68] Middle-high SES: $\bar{g}_{\Delta} = 0.22$ [0.06, 0.37]
Separate models for each moderator (randomized studies)				
Active control	1.3	1, 5.9	.298	Active: $\bar{g}_{\Delta} = 0.23$ [−0.13, 0.58] Passive: $\bar{g}_{\Delta} = 0.32$ [0.18, 0.46]
Blinding	0.36	1, 5.9	.573	Blinded: $\bar{g}_{\Delta} = 0.27$ [−0.08, 0.62] Unblinded: $\bar{g}_{\Delta} = 0.26$ [0.00, 0.52]
Age	0.60	1, 3.7	.485	$\beta = -0.032$
Duration	3.76	1, 2	.193	$\beta = 0.004$
Baseline difference	2.93	1, 4	.162	$\beta = -0.37$
Low SES	2.75	1, 1.7	.258	Low SES: $\bar{g}_{\Delta} = 0.38$ [0.23, 0.52] Middle-high SES: $\bar{g}_{\Delta} = 0.21$ [−0.05, 0.48]
Best meta-regressive model for randomized studies (~ Age + Baseline difference + Low SES)				
Age	19	1, 2	.051	$\beta = -0.06$
Baseline difference	10.6	1, 4.6	.026	$\beta = -0.56$
Low SES	13.2	1, 1.6	.098	$\beta = 0.28$

Table 3
Final effect of each type of cognitive/academic outcome.

Type of outcome	$\bar{g}_{\Delta}$	[95%CI]	m	k	p
Executive functions	**0.41**	**[0.12, 0.70]**	**7**	**41**	**.013**
Intelligence	0.29	[−0.00, 0.58]	9	19	.052
Literacy	**0.20**	**[0.06, 0.34]**	**10**	**18**	**.010**
Mathematics	0.23	[−0.41, 0.87]	4	5	.316
Phonological processing	−0.10	[−0.51, 0.31]	1	2	.999
Processing speed	0.26	[−0.06, 0.57]	5	13	.079
Short-term memory	**0.28**	**[0.15, 0.41]**	**7**	**17**	**.002**
Long-term memory	0.61	[−0.28, 1.5]	3	9	.098
Visuospatial abilities	**0.48**	**[0.13, 0.83]**	**1**	**1**	**.007**

Note. Significant results are depicted in bold; m = number of studies, k = number of outcomes, p = p value.

3. Results

Thirty-two empirical studies meeting the selection criteria were included in the systematic review, contributing a total of 179 cognitive/academic outcomes from 34 independent samples.[4] As a consequence of our comprehensive search among the gray literature, we identified four theses and a report from a charity foundation (Haywood et al., 2015) that met our inclusion criteria. Moreover, fifteen of the studies have not been included in the most recent meta-analysis by Sala and Gobet (2020), in part because their inclusion criteria excluded programs in which the participants self-selected the program (although, some self-selection studies were included in their set: Degé et al., 2011; Geoghegan & Mitchelmore, 1996; Habibi et al., 2018; Hogan et al., 2018; Kempert et al., 2016; with contributed with a null mean effect, $g = 0.03$). Ten of the new studies were programs that allowed the selection of the group, two were randomized and three were non-randomized. Additionally, regarding the studies with instrumental training that the present meta-analysis have in common with the recent one by Sala and Gobet (17 studies), we identified 14 outcomes that had not been previously analyzed that overall showed moderate effects in favor of musical training (mean $g = 0.40$).

Among all the independent samples, eight had random assignment of participants to groups, twelve were non-randomized, and fourteen were self-selection studies. Seven samples had both active and passive control groups, five only active, and 22 only passive. The main characteristics of the studies are summarized in Table 1. Regarding sample characteristics, the mean age of the samples

[4] Costa-Giomi (1999) and Costa-Giomi (2004) seem to be reports of the same samples, as well as Roden et al. (2012) and Roden, Grube, et al. (2014). We treated each of both pairs as coming from the same sample of participants.

included in our meta-analysis was 8 years ($SD = 2.2$; range: 3.9–14.7 years) and the mean duration of the programs was 17 months ($SD = 16.3$; range: 0.75–60 months). A total of 1664 children/adolescents took musical training, whereas 4334 were part of control groups (3670 in passive control groups and 664 in active control groups involving activities such as reading, drama, natural sciences lessons, visual arts, sports, dance, or non-musical computer-based programs).

3.1. Overall effect

The overall meta-analysis, including both randomized and non-randomized studies, showed a positive and significant average effect of musical training, $\overline{g}_{\Delta} = 0.26$, 95% CI [0.12, 0.39], $p < .001$, although heterogeneity was high, $\tau^2 = 0.15$; $I^2 = 83.89\%$. The same result appeared when self-selection studies were also included in the model, $\overline{g}_{\Delta} = 0.19$, 95% CI [0.10, 0.28], $p < .0001$; $\tau^2 = 0.09$; $I^2 = 76.09\%$. Interestingly, the pre-posttest difference was similar among the three groups of studies, even numerically smaller for self-selection studies (randomized: $\overline{g}_{\Delta} = 0.26$, $p = .013$; non-randomized: $\overline{g}_{\Delta} = 0.25$, $p = .015$; self-selection: $\overline{g}_{\Delta} = 0.11$, $p = .023$).

Subsequently, we assessed whether the observed heterogeneity could be due to the presence of outliers. Three outliers (Rauscher et al., 1997; Rauscher & Zupan, 2000; Roden, Könen, et al., 2014) were detected, as they contributed with implausibly large effect sizes (some of them larger than $g_{\Delta} = 1$). Interestingly, these three studies did not randomly assign participants to groups and had small samples, factors that might have contributed to their outcomes. All subsequent analyses were conducted without these studies. The overall effect (with randomized and non-randomized studies) remained significant but heterogeneity was still substantial, $\overline{g}_{\Delta} = 0.26$, 95% CI [0.13, 0.39], $p < .001$; $\tau^2 = 0.08$; $I^2 = 70.35\%$. Again, the final estimates of the three groups of studies did not differ (randomized: $\overline{g}_{\Delta} = 0.26$, $p = .013$, see Fig. 2; non-randomized: $\overline{g}_{\Delta} = 0.25$, $p = .021$, see Fig. 3; self-selection: $\overline{g}_{\Delta} = 0.11$, $p = .023$, see Appendix F, Figure F.1).

3.2. Assessment of baseline differences

To test whether there were systematic baseline differences between participants in the treatment and control conditions, we conducted a meta-analysis of g_{pre}. As expected, the mean effect size was non-significant for randomized studies, $\overline{g}_{\text{pre}} = 0.00$, 95% CI [−0.14, 0.15], $p = .957$; $\tau^2 = 0.01$; $I^2 = 14.20\%$ (see Appendix G, Figure G.1), confirming that randomization had been successful in these studies. Also, there was no baseline difference in non-randomized studies without group selection, $\overline{g}_{\text{pre}} = 0.03$, 95% CI [−0.08, 0.14], $p = .510$; $\tau^2 = 0$; $I^2 = 0\%$ (see Appendix G, Figure G.2). On the other hand, there was a positive and significant baseline difference in favor of musical training groups among self-selection studies, $\overline{g}_{\text{pre}} = 0.29$, 95% CI [0.12, 0.47], $p = .003$; $\tau^2 = 0.06$; $I^2 = 62.96\%$ (see Appendix G, Figure G.3), which suggests that children/adolescents who voluntarily selected musical training as an extracurricular activity (over other programs such as sports or drama lessons) showed better initial cognitive and academic scores than their counterparts. A multilevel Bayesian approach using the *brms* R package (Bürkner, 2017) replicated previous results. Whereas there was strong evidence in favor of the lack of difference at baseline in randomized studies, $BF_{10} = 0.09$, and non-randomized studies, $BF_{10} = 0.06$; it showed substantial evidence in favor of preexisting differences in self-selection studies, $BF_{10} = 7.20$.

3.3. Moderator analyses

Most of the moderators (randomization, active control, blinding of assessors/computerized measures, age of the participants, duration of the program, baseline difference, and low SES) were not significant when they were individually added to the model of the randomized and non-randomized studies (Table 2). Overall, the results suggested that several academic or cognitive domains were more sensitive than others to the impact of learning to play an instrument (see Table 3). To find out which combination of moderators provided the best fit for the data, we carried out a backward stepwise selection ($\alpha_{\text{exclusion}} = 0.10$) with all the moderators. The best meta-regressive model did not retain any moderator.

When the influence of moderators was assessed only with randomized studies, no separate variable reached the significance level explaining heterogeneity. However, when more complex structures of moderators were considered, the best meta-regressive model included age, baseline difference, and low SES (residual heterogeneity: $\tau^2 = 0.08$; $I^2 = 59.56\%$). The model suggests that the effect of musical training in randomized studies was smaller in older individuals and individuals with higher performance at baseline, whereas larger effects were found with low SES.

3.4. Publication bias

Visual inspectioning the funnel plot of the aggregates of randomized and non-randomized studies (self-selection studies were not included in publication bias analyses), there was no clear asymmetry in the distribution of effects (Fig. 4). Consistent with this, the trim-and-fill and RVE meta-regression showed no evidence of asymmetry of the funnel plot (i.e., publication bias and small-study effects). Trim-and-fill with the *R0* estimator detected one missing study (see white circle in Fig. 4), but not with the *L0* estimator (no missing studies). On the other hand, the regression coefficients for the standard error and the sampling variance were not significant in the RVE PET/PEESE meta-regressions (see Table 4). The likelihood ratio test of the Vevea and Hedges's selection model was not indicative of publication bias either ($p = .606$). Finally, in the Mathur and VanderWeele's sensitivity analysis, no value of η could render the estimate equal to 0 or non-significant. An $\eta \approx 9$ was necessary to diminish the final estimate to $\overline{g}_{\Delta} = 0.10$. Those results suggest that the meta-analytic conclusions are robust regardless of the severity of publication bias. Moreover, the multiple tests of

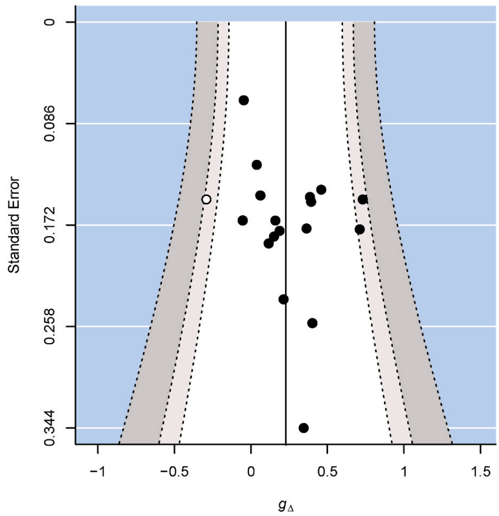

Fig. 4. Funnel plot with trim-and-fill of the aggregate effects of randomized and non-randomized studies (black circles). One missing study was imputed with trim-and-fill (white circle) using the *R0* estimator. The contour of the funnel takes into account the heterogeneity of the trim-and-fill model. The light gray zones show effects between $p = .10$ and $p = .05$, and the dark gray zones show effects between $p = .05$ and $p = .01$.

Table 4
Tests of publication bias for randomized and non-randomized studies combined.

	Trim and fill	RVE PET	RVE PEESE	Selection model	Sensitivity analysis
Test of publication bias	*L0*: No missing studies	Modified SE: $\beta = 0.96$, $p = .283$	Modified variance: $\beta = 0.86$, $p = .552$	Likelihood ratio test: $\chi^2(1) = 0.27$, $p = .606$	$\bar{g}_\Delta = 0$: not possible
	R0: 1 missing study	Transformation SE: $\beta = 0.94$, $p = .270$	Transformation variance: $\beta = 0.99$, $p = .697$		$\bar{g}_\Delta = 0.10$: $\eta = 9.02$
Corrected estimate	*L0*: $\bar{g}_\Delta = 0.26$, $p < .0001$	Modified SE: $\bar{g}_\Delta = 0.01$, $p = .958$	Modified variance: $\bar{g}_\Delta = 0.19$, $p = .194$	$\bar{g}_\Delta = 0.30$, $p = .005$	$\eta = 1.5$: $\bar{g}_\Delta = 0.23$, $p = .003$
	R0: $\bar{g}_\Delta = 0.22$, $p < .001$	Transformation SE: $h = 0.01$, $p = .950$	Transformation variance: $h = 0.25$, $p = .023$		$\eta = 5$: $\bar{g}_\Delta = 0.13$, $p = .003$

publication bias yielded similar results when they were conducted only with randomized studies, suggesting little evidence of selective reporting or small-study effects (Table 5).

Regarding the adjustment of the multiple methods, the corrected effect sightly differed from the uncorrected estimate ($\bar{g}_\Delta = 0.26$) in most of the cases (see Table 4). Only regression-based methods yielded non-significant estimates and, among them, only PET returned a negligible corrected estimate ($\bar{g}_\Delta = 0.01$, $p = .958$). The Mathur and VanderWeele's sensitivity analysis yielded an effect closely identical to the uncorrected one ($\bar{g}_\Delta = 0.23$, $p = .003$) with the mean value of η in psychology literature ($\eta = 1.5$). When the publication probability for positive results was five times the probability for null or negative (the 95th quantile in psychology; Mathur & VanderWeele, 2020), the adjusted effect remained positive and significant ($\bar{g}_\Delta = 0.13$, $p = .003$). Despite the smaller number of randomized studies ($m = 8$), the results were similar when the adjustments were applied in that group of studies (Table 5).

In summary, none of the methods detected substantial evidence of publication bias or small-study effects, including those with higher power, such as the Vevas and Hedges' selection model. In addition, the corrected estimate had similar size in most of the cases. Only the RVE PET approach showed a reduction in the effect. However, it is probable that the attenuation with RVE PET was a consequence of its worse performance under the observed conditions of moderate-to-high heterogeneity, small number of studies, and small effect size (Stanley, 2017; also see our performance simulation with Carter et al.'s software, Appendix B). Previous simulation studies showed that PET tends to underestimate the true effect under the conditions observed in our meta-analysis (Stanley, 2017). Therefore, taking all the approaches in consideration, the results suggest that the true underlying effect is non-zero.

4. Discussion

The present meta-analysis investigates the causal effects of learning to play an instrument on cognitive skills and academic achievement during the school years. Overall, a small benefit ($\bar{g}_\Delta = 0.26$) was found with relatively short-term programs (with a mean

Table 5
Tests of publication bias for randomized studies.

	Trim and fill	RVE PET	RVE PEESE	Selection model	Sensitivity analysis
Test of publication bias	*L0*: 2 missing studies	Modified SE: $\beta = 1.21$, $p = .331$	Modified variance: $\beta = 0.96$, $p = .651$	Likelihood ratio test: $\chi^2(1) = 1.08$, $p = .298$	$\bar{g}_\Delta = 0$: not possible
	R0: No missing studies	Transformation SE: $\beta = 1.15$, $p = .335$	Transformation variance: $\beta = 1.03$, $p = .782$		$\bar{g}_\Delta = 0.10$: not possible
Corrected estimate	*L0*: $\bar{g}_\Delta = 0.19$, $p = .008$	Modified SE: $\bar{g}_\Delta = -0.04$, $p = .881$	Modified variance: $\bar{g}_\Delta = 0.18$, $p = .336$	$\bar{g}_\Delta = 0.15$, $p = .207$	$\eta = 1.5$: $\bar{g}_\Delta = 0.26$, $p < .001$
	R0: $\bar{g}_\Delta = 0.25$, $p = .002$	Transformation SE: $h = -0.02$, $p = .907$	Transformation variance: $h = 0.25$, $p = .051$		$\eta = 5$: $\bar{g}_\Delta = 0.16$, $p = .001$

duration of 17 months), regardless of whether or not there was a random assignment of participants to musical training versus control groups, and independently of the type of control group (i.e., active vs. passive). The fact that a positive result was also found in randomized designs taken alone supports the idea of a causal role of musical training in the observed improvements. Complementarily, it is important to note the detection of a bias in baseline performance in favor of music groups across studies in which the participants chose the training group ($\bar{g}_{pre} = 0.29$). This indicates that participants who self-selected to play an instrument consistently showed better performance prior to the beginning of the intervention, compared to those who decided to enrol in an alternative control activity. As this pretest disparity was small, and most of the studies were underpowered to detect it,[5] it is perhaps unsurprising that the authors of those studies usually claimed to have matched groups. However, our meta-analytic evidence reveals that this was not the case. In contrast, and importantly, the pretest differences were null in randomized studies, as one would expect from truly random assignment of participants to groups. Furthermore, there was scarce evidence of publication bias and our conclusions remain valid under almost all the bias-correction methods that we applied (trim-and-fill, selection model, PEESE, and sensitivity analysis), except PET. Simulation studies have found that the last method performed poorly under conditions of moderate-to-high heterogeneity, reduced number of studies, and a putative small true effect as the one explored in the present meta-analysis. Therefore, it reinforces the conclusion that current evidence supports a causal effect of instrumental musical training on cognitive skills and academic achievement in children and adolescents.

Our findings are in line with a *nature and nurture* approach (Wan & Schlaug, 2010). According to this view, preexisting cognitive advantages and higher levels of academic achievement, such as those we observed at baseline in self-selection studies, would facilitate the learning of musical skills. In addition, engagement in the complex activity of learning to play a musical instrument for a long period of time would lead to neurocognitive adaptations producing further enhancements in general cognitive skills and academic achievement. Even for expert music performance and the skills directly trained, deliberate practice seems insufficient to wholly explain individual differences (only ~ 30%; Hambrick et al., 2014), and part of the remaining variability might come from preexisting factors such as genetic factors and early musical experience (Seesjärvi et al., 2016). To our knowledge, only one experimental study has investigated far transfer with instrumental learning using a monozygotic cotwin control design (Nering, 2002). In this study, one of the twins was randomly selected to take a piano training program while the other was assigned to a waitlist group. After 7 months, experimental twins overperformed the control group in intelligence scores. Although the comparison group did not participate in an alternative activity (such as in other experimental studies with positive outcomes; e.g., Frischen et al., 2021), the inclusion of monozygotic twin pairs with a common genotype and an early rearing environment supports that musical training has an impact on extra-musical cognitive skills even when genetic factors and shared environment are controlled.

Under a *nature and nurture* approach, it is not surprising that the differences reported previously between musicians and non-musicians in correlational studies ($\bar{g} = 0.8$–1; Corrigall et al., 2013) tend to be remarkably larger than the effects of short-term training in children that we observed in our meta-analysis of experimentally controlled studies ($\bar{g} \approx 0.2$). The combination of both initial differences and additional enhancements produced by the involvement in musical training for many years can explain the larger effect observed in correlational studies comparing adult musicians and non-musicians. In a recent study, Mankel and Bidelman (2018) reported similar findings with auditory processing, where listeners with inherently more adept auditory skills but no formal musical training showed better speech encoding than a low-musicality group, whereas formally trained musicians showed superior musicality and outperformed both groups of non-musicians on speech encoding. Taken together, their results suggest that preexisting factors may play a role in the relationship between musical experience and enhanced auditory functions, at the same time that musical training might provide an additional experience-dependent boost of preexisting differences.

Moreover, our results are in line with a recent longitudinal genetic study with over 1600 twins, including biological and adoptive adolescent siblings (Gustavson et al., 2021). Instrument engagement was highly heritable and genetically correlated with verbal abilities at 12 and 16 years of age, suggesting that a common set of genetic influences predisposes individuals towards both music engagement and high verbal intelligence (i.e., selection bias). However, instrument engagement was associated with later verbal ability (at 16 years old) even when controlling for 12-year full-scale intelligence or 12-year verbal intelligence, providing evidence for small direct benefits of musical training on later language abilities.

[5] A power analysis using G*Power 3.1 (Faul et al., 2009) for a two-tailed *t*-test and an alpha of .05 indicated that around 188 participants per group would be necessary to achieve an acceptable power of.80 with a Cohen's *d* of 0.29.

Following this logic, the less controlled the correlational studies, the larger one would expect the observed effect of musical training to be. For instance, Medina and Barraza (2019) observed an extremely large advantage in executive control for professional pianists ($d = 1.51$) using a visuospatial attentional task (i.e., the *Attentional Networks Test* or ANT; Fan et al., 2002), which correlated with the number of years of musical practice. This exceptionally large effect was likely inflated by the lack of control over several variables potentially enhancing attention. Indeed, in a similar study with an ANT-like task (i.e., the *Attentional Networks Test for Interactions and Vigilance – executive and arousal components* or ANTI–Vea; Luna et al., 2018), Román-Caballero et al. (2021) found a smaller difference ($d = 0.25$) when the effect of musical training was measured while controlling for a wide list of sociodemographic and lifestyle confounds. This inflation is still present in observational studies with large samples, such as Guhn et al. (2020; $N \approx 110{,}000$), in which reductions around 60% or more were observed in all the measures after controlling for multiple confounders (cultural background, socioeconomic status, sex, and prior academic achievement). Thus, the long history of training in professional musicians (about 12 years in Medina & Barraza, 2019) likely fosters their cognitive capacities, although in a more modest way than reported in uncontrolled cross-sectional studies.

4.1. Influence of moderators and individual differences

4.1.1. Methodological quality and other musical programs

Unlike previous studies reporting an inverse relationship between design quality and the magnitude of the effects (see Sala & Gobet, 2017a, 2020), we did not find a significant reduction in the size of the outcome of randomized studies compared to non-randomized ones. On the contrary, the benefits for studies with random allocation were numerically greater (randomized: $\bar{g}_{\Delta} = 0.26$, vs. self-selection: $\bar{g}_{\Delta} = 0.11$). As noted above, this inconsistency could be a consequence of non-instrumental programs being overrepresented in the studies with higher methodological quality in the meta-analysis by Sala and Gobet (2020; only 31% of those with higher methodological quality involved instrumental training). Previous studies show that the benefits of non-instrumental interventions, such as preschool training of musical skills or active listening, are smaller than those of instrumental training (Bugos, 2010; James et al., 2020). A plausible explanation is that non-instrumental programs are less cognitively demanding and also that the skills they train are more restricted to the music domain compared to instrumental programs.

Indeed, a reanalysis of the data meta-analyzed by Sala and Gobet (2020) supports these impressions. Excluding studies with self-selection of the musical training program (Geoghegan & Mitchelmore, 1996; Hogan et al., 2018; Kempert et al., 2016), those with only posttest designs (five), and those excluded as outliers, we identified 30 non-instrumental studies included in Sala and Gobet's review, which used computerized training of musical skills (4 studies), phonological processing training with music support (1), and Kindermusik, Orff, Kodály or other related methods (25). We compared these non-instrumental studies to the 18 studies with instrumental programs with random or not self-selected assignment included in our meta-analysis. When design quality was not taken into account (i.e, when studies with randomized and non-randomized allocation, as well as active and passive controls, were analyzed), both non-instrumental and instrumental programs showed similar and significant benefits ($\bar{g}_{\Delta,\ \text{instrumental}} = 0.26$, $p < .001$, vs. $\bar{g}_{\Delta,\ \text{non-instrumental}} = 0.20$, $p = .002$). However, this result changed remarkably when we constrained the analyses to randomized studies, finding that only instrumental programs had a significant effect ($\bar{g}_{\Delta,\ \text{instrumental}} = 0.26$, $p = .013$, vs. $\bar{g}_{\Delta,\ \text{non-instrumental}} = 0.11$, $p = .197$). Similarly, when the analyses were constrained to studies with active control groups, instrumental programs outperformed non-instrumental interventions ($\bar{g}_{\Delta,\ \text{instrumental}} = 0.23$ vs. $\bar{g}_{\Delta,\ \text{non-instrumental}} = 0.01$). Therefore, it seems that the null result with high-quality designs reported by Sala and Gobet (2020) was biased by the overrepresentation of non-instrumental interventions (73% of the randomized studies) that, according to our reanalyses, do not seem to produce far transfer benefits. The confound between design quality and the type of musical training in the previous meta-analysis makes it necessary to take their conclusions with caution and limits its generalizability to all musical programs. And again, it reinforces the importance of analyzing instrumental learning programs separately, as in the present meta-analysis.

Altogether, our results support the preferred use of random allocation of participants and pre-posttest designs, rather than only-posttest, to shed light on the debate about the causal role of musical training. However, the duration of studies involving randomized programs tends to be short and many children assigned to the musical training group may not be motivated to learn to play an instrument, both of which might undermine any potential effects of training. For instance, Schellenberg (2004; Corrigall et al., 2013) reported that the participants randomly assigned to music lessons had minimal practice between lessons (about 10–15 min/week), which contrasts substantially with the practice at home of children who motivationally select music as an extracurricular activity. While further studies are necessary with randomized pre-posttest designs, active control groups and blind assessment, the evidence from programs where the children select the activity is also interesting on its own, as these studies usually investigate the effects of longer-term interventions and in ecological situations (Habibi et al., 2018; Tervaniemi et al., 2018). In any case, when it comes to instrumental learning, and not musical education in general, conclusions such as "since there is no phenomenon, there is nothing to explain" (Sala & Gobet, 2020, p. 9) or "researchers and policymakers should seriously consider stopping spending resources for this type of research" (Sala & Gobet, 2017b) seem overpessimistic in light of our results, and upcoming investigation will be essential to clarify this debate.

4.1.2. Baseline differences, socioeconomic status, and age of the participants

Although randomization and the inclusion of an active control group did not explain between-studies variability in our meta-analysis, other moderators accounted for part of the heterogeneity. In the model of randomized studies, three variables were shown to be influential: baseline differences between groups, age of the participants, and SES. First, the larger the baseline difference, the smaller the observed effect of musical training. This could be due to children with a lower initial level of performance having a greater window of opportunity, and vice versa. Similar results have been found for general cognitive training (Jaeggi et al., 2011; Whitlock et al., 2012). Conversely, participants who had the chance to choose musical training programs showed better academic and cognitive scores at baseline, but their benefits ($\bar{g}_\Delta = 0.11$) were numerically the smallest compared to those in random ($\bar{g}_\Delta = 0.26$) or other types of non-random allocation ($\bar{g}_\Delta = 0.25$), in which there was no pretest bias. However, when baseline performance is explicitly controlled in the model of self-selection studies, it predicts a similar pre-postest difference under conditions of no pretest bias (fitted $\bar{g}_\Delta = 0.19$ for self-selection studies vs. fitted $\bar{g}_\Delta = 0.22$ for randomized studies). An alternative explanation for the pretest effect is a regression toward the mean of those samples of children who showed remarkably disparate scores at baseline (higher or lower).

In the same vein, participants with lower SES showed greater improvements compared to those with middle-high SES. Again, this might be the consequence of a large margin for improvement for individuals whose development of cognitive skills and academic achievement is limited by their socioeconomic environments (Diamond, 2012). Therefore, this suggests that, although higher-functioning individuals are more likely to select and maintain musical practice for many years, children with a less favorable background can also benefit from musical training as long as they engage in it for enough time (Fasano et al., 2019; Portowitz et al., 2009; Tierney et al., 2015). If this finding is confirmed by future research, musical training can become an excellent candidate to contribute to reducing cognitive and academic differences due to social disparities.

Finally, the age of the participants at the beginning of the training program seems to modulate the impact of musical training. Our results are consistent with previous cross-sectional studies that show greater neural and cognitive advantages for earlier onsets of the training (Fauvel et al., 2014; Hanna-Pladdy & Gajewski, 2012; Schlaug et al., 1995; Vaquero et al., 2016). This relationship is suggestive of a sensitive period during which instrumental learning is likely to have stronger and more permanent effects on non-musical skills (White-Schwoch et al., 2013), perhaps as a consequence of greater neural plasticity earlier in development, and because those early neurocognitive changes might serve as a scaffold for future training (Vaquero et al., 2016).

4.1.3. Type of outcome and other moderators

Despite the identification of several moderators, heterogeneity remained moderate ($I^2 = 59.56\%$). Part of this variability may be due to artifacts such as differences in measurement error (in relation to the reliability and validity of the tests) or reporting and transcriptional errors (e.g., inaccuracy in coding data, computational errors, errors in reading computer output, or typographical errors). Additionally, although the duration of the programs was known, the participants might have had different levels of engagement and differed in the amount of between-lessons practice. Unfortunately, this information is rarely reported in the studies, so it is hard, if not impossible, to detect this type of biases in most studies (especially, when the outcomes are not outlier values). On the other hand, this heterogeneity may indicate the existence of other unknown variables that can modulate the final effect. In this sense, the type of outcome was a significant moderator when it was individually entered in the overall model, suggesting that the impact of the interventions is not the same for all cognitive and academic domains. Looking at Table 3, we observed that some cognitive abilities, such as executive functions ($\bar{g}_\Delta = 0.41$), improved more than others. Unfortunately, the number of observations per type of enhanced cognitive abilities was low (only two out of nine were assessed at least in ten studies). Thus, the analysis was overly underpowered and needs to be addressed in future research.

The characteristics of the training program might also explain part of the observed variability: the method of instruction, the instrument learned, the music style, or whether the tuition was individual or in small groups. Studies such as Bianco et al. (2017) and Guhn et al. (2020) pointed out that each instrument involves idiosyncratic skills that might have specific cognitive and academic consequences. For example, Bianco et al. (2017) interpreted the differences between drummers and no-drummer musicians in a go/no-go task as a result of the greater amount of physical activity necessary to play drums. Likewise, Guhn et al. (2020) alleged that vocal school music does not require learning musical notation or playing an instrument, which could explain the smaller academic improvements observed with vocal music (compared to instrumental learning programs). In the same vein, small-group learning has been shown to increase transfer compared to individual-learning programs (Pai et al., 2015). Although scarce, these studies open the door to further experimental research examining the influence of training program singularities.

4.2. Transfer in musical training

A relevant contribution of our meta-analysis is that the benefits of instrumental learning were observed in cognitive tasks and contexts quite distinct from musical performance. Computerized psychological tasks (e.g., go/no-go), and standardized tests of intelligence or academic achievement have little in common with playing a musical instrument at a concert or rehearsal. Thus, our findings are in accordance with the idea that, besides improving domain-specific abilities, involvement in the stimulating activity of playing a musical instrument enhances distant functions. Nevertheless, not all cognitive domains and academic achievement appear to be equally sensitive to instrumental training (see Table 3). For example, executive functions showed the most robust benefits. This is not surprising, as music-making places high demands on the abilities of control and self-regulation, monitoring, planning, and focused and sustained attention, among others.

Some authors have expressed skepticism about far transfer (Roediger, 2013; Sala & Gobet, 2019; Thorndike, 1906). Specifically, Thorndike (1906) proposed that transfer only occurs when trained and untrained processes share features in common. Under this approach, he concluded that “the most common and surest source of general improvement of a capacity is to train it in many particular connections” (Thorndike, 1906, p. 248). Unlike many other cognitive activities involving highly specific contexts and tasks, music-making requires the coordination of several skills and sensory modalities and involves a wide and constantly augmented variety of stimuli, social situations, and types of performance. Therefore, musical training has singular characteristics that made it a plausible cognitive enhancer, even from a skeptical perspective.

One explanation for far transfer is that regular training in a particular basic cognitive process fosters the process itself and, as a consequence, affords advantages to any daily task that also hinges on the same skill. However, this explanation is undoubtedly simplistic, as evoking a "brain as a muscle" metaphor fails to explain why cognitive training programs sometimes fail to extend their benefits to other activities (Gathercole et al., 2019; Roediger, 2013; Simons et al., 2016; Taatgen, 2013). An alternative proposal conceptualizes transfer as the consequence of acquiring complex cognitive skills that can be applied to untrained tasks with some overlap (Gathercole et al., 2019; Taatgen, 2013). The *cognitive routine framework* (Gathercole et al., 2019) posits that training on unfamiliar or highly demanding tasks, such as learning to play an instrument, leads to the development of new complex cognitive skills. Transfer then occurs when one of these new skills can be applied to a novel activity. In the case of musical training, several studies have reported superior memory scores for adult musicians when they were compared to non-musician counterparts (Franklin et al., 2008; Jakobson et al., 2008; for longitudinal studies, see Portowitz et al., 2009; and Roden et al., 2012), but the evidence suggests that the advantage is largely due to more robust and efficient coding (such as an improved rehearsal mechanism, Franklin et al., 2008; or increased use of semantic information organization strategies, Jakobson et al., 2008). In line with these results, musical training could stimulate the development of singular strategies, such as mental rehearsal or semantic organization, that can be applied in several non-musical tasks. Accordingly, the expansion of cognitive capacities along with the development of new complex skills could explain the broad benefits observed with musical instrumental learning.

Finally, the cognitive and academic benefits of musical training across a wide range of areas may be in part a consequence of its noticeable impact on attention and executive functions. Attention and executive functions are engaged in many daily activities as well as in many of the tasks used in the studies included in the present meta-analysis for measuring academic achievement and cognitive functions in the included studies. Therefore, any benefit in attention and executive functions might indirectly influence performance in those activities (i.e., acting as a mediator factor between musical training and non-musical skills; Hannon & Trainor, 2007; Moreno & Farzan, 2015; Román-Caballero et al., 2018).

Musical training and practice may also pose a unique type of ongoing challenge that might facilitate far transfer. No matter what level of technical and artistic mastery a musician achieves, there is always room for improvement. Furthermore, there are always new pieces, interpretations, styles, and genres of music to learn. And different musicians and ensembles to play with, adjust to, and learn from. Thus, improvement through the application of effortful control can remain a rewarding challenge throughout the lifespan. As a representative anecdote, when the virtuoso cellist Pau Casals was asked why he continued to practice four and five hours a day when he was eighty years old, he answered: "Because I think I am making progress" (Lyons, 1958).

4.3. *Practical significance*

Our results support that learning to play a musical instrument is an activity with cognitive and academic benefits, although they are fairly small. The overall effect in the present meta-analysis ($\overline{g}_{\Delta} = 0.26$) indicates a probability of 57.3% that a randomly selected person from the musical training group will show higher cognitive skills and academic achievement than a person selected from the control group (only 7.3% above chance level). One pertinent question is the practical significance of this effect, as musical training is an effortful activity that takes many years. In this regard, Hunter and Schmidt (2015) claimed:

> The question for a treatment is really not whether it had an effect but whether the effect is as large as a theory predicts, whether the effect is large enough to be of practical importance, or whether the effect is larger or smaller than some other treatment or some variation of the treatment. (Hunter & Schmidt, 2015, pp. 246–247)

For example, Schellenberg (2004), in one of the first randomized studies with children participants, found that after 36 weeks of intervention the difference between the IQ gain of the keyboard and the passive control groups was only about 2 points. The benefit was even smaller when music participants were compared to children who took drama lessons (a gain difference of 1 IQ point). Similarly, our meta-analysis of studies with programs lasting 16 months on average showed a similar overall increase, corresponding to about 3 IQ points. This contribution is rather small and probably makes very little difference in daily life, so, in that case, musical training might be not one of the first-choice interventions if the only purpose is cognitive enhancement. However, 1–1.5 years of musical training and, in some cases, with reduced engagement might be not enough to produce substantial benefits on cognition. The few studies that assessed longer training periods have shown a greater impact of playing an instrument (Costa-Giomi, 1999, 2004: 36 months, mean $g = 0.43$; James et al., 2020: 48 months, mean $g = 0.39$; Portowitz et al., 2009: 24 months, mean $g = 0.73$), opening the possibility that the changes have practical relevance in the long run, with years of training. Furthermore, in contrast to the general population, learning to play an instrument might have significant daily life implications, both in the short and long term, for populations with lower cognitive development (fitted $\overline{g}_{\Delta} = 0.69$, assuming one standard deviation below the comparison group at baseline), low SES (fitted $\overline{g}_{\Delta} = 0.41$), or both (fitted $\overline{g}_{\Delta} = 0.97$).

The earliest musical instruments date back more than 35,000 years, which indicates that human beings have practiced musical activities involving the use of instruments since the Upper Paleolithic (Conard et al., 2009). It is likely that music originally emerged as a cultural creation, anaexaptatio of the auditory system (i.e., pitch and timing processing) that had evolved for auditory scene analysis (Trainor, 2015). However, engaging in music-making could confer benefits, such as enhanced group cohesion, cooperation, and mood regulation, that may have led to music-specific adaptations and refine human musical skills (Savage et al., 2020; Trainor, 2015). Thus, although musical education might offer certain cognitive advantages, in the end, musicality and music traditions seem to be more strongly linked to other adaptive purposes, such as social bonding. It seems reasonable that the main functions and motives to be involved in musical activities (and subsequently, their more visible effects) are historically distinct from cognitive enhancement. Along these lines, several longitudinal studies have found benefits in such types of domains: emotional development and empathy

(Rabinowitch et al., 2013), prosocial skills (Schellenberg et al., 2015), self-esteem (Costa-Giomi, 2004; Rickard et al., 2013), academic self-esteem (Degé et al., 2014; Degé & Schwarzer, 2018), and mood and quality of life (Seinfeld et al., 2013). Therefore, the cognitive benefits that could appear with musical training should be not taken as the principal value or goal of playing an instrument in most contexts, but as a precious supplementary effect that adds value to an ancient human facet with many other functions.

5. Conclusions

The present meta-analysis shows that learning to play an instrument during the school years has a modest but significant cognitive and academic impact. Longitudinal evidence suggests both a causal role of musical training and the existence of a self-selection bias, whereby children with favorable backgrounds and higher initial functioning are more likely to choose to learn to play or keep learning an instrument. The contrast of these findings with the null results reported for other types of musical and cognitive programs indicates, once again, the rareness of far transfer. Although the mechanisms for transfer remain unknown, instrumental learning in structured programs would be an optimal framework to investigate them. Finally, given that reliable evidence is still scarce, further studies in this field will be relevant to reach firmer conclusions.

Author note

All the data and R script for the analyses are fully available in https://osf.io/9y5tp/. The authors declare no conflict of interest.

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Appendix. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.edurev.2022.100436.

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The references of the studies included in the meta-analysis are in bold and preceded by an asterisk.

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Appendix A2

Román-Caballero, R., & Lupiáñez, J. (2022). Suggestive but not conclusive: An independent meta-analysis on the auditory benefits of learning to play a musical instrument. Commentary on Neves et al. (2022). *Neuroscience & Biobehavioral Reviews, 142*, 104916.

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Data and R script are available at https://osf.io/qwx24/.

Suggestive but not conclusive: An independent meta-analysis on the auditory benefits of learning to play a musical instrument. Commentary on Neves et al. (2022)

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Transfer and skepticism in musical training

The last two decades have witnessed a growth in the interest of society in activities that can improve mental capacities. In this context, a wealth of studies reported positive effects of ordinary activities, such as physical exercise or playing a musical instrument, as well as programs specifically designed for cognitive training (e.g., working memory training programs). This literature suggests that both cognitive domains related to trained skills, and skills with little overlap, might be changed by experience (*near* and *far transfer*).

However, other authors have expressed their skepticism about these findings on the base that most of the evidence comes from designs that limit inferring causality (Sala & Gobet, 2020a): cross-sectional research, non-randomized interventions, passive comparison groups, etc. In the case of musical training, a recent meta-analysis (Sala & Gobet, 2020a) observed no effect on general cognitive abilities, such as attention or language. Similarly, other studies pointed out that early auditory skills predict later skills better than engagement in musical training (Kragness et al., 2021), in line with findings suggesting genetic influences in both musical abilities and the propensity to practice (Mosing et al., 2014).

In contrast, a subsequent meta-analysis (Román-Caballero et al., 2022) showed that programs comprising learning to play an instrument are more demanding and sufficient to produce transfer on general cognitive abilities. Previous null results (Sala & Gobet, 2020a) could be a consequence of the underrepresentation of this type of programs compared to other forms of musical training (e.g., computerized training or music education programs) and a failure to differentiate near and far transfer, among other issues (e.g., if control participants received phonological training and were assessed on phonological awareness, they were tested for near transfer; Bigand & Tillmann, 2022). The new meta-analysis by Neves et al. (2022) offers additional evidence to this debate, observing positive results of near and far transfer (i.e., over auditory and linguistic domains).

An independent replication

Motivated by the recent evidence against the benefits of musical training on auditory skills (Kragness et al., 2021; Mosing et al., 2014), we independently conducted a meta-analysis on this topic before knowing about Neves et al.'s study. Similar to them, we only selected intervention studies with pretest and posttest measures, and participants without previous formal musical training. In addition, we constrained our review to studies with formal learning of musical instruments[1].

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[1] Structured programs involving learning to play a complex musical instrument and to read music notation are the most similar to the type of training that expert musicians follow. As we showed in a previous meta-analysis (Román-Caballero et al., 2022), instrumental training programs are preferred for investigating the causal role of musical training on cognitive skills. Additional evidence found smaller benefits with other non-instrumental musical interventions, to the point of using them as active control activities (e.g., James et al., 2020).

Literature search

A systematic search was carried out in January of 2022 without any time restriction consulting ProQuest, Scopus, and Web of Science[2]. In total, 970 potentially relevant results were identified, among which seven met the inclusion criteria. These studies included 13 effect sizes and 609 participants, two of them not included in Neves et al.'s meta-analysis with instrumental programs (see **Supplementary Material**).

Selection criteria and statistical analysis

The selection criteria were almost the same as those in Román-Caballero et al. (2022), except we selected studies with at least one measure of auditory skills (criterion 6) and no age restriction (criterion 7). We followed the same effect estimation and analytic approach as in Román-Caballero et al. (2022). Thus, Hedges' *g* was meta-analyzed applying robust-variance-estimation (RVE) and Bayesian multilevel models.

Results

Both frequentist and Bayesian models found a positive effect of musical training over auditory skills, but it was not significant or did not get conclusive evidence: RVE model: $g = 0.36$, 95%CI [–0.08, 0.80], $p = .089$ (**Figure**); Bayesian model: $g = 0.34$, 95%CrI [–0.12, 0.74], $BF_{10} = 1.06$. Adding to the model the standardized difference at pretest (g_{pre}) to control for unequal starting points and removing one outlying study (see **Figure**)[3],

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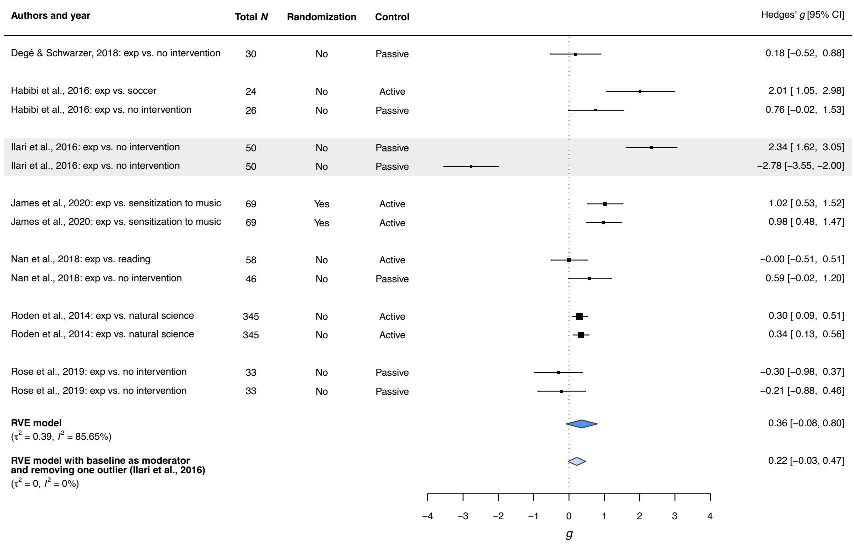
[2] We used the following search syntax: *("experimental stud*" OR "randomi$ed controlled trial*" OR RCT OR pre-post OR test-retest OR longitudinal) AND ("music* practi$e" OR "music* training" OR "music* instrument$" OR "music* activit*" OR "music making") AND (((music* OR auditory OR temporal OR time) AND (175bility* OR skill$ OR perception OR processing)) OR listening OR melod* OR rhyth* OR prosod* OR time OR pitch OR ton*).*

[3] We based the outlier detection on the studentized residuals (> 2) and Cook's distance (> $4/k$, where k is the number of effect sizes). One possible explanation for the extreme outcomes of the identified outlier was its large difference between the groups at pretest, in favor of the experimental group ($g_{pre} > 2$).

the final effect remained positive although the evidence in favor of the alternative hypothesis was still anecdotal: RVE model: g = 0.22, 95%CI [–0.03, 0.47], p = .065; Bayesian model: g = 0.27, 95%CrI [–0.01, 0.69], BF_{10} = 1.24.

Figure. *Forest plot of the standardized difference of mean change (pre-posttest difference) in auditory skills.*



Note. The light blue rhombus represents the summary effect size (i.e., the intercept of the meta-analytic model) after correcting for the between-group baseline difference and removing one outlying study, highlighted by a gray rectangle. The horizontal diagonal of the rhombus is the confidence interval for the final estimate.

The present results suggest that learning to play an instrument, one of the most demanding forms of musical training, might improve auditory skills and, therefore, suggests both near and far transfer (the present meta-analysis along with Román-Caballero et al., 2022). However, the current evidence is not sufficient to reach a firm conclusion, especially when only one study had random allocation of participants. It is noticeable that the literature on far transfer of instrumental musical training has been more prolific than that on near transfer (32 studies in Román-Caballero et al., 2022 compared to seven studies in the present meta-analysis), which limits the inferences of any analysis (i.e., the power of frequentist analyses, and the updating of posterior distribution for Bayesian). Although other types of non-instrumental musical training seem to rarely produce far transfer, one of the main goals of those programs is the promotion of musical skills. Indeed, when we added all the non-instrumental programs included in Neves et al., the evidence in favor of near transfer was strong (Bayesian model: $g = 0.26$, 95%CrI [0.12, 0.44], $BF_{10} = 11.84$), but again most of it came from studies without design-quality features (i.e., randomization and active control group). Without these features, individuals with superior musicality might be more prone to select instrumental programs (Kragness et al., 2021) and passive comparison groups do not allow controlling for placebo or motivation[4]. Indeed, when we controlled for preexisting

[4] Although the studies that used active control in the set of Neves et al. showed reduced auditory benefits compared to those with passive controls only numerically ($g = 0.19$ vs. 0.47; between-condition comparison: $p = .155$), this moderator approached the significance when the other influential variable (i.e., baseline performance difference) was taken into account (active vs. passive control: $g = 0.17$ vs. 0.32; between-condition comparison: $p = .061$). We ascribe this trend in the context of analyses with a small number of observations per level (5 samples with an active control group vs. 10 passive). A similar trend can be observed in our set of studies with instrumental programs ($g = 0.18$ vs. 0.32; between-condition comparison: $p = .232$), in which the number of observations is even more limited (4 with an active co ntrol group vs. 4 passive). Although they are not significant, these numerical trends are in line with the literature on cognitive training that points to a myriad of methodological issues regarding the use of passive groups as a comparison for any intervention (see Ciria et al., 2022).

Regarding the influence of randomization, our review and the one conducted by Neves et al. only identified one randomized study that examined the auditory benefits of an instrumental program (James et al., 2020). However, the studies included in Neves et al. showed a preexisting advantage in linguistic skills of the participants that selected instrumental programs (compared to controls) that did not appear in randomized studies (non-randomized vs. randomized: $g_{pre} = 0.15$ vs. -0.08; between-condition comparison: $p = .039$). A group imbalance in non-randomized designs has also been observed in previous meta-analyses on far transfer (Román-Caballero et al., 2022).

These findings represent empirical evidence for previous recommendations in the literature of refraining from inferring causality based only on quasi-experimental studies, or studies with a waitlist and other forms of passive control (Román-Caballero et al., 2022; Sala & Gobet, 2020).

differences and the inclusion of active control activities in the larger set of studies of Neves et al., the adjusted auditory benefit was substantially reduced (Bayesian model: g = 0.18, 95%CrI [−0.02, 0.40], BF_{10} = 0.56)[5]. Therefore, the literature would be only investigating the benefits, probably inflated, in individuals with preexisting advantages and willing to develop their musical skills.

Altogether, our results do not refute the findings by Neves et al. On the contrary, they also point out that musical training might lead to benefits in auditory skills, although more appropriate evidence is necessary to confirm the conclusions of this meta-analysis. Note that the only study that used randomization (James et al., 2020) was the only work that compared instrumental learning with an alternative musical activity (i.e., musical education). So, it was the only work that tested near transfer in both groups, and, despite that, they still observed auditory benefits of learning to play an instrument (for a detailed discussion on this topic, see Bigand & Tillmann, 2022). Whereas randomization allows controlling many confounds and makes it ideal for establishing causal relationships, it has its own drawbacks. It is difficult to achieve good levels of adherence over long periods for activities to which participants were randomly assigned and might not be motivated to practice (Tervaniemi et al., 2022). A high dropout rate might lead to a situation in which the most motivated participants remain in the program. Even when unmotivated participants do not quit the long-lasting activity, it could compromise the efficacy of the program and, to some extent, be unethical (Habibi et al., 2018). Therefore, whereas randomized

[5] The effect reported here is the intercept of a meta-analytic model including type of control and baseline difference as moderators. When type of control is coded as a dummy variable with 0 representing active control groups and 1 for passive controls, the intercept corresponds with the estimated effect when the between-group comparison was conducted with active control activities (i.e., 0 level = active controls) and no between-group difference at pretest (g_{pre} = 0).

studies might be an excellent way to prove causality, their limitations pose the need to consider evidence from other types of design.

Measuring near or far transfer?

Furthermore, all the studies assessed auditory skills with tests in which participants have to hold in memory a reference auditory fragment and make a same/different judgment with a subsequent target melody or tone. This type of task relies on short-term memory and subsequently offers mixed measures of auditory skills. Previous twin studies found moderate heritability of performance on tests based on same/different judgments (Mosing et al., 2014). In contrast, the genetic influence on auditory tasks that do not involve memory demands seems to be reduced, whereas shared and non-shared environmental factors explain a large part of the individual differences (Seesjärvi et al., 2015). Although there is evidence of benefits of musical training on short-term memory (Román-Caballero et al., 2022), near-transfer effects of cognitive training tend to be larger than far transfer (Sala & Gobet, 2020b). Thus, tasks with fewer memory demands might be more sensitive to the changes produced by music-making experiences as they represent a purer measure of cognitive domain in which we would expect larger changes. Further research is needed to examine whether musical training improves auditory skills beyond the effects shown here when assessed with alternatives to same/different tasks[6].

Updating the skepticism

Although our meta-analysis and Neves et al.'s do not allow reaching a conclusive answer to the debate of near transfer with musical training, the

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[6] The format of tasks with fewer memory demands implies presenting only one melody at a time, where the participants have to judge the "correctness" of the pitches or the time using their prior musical knowledge. For a detailed comparison between this type of task and usual same-different tasks, see Seesjärvi et al. (2015).

findings are aligned with the results obtained for other cognitively stimulating activities. It is still controversial whether working memory training can generally enhance general cognitive functions and academic achievement (Sala & Gobet, 2020b), but it seems indisputable that this type of intervention has a positive effect on memory tasks. We attribute the lack of far transfer in working memory programs to their deliberate design to enhance specific cognitive processes.

Focusing on one cognitive domain, unlike playing a musical instrument or sports that presumably engage multiple higher-order processes, restricts the overlap between trained capacities and real-life skills (Sala & Gobet, 2020b). Moreover, working memory programs are not holistic leisure activities, in contrast to musical training or physical exercise, therefore not involving part of the socialization, pleasures, and personal interests. Part of the improvements in cognitive functioning of holistic leisure activities could come from their benefits on well-being (Särkämö, 2018), and the person's tendency to engage in effortful actions and enjoy them despite their cognitive or physical demands (Inzlicht et al., 2018). In the case of physical exercise, there is consensus that this activity can produce both near and far transfer (Ciria et al., 2022).

Cumulated evidence has shown similar near- and far-transfer effects with musical training but there has been a greater historical propensity towards skepticism in this literature that, in the light of the evidence, seems to be disproportionate. Paradoxically, whereas programs specifically designed for cognitive training, such as working memory training, only enhance those trained capacities, leisure activities such as musical training might extend their benefits to general cognitive abilities; they might do through the promotion of new cognitive strategies that improve the efficient use of the capacity, rather than by increasing capacity itself (von Bastian et al., 2022). However, we are not suggesting that all these leisure activities have interchangeable effects. Conversely, the benefits in some cognitive domains or processes might be more noticeable with certain holistic leisure activities and under certain conditions (e.g., musical education might be more effective in improving phonological awareness and reading skills in dyslexia than visual arts; Flaugnacco et al., 2015). New experimental studies with higher design quality and taking this idea in mind will be decisive to shed light on this debate.

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Appendix A3

Román-Caballero, R., Martín-Arévalo, E., & Lupiáñez, J. (2021). Attentional networks functioning and vigilance in expert musicians and non-musicians. *Psychological Research, 85*(3), 1121–1135.

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Preregister of the design of the study is available at https://osf.io/hzc6m.

Attentional networks functioning and vigilance in expert musicians and non-musicians

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Abstract

Previous literature has shown cognitive improvements related to musical training. Attention is one cognitive aspect in which musicians exhibit improvements compared to non-musicians. However, previous studies show inconsistent results regarding certain attentional processes, suggesting that benefits associated with musical training appear only in some processes. The present study aimed to investigate attentional and vigilance abilities in expert musicians with a fine-grained measure: the ANTI-Vea (*ANT for Interactions and Vigilance–executive and arousal components*; Luna et al., 2018). This task allows measuring the functioning of the three Posner and Petersen's networks (alerting, orienting, and executive control) along with two different components of vigilance (executive and arousal vigilance). Using propensity-score matching, 49 adult musicians (18–35 years old) were matched in an extensive set of confounding variables with a control group of 49 non-musicians. Musicians showed advantages in processing speed and in the two components of vigilance, with some specific aspects of musicianship such as years of practice or years of lessons correlating with these measures. Although these results should be taken with caution, given its correlational nature, one possible explanation is that musical training can specifically enhance some aspects of attention. Nevertheless, our correlational design does not allow us to rule out other possibilities such as the presence of cognitive differences prior to the onset of training. Moreover, the advantages were observed in an extra-musical context, which suggests that musical training could transfer its benefits to cognitive processes loosely related to musical skills. The absence of effects in executive control, frequently reported in previous literature, is discussed based on our extensive control of confounds.

Keywords: Musical training, attention, vigilance, cognitive training, alerting, executive control

1. Introduction

Attentional advantages related to musicianship

Over the last decades, activities such as physical exercise (Smith et al., 2010) and education (Vaqué-Alcázar et al., 2017) have proved to generate an enhancing effect on cognition. In particular, musical training could also be a promising cognitive enhancer, as it involves multiple cognitive systems in regular and motivated practice with constant challenges (Herholz & Zatorre, 2012). Accumulating evidence has associated musical training with cognitive benefits in children (Holochwost et al., 2017; Schellenberg, 2004), young adults (Sluming et al., 2007; Talamini et al., 2017) and older adults (Román-Caballero et al., 2018).

In particular, attention is one of the cognitive aspects in which musicians exhibit advantages compared to non-musicians. Playing an instrument (often in a group) implies indeed multiple attentional demands such as considering several stimuli at the same time (i.e., the score, body movements of other musicians, other melodies, etc.) or detecting and appropriately responding to them over long periods (Rodrigues et al., 2013). In this vein, there is evidence that musicians show benefits in selective, divided, and sustained visual attention compared to non-musicians (Rodrigues et al., 2013), besides less auditory distraction (Kaganovich et al., 2013). Similarly, several studies have indicated better executive control in musicians than their counterparts (Bialystok & DePape, 2009; Jentzsch et al., 2014; Travis et al., 2011). In a recent meta-analysis (Román-Caballero et al., 2018), we also found small-to-medium improvements associated with lifelong musical training in aged populations.

By contrast, other studies have not shown such advantages for musicians as compared to non-musicians in selective attention (Clayton et al., 2016; Roden et al., 2014), vigilance (Carey et al., 2015; Roden et al., 2014; Wang et al., 2015), or executive control (Clayton et al., 2016; Yeşil & Ünal, 2017; D'Souza et al., 2018). Furthermore, Lim and Sinnett (2011; see

Experiment 1) showed no differences between musicians and non-musicians in either exogenous or endogenous attentional orienting. Other mixed results were reported by Strait and colleagues (Strait et al., 2010), wherein musical training was associated with faster responses in an auditory alertness task, but not when the warning signals were visual.

Taking all the above-mentioned literature into account, although some studies have shown attentional advantages for musicians as compared to non-musicians, others have not. Thus, this previous literature suggests that musical training could be associated with enhanced attentional abilities, but the benefits could be rather specific to some attentional processes.

The three attentional networks model

One of the most relevant models of attention is the one proposed by Posner and Petersen (Petersen & Posner, 2012; Posner & Petersen, 1990), which considers the attentional system as organized in three independent (but interactive) neural networks. Firstly, the *orienting network* involves the ability to prioritize the relevant stimuli by selecting the location or sensory modality, or focusing selection at the appropriate processing scale. It includes cortical regions such as frontal eye fields and parietal cortices, and subcortical structures as the pulvinar nuclei and the superior colliculi. A second subsystem is an anterior network that mainly connects the anterior cingulate and prefrontal cortices. This network underlies *executive control* processes that select relevant information from the environment to adapt our behavior to long-term goals. The third subsystem is the *alerting network*, a brain circuit that connects the locus coeruleus with the parietal and prefrontal cortices. This network is responsible for increasing arousal up the necessary level for readiness to imminent events (*phasic alertness*), and it also involves the capacity to sustain attention for extended periods (*tonic alertness* or *vigilance*).

Several tasks have been developed to simultaneously measure these three components, such as the classic *Attentional Network Test* (ANT; Fan et al., 2002). The ANT is based on a flanker task (Eriksen & Eriksen, 1974) with arrows, in which the performance in a conflict situation (i.e., incongruent conditions with flanker arrows pointing to the opposite direction than the central target) in comparison to non-conflict conditions (congruent, or neutral, i.e., flanked by with non-directional lines) serves as a measure of executive control (*congruency effect*: reaction time [RT] in incongruent trials – RT in congruent trials). Moreover, the target display is preceded by either a spatial informative cue, a non-spatial cue or no cue at all. In the same way that the executive control network, RT subtractions can be used as efficiency indices of the alerting and the orienting networks. To analyze the interactions between the attentional networks, however, a different version of the ANT was developed in our lab (the *ANT for Interactions* or ANTI task; Callejas et al., 2004), in which the stimuli for measuring phasic alertness and orienting were dissociated. Unlike the ANT, and considering that auditory signals seem to be more effective to increase phasic alertness than visual ones (Fernandez-Duque & Posner, 1997), the ANTI includes an auditory tone as a warning signal. The independent manipulation of stimuli in the ANTI version allows observing the interaction between alerting and orienting (larger orienting with than without alertness), as well as the modulation of both over executive control (whereas orienting reduces interference, alertness increases it).

Both ANT and ANTI tasks are reliable measures of the three attentional networks, as well as sensitive to between-groups differences in different factors (e.g., with the ANT: development and video games, Dye & Bavelier, 2009, bilingualism, Costa et al., 2008, or aging, Mahoney et al., 2010; with the ANTI: trait and state anxiety, Pacheco-Unguetti et al., 2010, acute sport and caffeine intake, Huertas et al., 2019, or Fibromyalgia, Miró et al., 2011). To the best of our knowledge, however, only one study so far

(Medina & Barraza, 2019) has directly investigated the three attentional networks in musicians by using the ANT, reporting faster overall responses and better executive control in musicians as compared to non-musicians.

Apart from the classic indices of the attentional networks (i.e., RT subtractions), other control outcomes can be obtained from the flanker task included in the ANT and the ANTI tasks. Thus, the congruency effect is smaller following an incongruent than a congruent trial (*Gratton effect*; Gratton, 1992), which has been associated with a first-order conflict adaptation (Egner, 2007; Jentzsch et al., 2014). Another measure comes from the adjustments immediately following an error; that is, an increase in RT after an error (*post-error slowing*; for reviews see Danielmeier & Ullsperger, 2011; Wessel, 2017). In a study by Jentzsch et al. (2014), the intensity of the musical training was associated with a reduction in both Gratton effect and post-error slowing, which suggested, according to the authors, an improvement in monitoring and a more effective response adjustment as a function of musicianship.

The multiple concepts of vigilance

Vigilance has been generally defined as the capacity to maintain an attentional activity over prolonged periods (Langner & Eickhoff, 2013; Lezak et al., 2012). Despite being considered in Posner's three attentional networks as part of the alertness function (as tonic alertness), it has a special status and has been extensively investigated in applied fields. Furthermore, vigilance does not seem to be a unitary concept. Indeed, a multiplicity of terms are used in the literature to refer to it: tonic arousal (Sturm & Willmes, 2001), tonic alertness (Posner, 2008), vigilant attention (Robertson & Garavan, 2004), sustained attention (Esterman & Rothlein, 2019), intrinsic alertness (Sturm et al., 1999) or psychomotor vigilance (Lim & Dinges, 2008). In this vein, some researchers (Langner & Eickhoff, 2013; Sturm et al., 1999; Luna et al., 2018) have drawn attention to a distinction between vigilance tasks involving fast responding to stimuli without much control over prolonged periods (tasks such as the *Psychomotor Vigilance Test*, PVT; Dinges & Powell, 1985), and more complex tasks requiring detection of infrequent (but relevant) stimuli and selection between two or more responses, thus involving executive aspects such as working memory, target detection, and response selection (e.g., the *Sustained Attention to Response Task*, SART, Robertson et al., 1997, or the *Continuous Performance Test*, CPT; Conners, 2000).

Thus, one component of vigilance involves the ability for sustaining attention over long time periods to keep a fast reaction to stimuli without selecting a specific response (hereafter called *arousal vigilance* or AV; Luna et al., 2018). This is distinguishable from the sustenance of attention for monitoring the occurrence of rare but critical events that must be detected by performing a specific response, different from the one expected for the remaining frequent events (hereafter called *executive vigilance* or EV; Luna et al., 2018). Neuroimaging and neuropsychological studies have shown that both categories of vigilance tasks involve a brain circuit similar to the Posner and Petersen's alerting network, involving right-lateralized frontoparietal cortices and subcortical regions such as the thalamus, the pons, and the locus coeruleus (Langner & Eickhoff, 2013). This network has been posited to subserve the endogenous generation of an optimal level of alertness and its maintenance over time. Whereas the ascending noradrenergic and pontine cholinergic projections seem to enhance cortical arousal (Langner & Eickhoff, 2013; Sarter et al., 2001), frontal areas may exert top-down modulation over this alerting system (a) initiating and maintaining preparation and task schema ("energizing"), and (b) monitoring performance and the environment to implement adjustments (Langner & Eickhoff, 2013; Shallice et al., 2008). Additionally, the left hemisphere is recruited in more challenging contexts of vigilance (i.e., executive vigilance tasks), comprising aspects of working memory and selective attention (Sturm et al., 1999).

As neither the ANT nor the ANTI included a direct measure of vigilance, more recent versions have incorporated additional manipulations to assess that function (*ANTI-Vigilance* or ANTI-V; Roca et al., 2011; *ANT for Interactions and Vigilance – executive and arousal components* or ANTI-Vea; Luna et al., 2018). Importantly, this latter version (ANTI-Vea) incorporates two independent measures for the executive (EV) and arousal (AV) components of vigilance. For EV, a few trials have a large vertical displacement of the central arrow, which has to be detected with a different response key. On the other hand, AV is measured with the fast response to a perceptively different stimulus (i.e., a red down counter) by pressing any key.

Like the ANT and ANTI, the ANTI-Vea has been validated to assess – simultaneously and in a single session– the independence and interactions of phasic alertness, orienting, and executive control, along with the executive (EV) and arousal (AV) components of vigilance (Luna et al., 2018). In a large sample (~ 600 participants) high reliability was found for overall ANTI scores, as well as for all the EV and AV outcomes, for both the standard laboratory and online version (split half-reliability higher than .70 in all cases; Luna et al., in preparation). Furthermore, the task has proven to be sensitive to the specific impact of factors over EV and AV, allowing to dissociate between them: anodal high-definition transcranial direct current stimulation over right frontal and parietal cortices (reduced EV decrement on discriminability, but not in AV decrement; Luna et al., under review), fatigue across eight hours of testing (increased AV decrement, but no effect on EV; Feltmate et al., 2019), acute moderate exercise (reduced EV decrement on mean RT, but not in AV decrement), or acute caffeine intake (reduced AV decrement on mean RT and RT variability, but not in EV; Sanchis et al., under review).

Aim of the present study and hypotheses

In the present work, we used a fine-grained approach by using the ANTI-Vea, to better investigate the putative relationship between musicianship and the functioning of the attentional networks and vigilance. Despite the well-known inferential problems of non-experimental studies, our correlational design tried to partially solve the limitations of previous correlational studies. Thus, we extensively controlled for confounds with a wide list of inclusion criteria and matching variables. Furthermore, and importantly, we preregistered our hypotheses and analysis plan (https://osf.io/hzc6m): we expected (i) faster overall responses for musicians as compared to non-musicians, as has been often observed previously (Jentzsch et al., 2014; Medina & Barraza, 2019; Román-Caballero et al., 2018); (ii) improvements in both alerting and executive control but not in orienting (Lim & Sinnett, 2011; Medina & Barraza, 2019; Strait et al., 2010); and (iii) benefits in the sustained aspects of attention (Rodrigues et al., 2013; especially in EV because of the implication of more executive components). Additionally, (iv) we hypothesized to replicate the results by Jentzsch et al. (2014), in which musicians showed a reduced Gratton effect and smaller post-error interference, as additional outcomes of executive control.

2. Methods

2.1. Participants

To determine the sample size, we performed a power analysis with G*Power 3.1 (Faul et al., 2009) with an alpha of .05 and a power of .80. Since we were mainly interested in between-group (musicians and non-musicians) comparisons (with clear *a priori* hypotheses) and considering the medium effect size of attention in our previous meta-analysis (Román-Caballero et al., 2018), we chose a one-tailed *t*-test with a Cohen's *d* of 0.5

(https://osf.io/mb8r7). This approach indicated that around 50 participants per group (musicians and non-musicians) were necessary.

A total of 147 healthy volunteers meeting our inclusion criteria were recruited by posting information about the study in social media and webpages. All participants signed informed consent and participated on-line in the experiment for monetary compensation (a monthly draw of 50€ of tickets for shows). Participants were between 18 and 35 years old and had normal or corrected-to-normal vision and hearing, no history of head injury, neurological or psychiatric illness, infarction or heart disease, diabetes, untreated hypertension, chronic use of psychoactive medication (more than 6 months), drug abuse, or alcoholism. According to their musical background, participants were assigned to one of two groups. The group of musicians was defined as participants who could read musical scores and had played an instrument and/or sung for ten years or longer, at least five years of formal musical training, and an age of musical training onset before 14 years old. The non-musician group was defined as adults who could not play any instrument or read scores (and therefore, without any formal musical instruction) and had no experience as singers. Additionally, participants with fewer than ten years of practice or five years of formal training were also included as a group of intermediate musicians. Note that this last group was used only in exploratory correlational analyses between cognitive benefits and musical variables, as our main interest was the between-extreme-group comparisons. Therefore, our sample size was a priori estimated to provide sufficient statistical power for the main analyses (i.e., the contrast between musicians and non-musicians). A post-hoc power analysis for exploratory correlational analyses showed that our final sample of 72 musically trained participants provided a power of .73 (two-tail) for detecting a medium correlation coefficient of .3 (α = .05). Moreover, the statistical power would decrease if the observed effect were smaller.

After the initial assignment to groups, we identified seven outlier participants for exclusion: one musician, four non-musicians, and two intermediate musicians. Outlier detection was based on performance (i.e., considering mean RTs in the three types of trials; and accuracy, % of errors in ANTI trials, % of hits in EV trials, and % of lapsus in AV trials) identified as poor in terms of meeting all the following indices: standard deviation from the mean (> 2.5), studentized deleted residuals ($> t_{n-k-1;\ \alpha/n}$), and Cook's D_i ($> F_{k+1,\ n-k-1;\ \alpha = .50}$; Aguinis et al., 2013). A total sample of 140 participants remained (52 musicians, 65 non-musicians, and 23 intermediate musicians). Characteristics of musical experience for the musician groups (musicians and intermediate musicians) are depicted in **Table 1**.

The study was conducted in accordance with the ethical guidelines laid down by the University of Granada, under the ethical standards of the 1964 Declaration of Helsinki (last update: Seoul, 2008), and was part of a larger research project (PSI2017-84926-P) approved by the University of Granada Ethical Committee (536/CEIH/2018).

2.2. Materials

The information about inclusion criteria, confounds (see **2.4. Propensity-score matching**) and musical variables were obtained from participants by an in-house questionnaire, containing Likert-type, open-ended, and yes/no questions (see **Appendix A**). The attentional performance was assessed with the web version of the ANTI-Vea task (https://www.ugr.es/~neurocog/ ANTI/), designed and run with Javascript ES5, HTML5, CSS3, and AngularJS. Stimuli for ANTI and EV trials are the same: a fixation cross (~7 px), a black asterisk (~14 px), a warning tone (2000 Hz) and five arrows (the central target and four flankers; 50 px wide × 23 px high each). Each arrow is separated horizontally by ~13 px from adjacent arrows. In EV trials, the central arrow is vertically

Table 1. Characteristics of musical experience in the final musician groups (musicians and intermediate musicians), after matching (see **2.4. Propensity-score matching**). Standard deviations in brackets.

	Years of practice	Age of onset	Years of lessons	Professionals	N. of instruments	Main instrument	Main style
Musicians (n = 49)	14.76 (3.83)	7.40 (1.67)	11.84 (4.11)	63.27%	2.65 (1.25)	- Piano: 10 - Cello: 7 - Violin/Clarinet: 6 - Flute: 5 - Guitar: 4 - Singers/Viola: 2 - Trumpet/Drum/Horn/ Saxophone/Bassoon/Bass: 1	- Classical music: 83.67% - - Pop/Rock: 8.16% - - Popular: 6.12% - - Jazz/Blues: 2.04%
Intermediate musicians (n = 23)	5 (3.40)	11 (3.86)	3.42 (1.74)	4.35%	1.74 (1.42)	- Guitar: 9 - Piano: 3 - Drum/Clarinet/Trumpet: 2 - Canary Timple/Flute/Saxophone/ Cello/Saxhorn: 1	- Classical music: 34.78% - - Pop/Rock: 26.09% - - Popular: 21.74% - Jazz/Blues: 4.35% - Flamenco: 4.35%

displaced by 8 px (either up or down). In addition to this displacement, a random variability of ±2 px is applied to the horizontal and vertical positions of each arrow (both flanker and central arrows) in order to increase the difficulty to detect the displacement of the target. A red millisecond down counter (~110 px height each number) was presented at fixation in AV trials (20% of the total trials).

2.3. Procedure

Participants followed a link to participate in the study. Prior to the experimental task, participants completed the on-line questionnaire about inclusion criteria, confounds and musical variables. After completing the questionnaire, the link brought them to perform the on-line ANTI-Vea task to assess the functioning of the three attentional networks (ANTI trials) and the executive and arousal components of vigilance (EV and AV trials, respectively). The stimuli sequence, procedure, and correct responses for each type of trial are depicted in **Figure 1**. In ANTI (60%) and EV trials (20%), an auditory warning signal (2000 Hz tone) preceded the target display in half of the trials. In each half of trials, an asterisk (i.e., visual-spatial cue) was presented afterward either in the same (valid trials) or the opposite location (invalid trials) whereas no cue was presented in the remaining third of trials. Irrespective of the preceding stimuli, participants had to discriminate the direction of the central arrow (by pressing either "c" for leftward direction or "m" for rightward direction), while ignoring the flanking arrows. In EV trial, however, participants had to detect the large target displacement (up or down) by pressing the space bar while ignoring its direction. Finally, in AV trials (20%), a red millisecond down counter appeared after a variable time interval (900–2100 ms), in the absence of a warning signal and visual cue, and participants had to stop the down counter by pressing any key as fast as possible.

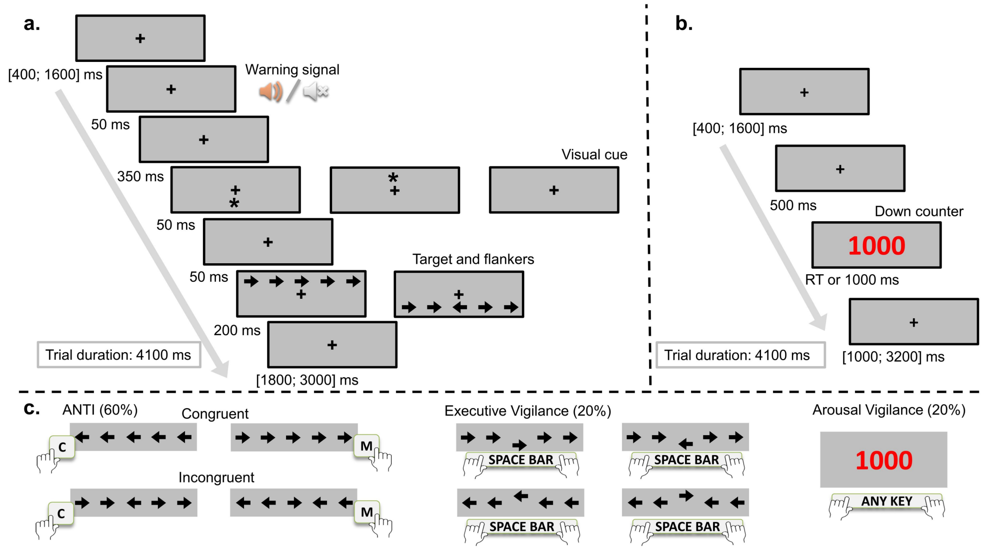

Figure 1. ANTI-Vea procedure. Temporal sequence in ANTI and EV trials (a) and AV trials (b). Panel (c) shows arrow displacements (the five arrows are randomly displaced ±2 px to generate noise in ANTI trials and the target is displaced 8 px in EV trials).

The ANTI-Vea task started with a practice phase, as in Luna et al. (2018). Instructions and practice blocks (with visual feedback) were given gradually. Also, participants were encouraged to keep their eyes on the fixation point all the time and to respond as quickly and accurately as possible during the whole task. The practice phase comprised (in the following order) 16 ANTI trials, 32 randomized trials (16 ANTI and 16 EV), and 48 randomized trials (24 ANTI, 8 EV and 8 AV) all with feedback, and then 40 randomized practice trials without feedback (24 ANTI, 8 EV and 8 AV). Prior to the experimental trials, participants could repeat the last practice block if they thought it was necessary. The experimental task consisted of six blocks of 80 randomized trials (48 ANTI, 16 EV, and 16 AV), with no breaks or feedback.

2.4. Propensity-score matching

In addition to the inclusion criteria, we also controlled for confounds by matching groups on several variables that are well-known for exerting an influence on cognitive performance (Park & Reuter-Lorenz, 2009; Reuter-Lorenz & Park, 2014). Note that the traditional use of covariates may be too stringent, as the covariate and the independent variable are frequently related, meaning that they could share part of the explained variance (Anderson et al., 2018). Therefore, we made use of an alternative approach that has been proposed in non-randomized studies: propensity-score matching (Adelson, 2013). This approach uses logistic regression to predict group membership probability (propensity score) based on several characteristics (or confounds) and permits the matching of participants from one group to the other. Thus, this method allows using a rich and complete model of background variables and considers multivariate interactions among confounds. This method has been successfully used with a sample of around 60 participants in the cognitive reserve field, smaller than our sample size (Anderson et al., 2018).

Thus, we used propensity-score matching to generate similar groups considering multiple relevant background characteristics such as age, sex, education level, lifelong tobacco consumption, physical exercise, bilingualism, second language use, involvement in cognitively stimulating activities, and video game playing. We used the *MatchIt* R package (Ho et al., 2010) to perform the analysis.

Musicians and non-musicians differed in several variables previous to matching (**Table 2**), but not after propensity-score matching. The resulting sample included 49 musicians and 49 non-musicians (**Figure 2**). The results indicated no significant difference between matched groups in any of the confounding variables, as shown in **Table 2**.

Table 2. Confounding variables in both groups, before and after propensity-score matching. Significant differences ($p < .05$) are indicated by *, while trends ($.05 \leq p \leq .1$) are indicated by †.

	Unmatched						Matched				
	Musicians (n = 52)		Non-musicians (n = 65)				Musicians (n = 49)		Non-musicians (n = 49)		
	M	SD	M	SD	Statistic	p	M	SD	M	SD	Statistic
Age	**23.73**	**3.70**	**22.03**	**3.85**	***U* = 1188.5**	**.006***	23.25	3.19	22.59	4.05	U = 101
Sex (n Males)	21		15		χ^2 (c.c.) = 3.291	.070†	18		13		χ^2 (c.c.)
Handedness (n left-handed; n ambidextrous)	3; 4		9; 1		χ^2 = 4.410	.110	2; 2		8; 1		χ^2 = 4.22
Nationality (n Spanish)	46		57		χ^2 (c.c.) = 0	1	4		7		χ^2 (c.c.)
Education	**4.08**	**0.79**	**3.74**	**0.82**	***U* = 1297**	**.022***	4.06	0.80	3.90	0.82	U = 105
General tobacco	0.39	0.84	0.23	0.55	U = 1598	.473	0.22	0.55	0.22	0.47	U = 117
Actual tobacco	0.17	0.62	0.20	0.54	U = 1598	.387	0.1	0.47	0.18	0.44	U = 108
Physical exercise	62.20	35.15	50.19	32.51	U = 1348	.061†	61.70	35.93	51.63	33.61	U = 100
Bilingualism (n bilingual)	23		17		χ^2 (c.c.) = 3.431	.064†	20		16		χ^2 (c.c.)
L2 use	**2.87**	**1.63**	**1.95**	**1.63**	***U* = 1159**	**.003***	2.76	1.61	2.27	1.71	U = 995.
L2 age of onset	7.22	5.30	6.67	5.16	U = 1200.5	.210	7.44	5.36	6.81	5.70	U = 843
Cognitive activities	6.87	3.62	5.57	3.07	U = 1339.5	.053†	6.78	3.68	6.06	3.15	U = 107
Video games	0.73	1.09	1.14	1.49	U = 1451	.149	0.74	1.10	0.84	1.30	U = 117

L2 = second language; (c.c.) = continuity correction. M = average; SD = standard deviation.

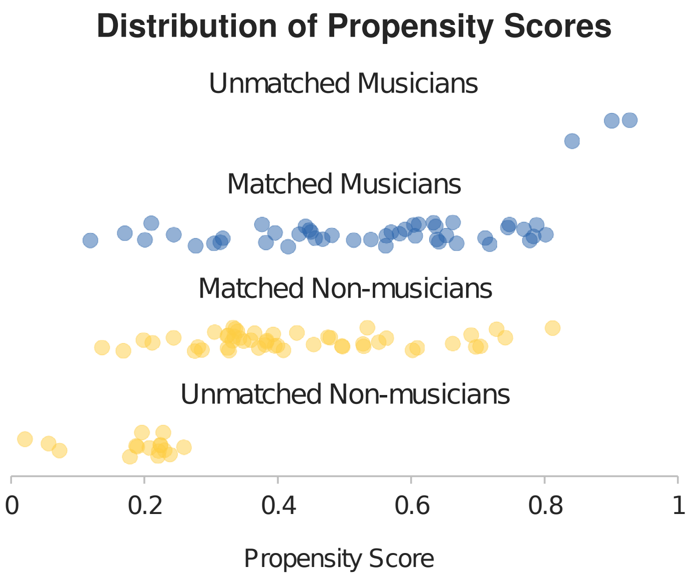

Figure 2. Distribution of Propensity Scores. Groups were matched in nine variables: age, sex, education, lifelong tobacco consumption, physical exercise, bilingualism, second language use, involvement in cognitively stimulating activities, and video game playing.

2.5. Data analysis

Behavioral data were analyzed as in Luna et al. (2018), and according to our preregistered analysis plan (https://osf.io/hzc6m), conducting separate tests for ANTI, EV, and AV trials. Participants who did not finish the task but reached at least the 5th block were also included (15 participants; 15.31% of the total) in the analyses of the ANTI trials, as we had observed in previous studies that four blocks (20 minutes approx.) are enough to measure the three attentional networks[1]. For RT analyses of

[1] Note that these 15 participants were not included in the analysis of vigilance decrements (both EV and AV) because the analyses included time (6 blocks) as a factor. Additionally, however, the same analyses were repeated with the whole sample but using only the first four blocks, in order to confirm the results without loss of statistical power. Note that we also observed in previous studies that 4 blocks are enough to observe the vigilance (EV and AV) decrement phenomenon.

the ANTI measures, trials with incorrect responses (4.71%), RTs smaller than 200 ms or RTs higher than 1500 ms (0.53%) were excluded.

Parametric assumptions of normality, homoscedasticity, and sphericity were tested with Shapiro-Wilk, Levene's, and Mauchly's tests, respectively. We used a Student's *t*-test when parametric assumptions were accomplished, or (alternatively) the non-parametric Mann-Whitney *U* test, for comparisons in a single dependent variable. For ANTI trials, mixed ANOVAs that included musicianship (musicians/non-musicians) as a between-participants factor, and alerting (no tone/tone), orienting (invalid/no cue/valid), and congruency (congruent/incongruent) as within-participants factors were used for both mean RTs and percentage of errors. Further analyses were conducted with attentional networks indexes, calculated according to the following formulas: *Alerting index = RT no tone – RT tone (only with no spatial cue trials)*; *Orienting index = RT invalid – RT valid*; and *Congruency index = RT incongruent – RT congruent.* Like in Jentzsch et al., (2014), Gratton and post-error effects were calculated as RT subtractions: *Gratton effect = RT congruency effect in trials after congruent conditions – RT congruency effect in trials after incongruent conditions*; *post-error slowing = RT post-error trials – RT post-correct trials*.

For EV trials, we used mixed ANOVAs or their non-parametric alternative two-way rank test (F1-LD-F1 model; Brunner et al., 2002; *nparLD* R package; Noguchi, Gel, Brunner & Konietschke, 2012), with musicianship (musicians/non-musicians) as between-participants factor and time (6 blocks) as a within-participants factor, for each dependent variable: mean RT, *A'* (discriminability), and *B"* (response bias). The same was applied for AV trials, with the dependent variables mean RT, SD of RT, and percentage of lapsus (lapsus were defined as the percentage of AV trials without response or with RT higher than 600 ms; Luna et al., 2018).

Finally, we explored the relationship between significant behavioral outcomes and musical variables (i.e., lifelong musical training, age of onset, and years of formal training) in the groups of expert and intermediate musicians (excluding non-musicians). For this purpose, we conducted multiple Pearson correlations or the non-parametric Kendall rank correlation. The *p*-values were corrected for multiple correlations with the Benjamini-Hochberg procedure (Benjamini & Hochberg, 1995).

3. Results

3.1. ANTI trials: Phasic alertness, Orienting, and Executive Control

Mixed ANOVAs revealed the main effects usually reported with the ANT (Fan et al., 2002) and ANTI (Callejas et al., 2004) tasks. Thus, responses were faster in the tone than in the no-tone trials, $F_{(1,96)} = 152.89$, $p < .001$, $\eta^2_p = .614$, in valid as compared to invalid trials, $F_{(2,192)} = 162.69$, $p < .001$, $\eta^2_p = .629$, and in congruent as compared to incongruent trials, $F_{(1,96)} = 222.11$, $p < .001$, $\eta^2_p = .698$. In addition, the usual two-way interactions were also observed: alerting × orienting, $F_{(2,192)} = 21.60$, $p < .001$, $\eta^2_p = .184$, alerting × congruency, $F_{(1,96)} = 19.50$, $p < .001$, $\eta^2_p = .169$, and orienting × congruency, $F_{(2,192)} = 9.03$, $p < .001$, $\eta^2_p = .086$. These results are in line with the classic effects of alerting, orienting, and executive control used as measures of the three attentional networks and their interactions (Callejas et al, 2004).

Regarding between-group differences, a one-tailed *t*-test revealed faster responses in ANTI trials for musicians than for non-musicians, $t(96) = 2.07$, $p = .021$, $d = 0.418$ (see **Figure 3a** and **Table 3**). Furthermore, the alerting x musicianship interaction was significant, $F_{(1,96)} = 6.29$, $p = .014$, $\eta^2_p = .061$, as musicians showed a smaller alerting effect as compared to non-musicians, $t(96) = 2.20$, $p = .030$, $d = 0.445$. On the contrary, there were no between-groups differences in the rest of indices (all *p*s > .05; **Figure 3b**).

Table 3. Main ANTI, EV and AV outcomes. Significant differences (p < .05) are indicated by *, while trends (.05 ≤ p ≤ .1) are indicated by †.

		Musicians (n = 49)		Non-musicians (n = 49)				
		M (SD)	Md	M (SD)	Md	Statistic	*p*	Effect
ANTI outcomes								
Mean RT		620.51 (73.58)	617.2	659.32 (108.66)	644.4	(one-tailed) t = 2.07	.021*	0.41
Alerting Index	RT	32.17 (34.65)	30.08	46.71 (30.63)	50.39	t = 2.20	.030*	0.44
Orienting Index	RT	43.98 (21.39)	41.51	40.87 (23.69)	45.49	t = -0.68	.496	-0.1
Congruency Index	RT	39.58 (25.53)	39.84	44.72 (30.50)	44.72	(one-tailed) U = 1052	.147	0.12
Gratton effect	RT	6.54 (35.05)	10.51	12.35 (39.85)	6.63	(one-tailed) t = 0.77	.223	0.15
Post-error slowing		47.85 (39.98)	40.49	39.17 (37.19)	27.36	U = 953	.079†	-0.2
EV outcomes								
Mean RT		729.8 (82.33)	724	772.4 (92.15)	777.7	(one-tailed) t = 2.41	.009*	0.48
A' slope		-0.0004 (0.011)	-0.003	-0.004 (0.010)	-0.006	(one-tailed) t = -1.69	.048*	-0.4
B''		0.41 (0.48)	0.54	0.52 (0.38)	0.64	(one-tailed) U = 1068	0.11	0.11
AV outcomes								
Mean RT		493.5 (53.67)	494.4	529.1 (65.53)	522.4	(one-tailed) U = 831	.004*	0.3
Standard deviation		81.99 (31.97)	74.84	92.25 (31.73)	87.63	(one-tailed) U = 911	.020*	0.24
% of lapsus		10.90 (13.60)	6.25	18.76 (18.55)	14.58	(one-tailed) U = 811	.003*	0.32

[a] Effect sizes were estimated with Cohen's d for t-tests and rank-biserial correlation for Mann-Whitney U tests.

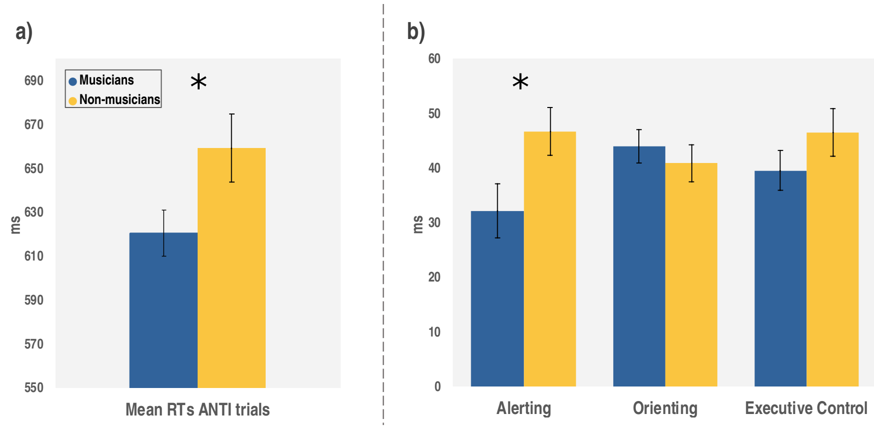

Figure 3. (a) Mean RTs in ANTI trials and (b) attentional network indeces. Musicians showed lower overall RTs and a smaller alerting index than non-musicians. Significant differences (p < .05) are indicated by *. Error bars represent standard errors of the means.

3.2. Executive vigilance trials

There was a main effect of musicianship for RTs, $F_{(1,80)} = 11.22$, $p = .001$, $\eta^2_p = .123$, as musicians were faster than non-musicians. However, neither the main effect of block nor the two-way interaction between musicianship and block was significant (*F*s < 1).

Moreover, a significant decrement across blocks was observed on *A'*, F1-LD-F1 test: ATS = 2.89, $p = .014$, and a significant block × musicianship interaction, ATS = 2.50, $p = .031$. With no differences at baseline, $U = 695$, $p = .137$, $r_B = .19$, the trends in discriminability were clearly different for the two groups, as shown in **Figure 4c**. Whereas *A'* for non-musicians tended to decline across blocks, musicians did not show such a decrease in *A'*. There was only one significant main effect of block for *B"* (F1-LD-F1 test: ATS = 3.34, $p = .007$); with both groups of participants becoming more conservative across blocks. Note that these results did not substantially change using the whole sample but considering only the first 4 blocks of trials (**Appendix B**).

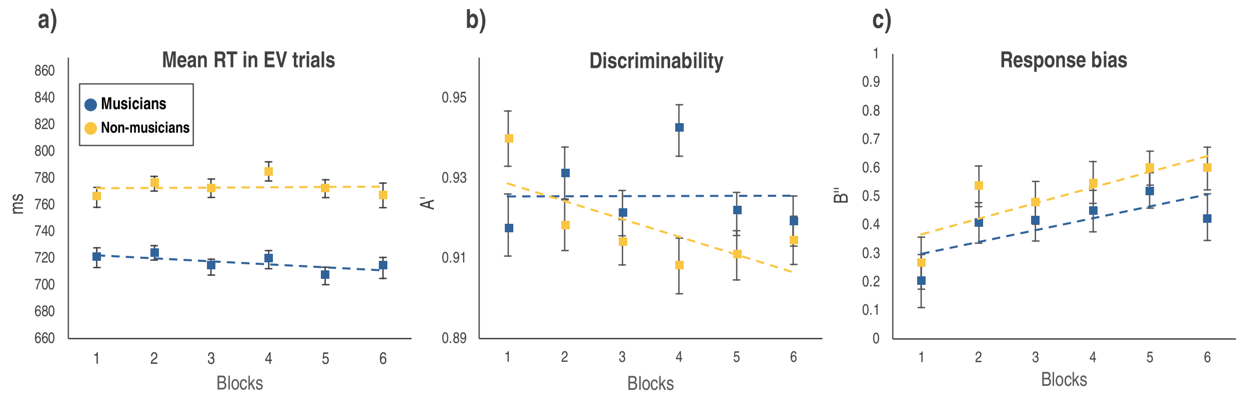

Figure 4. Executive vigilance outcomes in both groups, musicians (in blue) and non-musicians (yellow). Musicians showed smaller overall mean RTs than non-musicians (a) and no decrement in discriminability across blocks (b). On the other hand, both groups showed a similar change in the response bias, becoming more conservative over time (c). Error bars represent standard errors of the means, with between-participants variance removed using Cousineau-Morey method (Morey, 2008).

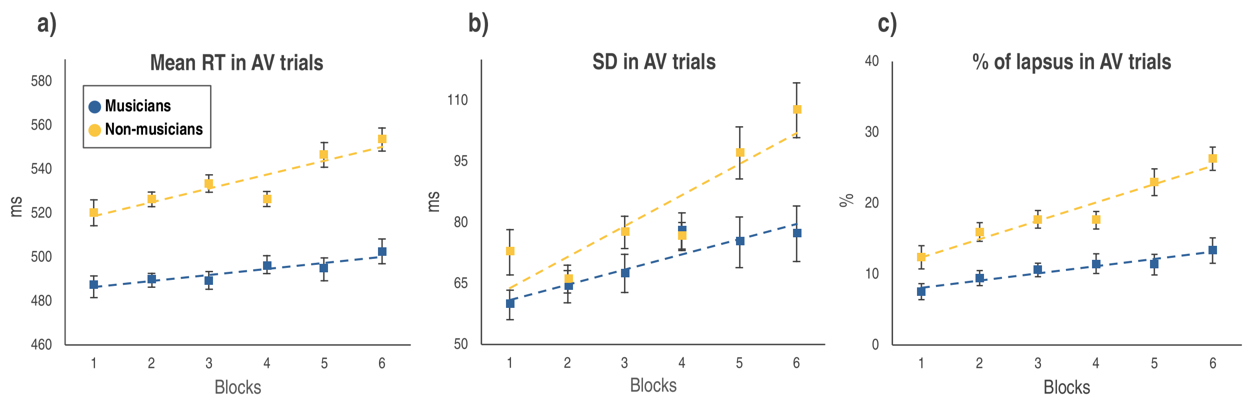

Figure 5. Arousal vigilance outcomes in both groups, musicians (in blue) and non-musicians (yellow). Musicians showed overall faster responses (a), smaller SD in RTs (b), and higher proportion of lapsus than non-musicians (c). Error bars represent standard errors of the means, with between-participants variance removed using Cousineau-Morey method (Morey, 2008).

3.3. Arousal vigilance trials

In AV trials, the main effects of musicianship, F1-LD-F1 test: ATS = 6.63, $p = .010$, and block, ATS = 6.84, $p < .001$, were significant for RTs, with musicians showing overall faster responses than non-musicians and RTs tending to become slower over time-on-task (**Figure 5a**).

SD analyses also revealed significant main effects of musicianship, F1-LD-F1 test: ATS = 19.38, $p < .001$, and block, ATS = 8.60, $p < .001$, with less variable RT for musicians than for no-musicians and a linear increase across blocks (**Figure 5b**). Results were similar for the percentage of lapsus, which showed effects of musicianship, F1-LD-F1 test: ATS = 7.54, $p = .006$, and block, ATS = 10.49, $p < .001$. Overall, musicians showed fewer lapsus than non-musicians and the proportion of lapsus increased progressively across blocks in both groups (**Figure 5c**). A larger AV decrement for non-musicians than for musicians was apparent, as can be observed in **Figure 5**, although with no variable the two-way interaction reached statistical significance (ATSs < 1). Again, note that the results did not change substantially using the whole sample and analyzing until the 4th block (**Appendix B**).

3.4. Gratton and post-error effects

Although our data were numerically in line with the results of Jentzsch et al. (2014), we did not find a significant difference between groups in the Gratton effect ($t < 1$). However, one-sample *t*-tests showed that the Gratton effect did not differ statistically from zero for musicians, $t(48) = 1.31$, $p = .198$, $d = 0.187$, but did so for non-musicians, $t(48) = 2.17$, $p = .035$, $d = 0.310$. On the other hand, we found a trend in post-error slowing, $U = 953$, $p = .079$, $r_B = -.21$, with a higher effect for musicians than for non-musicians.

3.5. Relationship between cognitive outcomes and musical characteristics

To assess the relationship between musical training and cognitive improvements, we computed Kendall rank correlations with musical characteristics (excluding non-musicians group) such as years of practice, age of onset, years of lessons, and those outcomes that showed a between-group difference (overall mean RT in ANTI, EV, and AV trials; Alerting effect; *A'* slope in EV trials; mean SD and % of lapsus in AV trials). Note that in this analysis data from intermediate musicians were considered in order to have a wider range of values in musical variables. Three correlations were significant prior to correcting for multiple comparisons: years of practice–percentage of lapsus in AV trials, Kendall's $\tau = -.22$, $p_{\text{uncorrected}} = .008$; years of lessons–percentage of lapsus in AV trials, Kendall's $\tau = -.22$, $p_{\text{uncorrected}} = .010$; and years of lessons–Alerting effect, Kendall's $\tau = -.18$, $p_{\text{uncorrected}} = .042$. None of these correlations remained significant after Benjamini-Hochberg correction though. As we mentioned in the Methods section, our design was underpowered for correlational analyses with small-to-medium effects such as the previous ones. Future studies with larger samples are required to establish firmer conclusions.

4. Discussion

The present study investigated the relationship between musicianship and multiple aspects of attention (i.e., the three attentional networks, and the executive and arousal components of vigilance). A relevant contribution of this preregistered study is that assessment was carried out in a large sample of participants divided into two well-matched groups of expert musicians and non-musicians (giving an a priori statistical power of at least .80), and with extensive control of confounds (more than ten influential variables). With that design, advantages in both processing speed and the two components of vigilance were associated with musical training, whereas we did not find any association between musicianship and attentional orienting or executive control. Moreover, there was a significant relationship with phasic alertness, in which musicians showed a smaller phasic alertness effect than non-musicians.

Advantages in vigilance related to musicianship

Consistent with our hypothesis, the sample of musicians outperformed non-musicians in almost all the outcomes of both executive and arousal vigilance, with evidence of a reduced executive vigilance decrement over time-on-task (i.e., no EV decrement on discriminability). Therefore, expert musicians exhibited superior ability for sustaining attention over time, both in conditions that involves high demands on change monitoring, switching, and decision making for the selection of an appropriate response (EV conditions), as well as in tasks with low demands on response and perceptual selection and which depend more on the general level of alertness (such as the influence of the sleep-wake cycle; AV conditions).

In particular, musical training usually involves prolonged performances (in concerts as well as rehearsals) and the detection of stimuli needing a response. For example, classical musicians have to play continuously for more than an hour in the interpretation of symphonies or operas, while conductor movements (among other relevant stimuli) express crucial changes in rhythm, volume, or the beginning of a melody, which the orchestra must consider to accomplish a synchronized performance. Thus, one explanation for the pattern of results observed here could be that the high vigilance demands of musical performance may constitute effective training for other future tasks that require vigilance. In parallel, it might produce changes in the neural systems which underpin vigilance. However, this type of explanation, conceiving the improvements as a consequence of the use and the demands on certain cognitive processes, has been considered rather simplistic. It has been claimed to evoke a "brain as a muscle" metaphor which fails to give a complete explanation of why cognitive training programs have, in many cases, little benefit in real-life activities (Gathercole, Dunning, Holmes, & Norris, 2019; Roediger III, 2013; Simons et al., 2016; Taatgen, 2013), and offers a partial (or even incorrect) picture of the effect of training.

Alternatively, learning to play and playing an instrument are demanding tasks that would lead to the development of new complex cognitive skills or strategies, which could be applied to different activities, not necessarily musical (Gathercole et al., 2019). It could explain how musicians showed better performance in a task that is quite different from those that are part of musical training. This interpretation is in line with the assumption that musical training, besides improving musical-related skills, transfers its benefits to distant tasks such as long-term memory and working memory (Talamini et al., 2017), and visuospatial abilities (Sluming et al., 2007). For example, Huang et al. (2010) found visual cortex activation during verbal memory retrieval in musicians, but not in participants without systematic musical training, who also showed lower recall. The activity of visual areas in the retrieval of verbal information could be related to the use of singular strategies to accomplish the task, such as visual imagery. Jakobson and colleagues (Jakobson et al., 2008) also showed that adult musicians exhibited greater use of semantic clustering than non-musicians during the learning of a word list, and this encoding strategy was associated with better recall.

Nevertheless, it is important to highlight that our correlational design does not allow us to determine whether the observed cognitive advantages associated with musicianship are a consequence of musical training, or rather the cognitive advantages preceded training. There exists the possibility that high-functioning individuals are more likely to keep attending music lessons (Corrigall et al., 2013), supporting pre-existing advantages. Previous evidence already pointed out that there are cognitive and personality differences in people who follow musical training (Corrigall et al., 2013; Swaminathan et al., 2015). Alternatively to either *nurture* or *nature* explanations, a *nature and nurture* approach (Wan & Schlaug, 2010) seems more plausible. Accordingly, expert musicians might tend to have inherent advantages that would facilitate their acquisition of musical skills and continuous training, along with the fact that long-term involvements in that complex activity could also produce several neural and cognitive changes that could underlie the observed cognitive advantages. Thus, although musical training might have a neurocognitive impact on any individual who undertakes it, certain backgrounds could increase the probability to select it as a lifestyle. Other variables such as personality, sociodemographic background, or other lifestyles (Corrigall et al., 2013) could be highly related to musical training. Although we tried to reduce the selection bias by controlling for a large number of lifestyle and influential cofounds, future studies with experimental and longitudinal designs are necessary to better understand the causal relationship between musical training and cognitive differences (for an example of a longitudinal study with children from underserved communities, see Sachs et al., 2017).

Other cognitive results related to musicianship

In addition to the previous results, we also found overall faster RTs for musicians than non-musicians, indicating faster processing speed in that sample. In this vein, previous studies (Chang et al., 2014; Hughes & Franz, 2007; Landry & Champoux, 2017) have shown similar results with simple psychomotor tasks, wherein participants have to rapidly detect a certain stimulus. Thus, musical training might enhance multisensory and sensorimotor integration, as musical performance involves strong associations between multiple sensory inputs, as well as coupling of visual stimuli (e.g., notes on the staff) and motor commands (Landry &

Champoux, 2017). To the best of our knowledge, the only study that has used the ANT task to assess attention (Medina & Barraza, 2019) also found faster RTs in musicians in comparison with their non-musicians counterparts. Moreover, processing speed is a key cognitive resource that has been associated with whole-brain white matter volume (Magistro et al., 2015) and its structural integrity (Deary et al., 2004; Penke et al., 2010). Coherently, some evidence has indicated greater volume and integrity of white matter in several brain areas for musicians than for non-musicians (see Bengtsson et al., 2005; Halwani et al., 2011; Steele et al., 2013), as well as in longitudinal designs (Habibi et al., 2018).

Critically, we observed a difference in phasic alertness between musicians and non-musicians as a result of a smaller phasic alertness effect in expert musicians. We suggest that That difference, however, has to be considered in the context of an optimal state of vigilance in musicians, and a smaller effect does not have to mean worse phasic alertness functioning. In the same way, the opposite effect (i.e., larger phasic alertness effect in a group with reduced vigilance) has been observed in people suffering from fibromyalgia (Miró et al., 2011), and in participants with reduced vigilance after a night of no sleep (Roca et al., 2012). Interestingly, Medina and Barraza (2019) found no difference in phasic alertness with the ANT, which uses a visual stimulus instead of an auditory warning. Furthermore, the duration of the task in that study was half that of the ANTI-Vea in the present study (~20 min. vs. ~45 min., respectively), at the same time that the demands on executive vigilance in the ANT are lower, with a single task (i.e., flanker task) instead of three simultaneous tasks. This could explain the differences between studies. It is also important to note that musical instruction implies intensive training with tones. Therefore, we could expect that musicians took more advantage of auditory alerting signals and showed faster responses than in the absence of that type of warning (see the results in Strait et al., 2010). However, the opposite effect was observed with a smaller alerting effect in musicians, which therefore rather seems to indicate that the group of non-musicians benefited from warning signals during the task more than musicians, who likely could be more vigilant across the whole time-on-task.

Moreover, we did not find advantages for orienting or executive control associated with musicianship. The absence of difference in exogenous orienting in our data is in accordance with prior results (Lim & Sinnett, 2011; Medina & Barraza, 2019). Note that the larger sample of participants used in our study lends confidence that the lack of between-group differences in orienting was not a consequence of insufficient power. Finally, the differences in executive control did not reach statistical significance in our sample, although we also observed a smaller congruency effect measure (i.e., better performance) for musicians than for non-musicians. Improved executive control associated with musical training is a common result in studies that compare adult musicians with non-musicians (Bialystok & DePape, 2009; Jentzsch et al., 2014; Travis et al., 2011), as well as in studies of musical training with older participants (Román-Caballero et al., 2018). A possible explanation for this result is that previous studies may not have successfully controlled for the influence of some confounds, especially the impact of other stimulating activities, which in some cases may have inflated the effects related to musicianship (Cohen's d = 1.51 in Medina & Barraza, 2019; vs. d = 0.25 for the between-groups differences in the congruency index of the current study). A similar result was observed in a study by Slevc, Davey, Buschkuehl & Jaeggi (2016), in which musical ability was not related to executive control after controlling for relevant confounds, such as socioeconomic status or bilingualism. Moreover, it is also worth noting that the samples in our study were composed of adults with a high education level and, in general, healthy lifestyles (with overall low tobacco consumption, and a moderate-to-high involvement in physical and cognitively stimulating activities). Thus, the impact of musical training on executive control may be limited in this scenario, whereas it would have a wider window of action in other samples with less favorable characteristics. Again, it is speculatively possible that the differences in executive control previously observed correspond (totally or partially) to pre-existing advantages in musicians (Swaminathan et al., 2015), not finding that result due to the selection of a control group with favorable background characteristics that might also influence their cognitive functioning. Future studies should continue investigating the possible benefit to executive control produced by musical training, ensuring extensive control in experimental designs, and perhaps also exploring other samples (e.g., with a low level of education or low socioeconomic status; Arenaza-Urquijo et al., 2013; Hackman & Farah, 2009).

5. Conclusions

Playing a musical instrument is a complex cognitive activity that has been linked to advantages in particular components of attention. In comparison to a well-matched group of non-musicians, we found advantages in two components of vigilance in expert musicians, which suggests a greater capacity for endogenously sustaining high preparation levels over time-on-task. Additionally, a previously observed benefit of musical training on executive control was not observed as significant in our study; a finding that may be related to limitations in control of selection bias in many correlational studies or pre-existing differences between expert musicians and non-musicians. More research is needed, especially from experimental paradigms that examine the causal role of musical training in superior cognitive and attentional function in musicians. Thus, one possible explanation for our findings is that musical training may to some extent transfer to enhance cognitive performance in extra-musical contexts.

Preregister, data and materials availability

The design of this study was preregistered before carrying out any statistical analysis (available on https://osf.io/hzc6m; correction: https://osf.io/mb8r7). Also, raw behavioral data and scripts are fully available on https://osf.io/ktd2q. Finally, the web version of the ANTI-Vea task is accessible from https://www.ugr.es/~neurocog/ANTI/; and the questionnaire used to assess confounding and musical variables is in Appendix A.

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Compliance with ethical standards

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- **Conflict of Interest:** Authors declare no conflict of interest.
- **Ethical approval:** All procedures performed in studies involving human participants were in accordance with the ethical guidelines laid down by the University of Granada, under the ethical standards of the 1964 Declaration of Helsinki (last update: Seoul, 2008), and was part of a larger research project (PSI2017-84926-P) approved by the University of Granada Ethical Committee

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- **Informed consent:** Informed consent was obtained from all individual participants included in the study.

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Appendix A4

Román-Caballero, R., Martín-Arévalo, E., & Lupiáñez, J. (2023). Changes in response criterion and lapse rate as general mechanisms of vigilance decrement: Commentary on McCarley and Yamani (2021). *Psychological Science, 34*(1), 132–136.

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Changes in response criterion and lapse rate as general mechanisms of vigilance decrement: Commentary on McCarley & Yamani, 2021

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Abstract

Multiple theories have used perceptual sensitivity and response criterion indices to explain the decrements in performance across time-on-task (i.e., vigilance decrement). A recent study by McCarley and Yamani offered conceptual and methodological advances to this debate by using a vigilance task that parametrically manipulates noise and signal and analyzes the outcomes with psychometric curves. In the present commentary, we reanalyze data (*n* = 553) from an already existing different vigilance task, the Attentional Networks Test for Interactions and Vigilance − executive and arousal components (ANTI-Vea; Luna et al., 2018). Psychometric curves with the ANTI-Vea showed robust changes in response criterion and lapse rate, although not in sensitivity. We interpret that the need to keep in memory the standard in McCarley and Yamani's task could produce a decrease in sensitivity and be related to reduced fidelity of the memory representation rather than to a decrement in perceptual abilities across time-on-task.

Statement of Relevance

Decrement in performance in sustained-attention tasks is a ubiquitous phenomenon (i.e., vigilance decrement). In the debate about whether it is produced by depletion of attentional resources or by a reallocation of the resources from primary task toward internal thoughts, the outcomes in the sensitivity parameter from signal-noise discrimination models such as the signal detection theory (SDT) have become crucial evidence. Our analysis with a new vigilance task, the ANTI-Vea, and comparing our results with those obtained by McCarley and Yamani showed that vigilance decrement could be measured across tasks mainly as increases in response criterion and lapse rate, but not always as changes in sensitivity. When a sensitivity change is observed, as in McCarley and Yamani, it might instead indicate reduced fidelity of the memory representation of the standard rather than truly reduced perceptual sensitivity. Therefore, whereas psychometric curves improve the analysis of vigilance tasks, they do not support the idea of a loss in perceptual ability regardless of the type of task.

Sustaining attention over long periods of time is a demanding activity, especially when attention is deployed to detect a rare event in a monotonous situation, where people's performance decreases with time on task (i.e., vigilance decrement). Multiple accounts have based their hypotheses about the nature of vigilance decrement on the two main indices of signal detection theory (SDT): *d'* and β. The SDT framework conceptualizes the observer's ability to differentiate signal from noise (d' or observer's sensitivity) and the internal decision-making process of the observer to give a response (β or response criterion). In this context, whether or not a progressive decline in sensitivity is observed due to a loss in the ability to distinguish the target from non-targets has become crucial to disentangle the different explanations. Although hits (i.e., responding 'signal' to signal) tend to decrease across time, the frequent use of clearly distinct signal and noise stimuli (such as digit 3 being signal and any other digit being noise) leads to a floor effect in false alarms (FAs; responding 'signal' to noise) that often prevent observing changes in the response criterion. Thomson et al. (2016) addressed this problem by adding noise stimuli with a more overlapping representation with the target (i.e., lures) and restricting the SDT analyses to those similar-to-signal noise stimuli. When solving the problem of a floor effect in FAs, their approach successfully revealed a temporal shift in response bias (becoming more conservative across time) without any loss of sensitivity.

However, as the similarity between noise and signal is typically not manipulated parametrically, it is not possible to characterize with these paradigms the nature of FAs and misses; that is, whether a FA is made because the noise is perceived as very similar to the signal or because the same perceptual evidence from the noise is categorized as signal due to a criterion shift or an attentional lapse. The same logic can be applied to misses. Thus, we value the critical methodological contribution by McCarley and Yamani (2021) by using continuous distributions of signal and noise instead of binary stimuli. With such an approach, errors made due to perceptual difficulty would be more frequent the more like the signal is the noise, while errors due to attentional disengagement would be the same, no matter the perceptual signal-noise similarity.

At the analytic level, McCarley and Yamani proposed a new psychometric-curve analysis (see panel A in the **Figure**) that offers three instead of two potential indices of the vigilance decrement: *scale*, associated with sensitivity; *shift*, related to response criterion; and *lapse rate*, proposed as an index of task disengagement or mind wandering. With the addition of the lapse rate, the analysis allows distinguishing between changes in FAs and hits that are generalized to any stimulus in the distribution of signal and noise (even in cases wherein the stimulus category is evident), corresponding with lapse rate; and changes that are specific for near-threshold stimuli, therefore primarily affecting the sensitivity parameter.

Psychometric curve in a different task

Here, we reproduced McCarley and Yamani's psychometric-curve analysis with their data and with the general database of a vigilance task recently developed by our research group: the ANTI-Vea (Luna et al., 2018). With the ANTI-Vea, we observed changes in response criterion and lapse rate but not in the sensitivity parameter. Therefore, their critical finding of a vigilance effect on sensitivity (see panel A in the **Figure**) could be due to their task's particular characteristics rather than the analysis method.

Method

As McCarley and Yamani's task, the ANTI-Vea is a non-binary vigilance task that makes it suitable for psychometric curves (see Luna et al., 2018, for task details). In most trials (80%), a central arrow is presented flanked by two arrows on each side. In some of these trials (20%; signal), the central arrow presents a substantial displacement along the vertical axis (8 pixels), and participants are instructed to detect these infrequent signal trials by pressing the space bar. In the remaining frequent trials (60%; noise), the five arrows are aligned (although with some noise, ± 2 pixels from the midline, so that the maximum displacement among adjacent arrows, including the central arrow and its closest flankers, is 4 pixels), and participants do not have to press the space bar (they instead have to discriminate the target direction while ignoring adjacent flanker arrows). Those trials constitute the signal and noise trials of an executive vigilance (EV) task, as in McCarley and Yamani (2021). In an additional 20% of the trials, a red down counter appears, which participants must stop by pressing

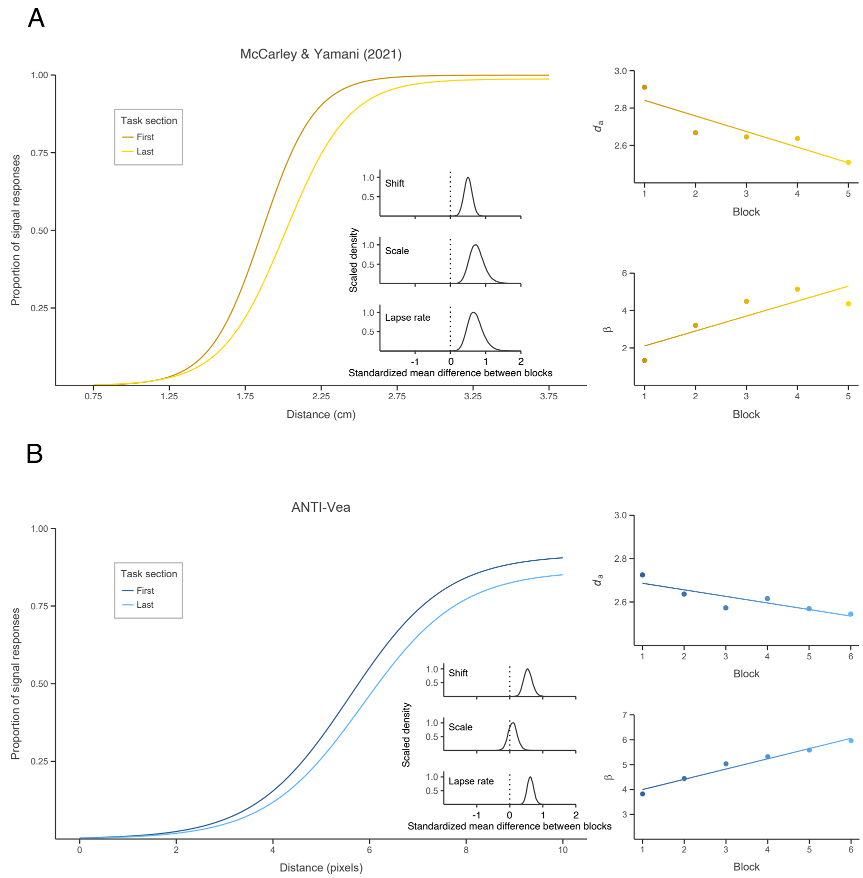

Figure. Psychometric curve for the first and last sections of the task fitted with McCarley and Yamani's task (panel A), and with the ANTI-Vea (panel B). Note the changes in the height of the positive asymptote and the horizontal shift of the curve in both tasks, confirmed by the posterior distribution of standardized mean differences in lapse rate and shift between the first and the last sections of the tasks. In contrast, there was a change in scale only in McCarley and Yamani's task. In the ANTI-Vea, whereas the increase in response criterion with the SDT approach (β) was replicated in the bias parameter of the psychometric curve, the decrement in the SDT sensitivity parameter (d_a) was absent after taking into account the lapse in the model. The results with SDT (d_a and β) are presented on the right side of each panel.

any key. These trials are included to measure another component of vigilance (arousal vigilance; see Luna et al., 2018).

We used data from participants who performed the task in a laboratory context (n = 313) and from others who performed an online version at home (n = 303; https://osf.io/8v6u9/). There were six blocks without any rest between them, with 80 trials each one (approx. 40 min including practice trials). As described above, all arrows, flankers, and targets were vertically displaced with a ± 2 pixels random variability. In signal trials, the central target was displaced 8 pixels up or down. Therefore, noise trials comprise distances between the target and the two most proximal flankers from 0 to 4 pixels, while signal trials involve target–flanker distances from 6 to 10 pixels.

We conducted the original psychometric-curve analysis in McCarley and Yamani in the database of the ANTI-Vea, and, for a comparative purpose, the SDT indices, d_a and β. We used a log-linear transformation of hits and FAs in the SDT analyses to avoid extreme rate values (0 and 1; Verde et al., 2006)[1].

Results

To avoid the influence of those participants that misunderstood the instructions or did not perform the task successfully, we excluded participants with accuracies below three or more standard deviations in noise and signal trials, participants with three or more standard deviations in the number of no responses, and those who minimized the task screen in

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[1] We estimated d_a following the formula $d_a = \sqrt{\frac{2}{1 + s^2}} \times [z(H') - sz(F')]$, where s is the ratio of the standard deviations of noise and target, and H' and F' are the log-linear transformations of hit and FA rates given $H' = \frac{N_{\text{hits}} + 0.5}{N_{\text{signal}} + 1}$ and $F' = \frac{N_{\text{FAs}} + 0.5}{N_{\text{noise}} + 1}$. We also used the transformation of hits and FAs (H' and F') for estimating β.

the online version. In total, we analyzed the data of 297 participants with the laboratory version and 256 with the online version (n = 553). The results for both versions were similar. For the sake of simplicity, we only report the overall analysis on the whole sample[2].

Consistently with previous applications of the ANTI-Vea in large samples (Luna et al., 2020; Román-Caballero et al., 2021; $n \geq 92$), we found a decrement in sensitivity across time-on-task with SDT analyses, $t(3071.6) = -7.42$, $p < .0001$, along with an increase in the response bias, $t(3073.3) = 11.30$, $p < .0001$ (panel B in the **Figure**). However, the psychometric-curve analysis showed that the putative decrease in *d'* was due to an increase in the lapse rate rather than a change in sensitivity. Indeed, the parameters that reflected the vigilance decrement in the ANTI-Vea were exclusively the horizontal shift and the lapse rate, as observed in the posterior distributions of standardized mean differences across blocks (shift: standardized mean change of 0.55, 95% BCI [0.31, 0.83]; $BF_{10} > 10^3$; lapse rate: 0.63, 95% BCI [0.44, 0.83]; $BF_{10} > 10^6$; in contrast, scale: 0.09, 95% BCI [−0.17, 0.37]; $BF_{10} = 0.16$).

Response criterion and lapse rate underlie vigilance decrement

The present outcomes suggest that vigilance decrement is robustly associated with a more conservative response criterion and an increase in lapse rate across time. On the other hand, the possibility of a reduction in sensitivity such as the one observed with McCarley and Yamani's task (but

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[2] Both versions of the ANTI-Vea showed clear changes in horizontal shift and the lapse rate. For the online version, we respectively observed standardized mean changes in shift of 0.63, 95% BCI [0.24, 1.15], $BF_{10} = 36.64$, and in lapse rate of 0.56, 95% BCI [0.26, 0.90], $BF_{10} = 170.25$ (in contrast, inconclusive evidence of a change in scale: 0.49, 95% BCI [−0.01, 1.34]; $BF_{10} = 1.50$). For the laboratory version, we respectively observed standardized mean changes in shift of 0.48, 95% BCI [0.19, 0.82], $BF_{10} = 26.44$, and in lapse rate of 0.71, 95% BCI [0.47, 0.97], $BF_{10} > 10^3$ (in contrast, evidence against of a change in scale: −0.21, 95% BCI [−0.69, 0.19]; $BF_{10} = 0.33$). See an additional figure comparing the results of both ANTI-Vea versions on https://osf.io/xbs24/.

not in the ANTI-Vea task) could be specific to the task characteristics. This differential outcome might be explained by the memory demands in McCarley and Yamani's task. In particular, the participants must keep in mind the reference distance (2 cm, the standard) to judge whether the stimulus is a target or not (with an event rate of 40 trials per minute). A decrement in sensitivity is a classic pattern described by Parasuraman in 1979, in what he called *successive discrimination tasks*, which load memory and with a high event rate (30 trials per minute or more). In such paradigms, the decrement in sensitivity would represent the deteriorated fidelity of the reference-magnitude representation stored in working memory rather than a true decrement in perceptual sensitivity. In the same paper, Parasuraman showed no sensitivity decline in tasks without memory demands (e.g., *simultaneous discrimination tasks*), as can indeed be considered the ANTI-Vea: it has a low event rate (15 trials per minute), and executive vigilance trials do not pose memory demands as there is no standard to memorize; participants simply have to detect when the central arrow stands out of the line formed by the other four arrows. Alternatively, another potential factor present in McCarley and Yamani's task that could produce a decline in sensitivity is the perceptual degradation of the target by embedding it in visual noise. Nuechterlein et al. (1983) showed with classic SDT indices that degrading the target could also lead to a decrease in sensitivity across time-on-task. However, no matter whether the decreased sensitivity observed in McCarley and Yamani is due to working memory demands or perceptual noise, the current analysis of the ANTI-Vea data leads to the conclusion that a decrease in perceptual sensitivity is not always observed with the vigilance decrement, even if the data are analyzed with psychometric curves.

In addition, other methodological critical points should be borne in mind. First, McCarley and Yamani focused on the variation in the positive asymptote of the psychometric curve (lapse rate), which they linked to task disengagement, but the same effect can be assessed in the negative asymptote (i.e., guess rate). Even when time on task does not affect the guess rate, leaving free its estimation (instead of assuming a minimum zero value) could lead to different values for the rest of the parameters and their changes across time. Furthermore, it is relevant for parameter fitting to ensure that performance has reached asymptotic levels at the minimum and maximum stimulus magnitudes (i.e., to ensure that both asymptotes are reached; Prins, 2012). As can be observed in the McCarley and Yamani's Figure 3 (left panel), the participants' performance did not show a clear asymptotic level of performance at the minimum distance values (i.e., 0.75 and 1.25 cm). Future applications of the psychometric-curve analysis must bear in mind this aspect in the task design.

In conclusion, the vigilance decrement can be better measured with the psychometric-curve analysis proposed by McCarley and Yamani as a more conservative response criterion (curves horizontally shifted to the right) and higher task disengagement across time (indexed by a decrease in right-asymptote curve values; i.e., decreased correct categorization of the clearest signals). However, taking together our results with McCarley and Yamani's, decreased perceptual sensitivity across time-on-task (curves with a flatter slope) seems unusual in vigilance tasks. It might emerge only in tasks with high memory demands, perhaps due to the decay of the stored representation rather than decreased perceptual sensitivity.

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Appendix A5

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Data and R script for the analyses are available at https://osf.io/y4w89/.

RESEARCH ARTICLE

Musical practice as an enhancer of cognitive function in healthy aging - A systematic review and meta-analysis

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Abstract

Aging is accompanied by cognitive decline, although recent research indicates that the rate of decline depends on multiple lifestyle factors. One of such factors is musical practice, an activity that involves several sensory and motor systems and a wide range of high-level cognitive processes. This paper describes the first systematic review and meta-analysis, to our knowledge, of the impact of musical practice on healthy neurocognitive aging. The inclusion criteria for the review required that studies were empirical works in English or Spanish that they explored the effects of musical practice on older people; they included an assessment of cognitive functions and/or an assessment of brain status; and they included a sample of participants aged 59 years or older with no cognitive impairment or brain damage. This review led to the selection of 13 studies: 9 correlational studies involving older musicians and non-musicians and 4 experimental studies involving short-term musical training programs. The results of the meta-analysis showed cognitive and cerebral benefits of musical practice, both in domain-specific functions (auditory perception) and in other rather domain-general functions. Moreover, these benefits seem to protect cognitive domains that usually decline with aging and boost other domains that do not decline with aging. The origin of these benefits may reside, simultaneously, in the specific training of many of these cognitive functions during musical practice (*specific training mechanism*), in the improvement of compensatory cognitive processes (*specific compensatory mechanism*), and in the preservation of general functions with a global influence on others, such as perceptual capacity, processing speed, inhibition and attention (*general compensatory mechanism*). Therefore, musical practice seems to be a promising tool to reduce the impact of cognitive problems associated to aging.

Introduction

The world's population is currently experiencing a progressive aging process [1]. This demographic change poses new challenges for today's societies, which must address the difficulties of aging (such as age-related neurocognitive decline) and identify the factors that can offer protection against these problems.

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The existence of age-related cognitive and brain decline, which become more marked around the age of 60 [2–4], is well established today. Over the years, many cognitive functions tend to decline, such as processing speed, inhibition, attention, working and episodic memory, semantic fluency, visuospatial and visuoconstructional abilities, and executive functions [2,4–7]. Most of them are part of the construct known as 'fluid cognition' and are considered to experience a progressive decline throughout life beginning in early adulthood [4,7]. By contrast, skills based on the accumulation of knowledge through experience (i.e., 'crystallized cognition'), such as vocabulary or general information, tend to be maintained or even improve with age [4,7].

According to certain models of aging, most age-related differences in cognitive measures are associated with changes in a small group of functions. Specifically, there is evidence supporting the role of sensory capacity [8], processing speed [9] and inhibition [10] as possible mediators of the effects of aging on many other cognitive processes. A decline in sensory capacity seems to affect the early stages of processing, while slower processing seems to lead to incomplete later operations and reduce the amount of information available simultaneously [9]. In fact, processing speed acts as a mediator of many age-sensitive functions [11,12], including functions that involve both fluid and crystallized abilities, such as phonological fluency [13] and naming [14]. Moreover, inhibitory mechanisms seem to be central to the efficiency of working memory, limiting the entry of irrelevant information or rejecting irrelevant information that has gained access [10]. Therefore, inhibition could be important for avoiding distractions and also for speech comprehension, memory and flexibility. Finally, the increased complexity of the tasks used to assess all these functions has been found to affect the performance of older individuals more than that of younger ones (i.e., *complexity effect*) [11]. This effect seems to be mainly due to the decline in high-level processes (e.g., working memory).

In parallel, brain aging involves changes such as the loss of gray and white matter volume [15–18], as well as declines in white matter integrity [19–21]. At the microstructural level, rather than loss of neurons, which is estimated to be low [22], cell shrinkage, loss or regression of dendritic arborization and dendritic spines, and demyelination seem to occur (for a review, see [23]).

However, there is high heterogeneity in cognitive trajectories, as some individuals exhibit cognitive decline while others remain cognitively healthy across older age [24,25]. It appears that age-related cognitive decline is neither inevitable nor irreversible. Some of these differences may be due to protective genetic factors [26]. The concept of 'cognitive reserve' has also been proposed to explain the frequent discrepancy between an individual's degree of brain pathology (or age-related natural decline) and the functional and cognitive deficits observed [27]. Thus, engaging in certain stimulating activities throughout life helps to reduce the impact of brain diseases and cognitive aging. Education, physical exercise, occupation and engagement in intellectually stimulating leisure activities have all been associated with a reduced risk of dementia [28], as well as with neurocognitive benefits [29–32]. Since there is evidence that neurogenesis [33] and plasticity processes [34] still occur in the brain of older adults, it appears that these lifestyle factors may continue to produce benefits during the aging process.

Musical practice, that is, musical training and performance, is one of the activities that is considered to contribute to cognitive reserve. Playing an instrument involves multiple sensory and motor systems and requires a wide variety of higher-level cognitive processes [35]. Musical practice not only involves high sensorimotor integration; it also seems to be an optimal cognitive activity since it involves regular and motivated practice of progressive difficulty, with constantly renewed stimuli and tasks that represent continuous challenges for the individual [36,37]. Accordingly, lifelong musical practice has been associated with a lower risk of dementia and mild cognitive impairment [28], even when the contribution of genetics is controlled for [38]. Moreover, long-term musical practice has also been associated with multiple cognitive advantages in adult musicians. Some of these advantages occur in functions that could be considered specific to skills improved through musical performance (i.e., domain-specific functions), such as a more robust and efficient auditory processing of musical and speech stimuli [39–44]. However, many of the benefits observed extend to more general cognitive functions (i.e., domain-general functions), such as processing speed [45], inhibition [45,46], attention [44,47], episodic memory [48], working memory [48], visuospatial ability [49,50] and language [51,52].

This is accompanied by brain changes, as shown by the increase in gray matter volume in perceptual, somatosensory and motor-related regions, as well as in high-level functions areas [53,54]. Additionally, musicians also exhibit benefits in the white matter, such as in the corpus callosum and the arcuate fasciculus, among others [55,56].

Thus, musical practice may be a potential tool for mitigating both the impact of age-related non-pathological cognitive changes as well as the incidence of dementias. However, to our knowledge, no systematic reviews have been conducted so far in the field of aging. The aim of this research was to conduct a systematic review and meta-analysis in order to compile the most relevant data to date and draw the first conclusions on the impact of musical practice on cognitive and cerebral aging.

To this end, we decided to include studies with both an experimental and correlational design, given their complementarity: experimental methodology involves randomization and thus allows causal relationships to be established; by contrast, correlational designs offer the possibility of analyzing samples with a higher and more extensive level of musical practice over longer periods of time. Unfortunately, few experimental studies exist on this subject. However, these designs provide crucial evidence to clarify issues that are not clearly explained by correlational designs (i.e., whether cognitive improvements are due to practice or, conversely, a better cognitive status leads to a greater involvement in this activity). In addition, experimental studies are also interesting in themselves, as they can elucidate whether a late onset of the activity still provides neurocognitive benefits.

Methods

Literature search

A systematic review was conducted following the recommendations of PRISMA (see S1 Table and [57]). As a first step, we consulted the Ovid, ProQuest, PubMed, Scopus and Web of Science databases. The search equation used was *(aging OR older* OR elder*) AND (music* OR musical practice OR musical training) AND (cogniti* OR cognitive reserve OR plasticit*)*. Second, we consulted references from studies on this subject. Finally, we accessed the 'gray literature' via Google Scholar and TESEO. The latest search was carried out in August 2018, without any time restrictions. In total, 1699 potentially interesting results were found. After removing 855 duplicates, titles and abstracts of 843 studies were screened by RRC (Rafael Román-Caballero) to exclude articles that did not meet the inclusion criteria. The full text of 37 of the selected articles was assessed for eligibility by two independent reviewers (RRC and JL, Juan Lupiáñez). Any disagreements were resolved by discussion and consensus between both researchers. Finally, 13 of these articles were selected for inclusion in the review– 4 of them in the experimental study group and 9 in the correlational study group. A PRISMA flowchart summarizing the literature search process is depicted in Fig 1 (see S1 File for the specific search procedures of each database).

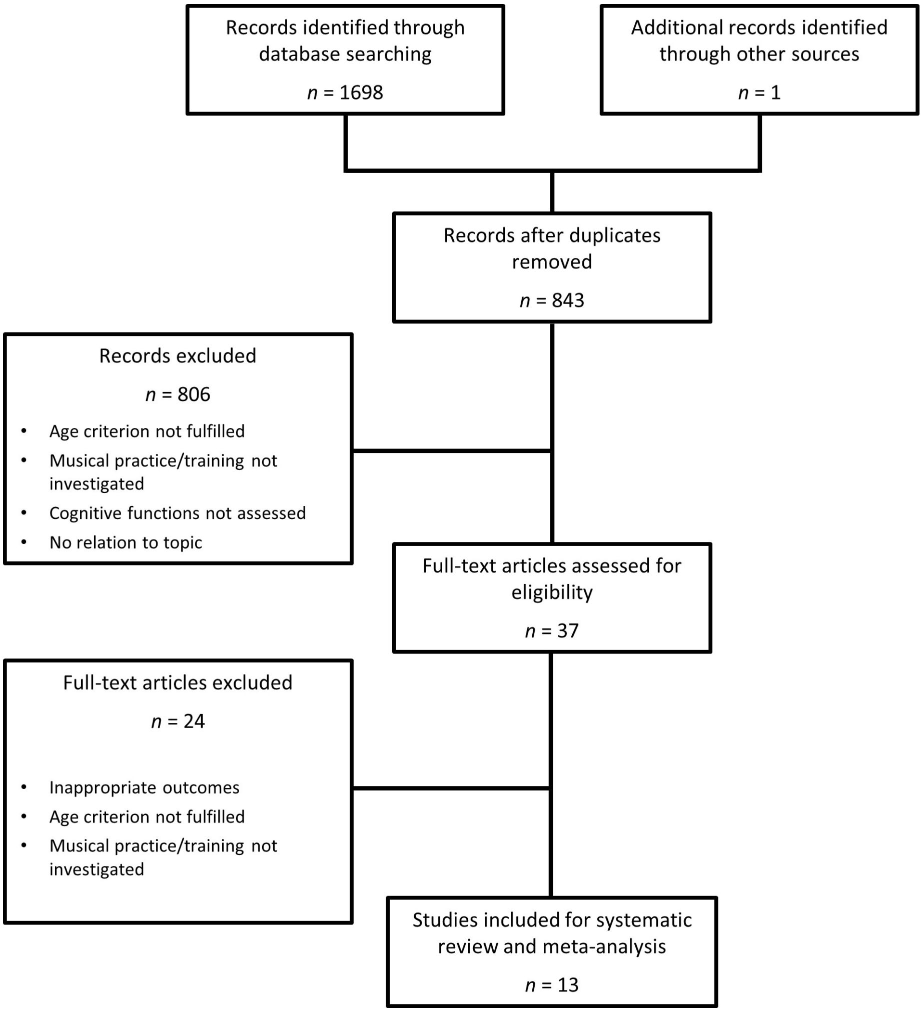

Fig 1. PRISMA flowchart of the studies included in the systematic review and meta-analysis.

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Selection criteria

The studies selected in the review met the following criteria: (1) be empirical; (2) explore the effects of musical practice on the sample; (3) include an assessment of cognitive functions and/or an assessment of brain status with a physiological recording and/or neuroimaging technique; (4) include a sample of participants aged 59 years or older with (5) no cognitive impairment or brain damage; and (6) be written in English or Spanish. The age criterion was selected on the basis of the existing evidence that cognitive [4] and cerebral [3] aging occurs most markedly around 60 years of age. We decided to extend a priori this age limit to 59 years in order to cover studies that by convention begin their range at this age.

Data extraction and quality assessment

Coding sheets were created for recording the variables (see S2 File). By using them, basic information, design, sample, outcomes and results were obtained from each of the selected studies. In the correlational studies, the variables related to the musical experience of the sample were also extracted. In the experimental studies, information of musical training programs and the follow-up assessments were collected. Moreover, information regarding the control variables was also collected in both types of studies.

Quality assessment was also performed using the Cochrane Risk of Bias (RoB) for experimental studies [58] and the Risk of Bias in Non-randomized Studies of Interventions (ROBINS-I) for correlational studies [59]. The judgment in the different domains for each study are summarized in Figs 2 and 3.

Statistical analysis

Effect size. To explore the effects of musical practice on the various cognitive functions, separate meta-analyses were performed for each function in each of the two types of studies (i.e., experimental and correlational). To this end, we used Hedge's *g* [60] as an estimator of effect size. The *g* values were interpreted according to Cohen's criteria: values of 0.2–0.5 are interpreted as small effect, 0.5–0.8 as medium effect, and > 0.8 as large effect [61]. In our study, a positive effect size denoted an improvement in favor of musical practice. In the experimental studies, which included both pre- and post-treatment measures, effect size was calculated following the proposal made by Morris [62]: $d = ((M_{post,T}-M_{pre,T})-(M_{post,C}-M_{pre,C})) / SD_{pre}$, where $M_{post,T}$ and $M_{pre,T}$ are the post- and pre- mean scores for the treatment group, whereas $M_{post,C}$ and $M_{pre,C}$ are the scores for the control group, and SD_{pre} is the pooled standard deviation for the pre-test scores of both groups. In studies that included two post-treatment measures (of which one was a follow-up measure), we calculated effect size in the first post-intervention assessment. In correlational studies with more than one group of musicians, we used the scores of the group of practice with the greatest expected effect (either high activity musicians [63] or active musicians [64]).

Outcome measures and aggregates. As most of the studies included multiple neuropsychological measures of the same function, we decided to generate aggregates following the recommendations of Borenstein et al. [65] (see S2 Table). The aggregates were produced with the Agg function of the MAd package in R [66]. In the absence of correlations between the different measures, the default correlation of 0.5 was selected, based on Wampold et al. [67]. The metafor package for R [68] was used to conduct the univariate meta-analyses of the various cognitive functions. Given the great variability of neuropsychological outcomes and other differences between studies (e.g., age, education, musical variables), a random effects model was used for the meta-analyses. The studies used different tests involving different scales, so the standardized mean difference (SMD) and the 95% confidence interval (CI) were used as the summary measure of effect. Significance was defined as the two-sided p-value of $<.05$. Indeed, the results found with the multivariate method were very similar to those obtained with the chosen univariate method on aggregates.

Heterogeneity. To ensure a sufficient consistency between studies and the generalization of the summarized findings, the usual heterogeneity indexes were computed: Q and its chi-squared significance test, τ^2 and I^2. I^2 values of 0–25% are interpreted as null, 25–50% as low,

	Confounding	Selection of participants	Classification of intervention	Deviations from intended interventions	Missing data	Measurement of outcomes	Selection of the reported result
Baird et al., 2017	−	+	+	+	+	+	+
Bidelman & Alain, 2015	+	+	+	+	+	+	+
Fauvel et al., 2014	+	+	+	+	+	−	+
Grassi et al., 2017	+	+	+	+	+	?	+
Hanna-Pladdy & Gajewski, 2012	+	+	+	+	+	?	+
Hanna-Pladdy & Mackay, 2011	+	+	+	+	+	?	+
Mansens et al., 2017	+	+	+	+	?	?	+
Moussard et al., 2016	+	+	+	+	+	?	+
Strong & Midden, 2018	+	+	+	+	?	?	−

Fig 2. Risk of bias summary for correlational studies.

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50–75% as moderate, and <75% as high heterogeneity [65]. Due to the low number of studies included (<10 in both cases [69]), we considered it inappropriate to use funnel plots and tests such as Egger's regression test [70] to assess publication bias.

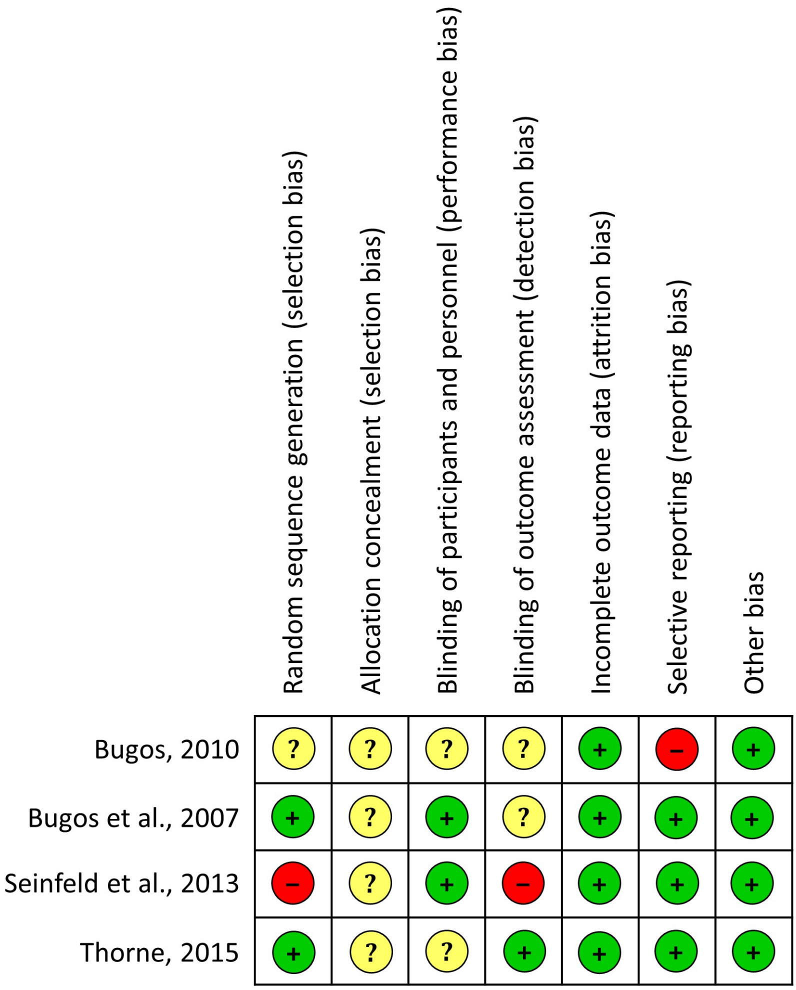

Fig 3. Risk of bias summary for experimental studies.

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Results

Correlational studies: Cognitive benefits associated with musical practice throughout life

Characteristics of the studies. Our research included 9 correlational studies, with a total sample of 1,530 subjects. The main characteristics of these studies are summarized in Table 1. The proportion of men and women was similar in most studies. The presence of neurological or psychiatric disorders and cognitive impairment in the studies was controlled for, and efforts

Table 1. Main characteristics of the correlational studies included in the systematic review and meta-analysis.

			Total sample			Groups	Results	
Authors	Year		Size	Age	Sex	Characteristics	Main	Others
Baird et al. [72]	2017		N = 22	≥ 65 years	–	Musicians (n = 15) Non-musicians (n = 7)	ns	–
Bidelman & Alain [73]	2015		N = 20	> 60 years	50% men	Musicians (n = 10) Non-musicians (n = 10)	–	Faster classification of speech sounds Brain coding of speech more efficient and robust; also possible improvement in attention
Fauvel et al. [74]	2014	Study 1	N = 68	≤ 55 years vs. ≥ 60 years	44% men	Older musicians (n = 15) Older non-musicians (n = 20) Middle-aged musicians (n = 19) Middle-aged non-musicians (n = 14)	↑ DSF ↑ D2 ↑ Letter fluency ↑ Semantic fluency	With aging: - Less decline in D2 - No decline in DSF and semantic fluency - Better letter fluency
		Study 2	N = 47	≥ 60 years	47% men	Older early musicians (n = 15) Older late musicians (n = 12) Older non-musicians (n = 20)	–	- Older musicians with early onset showed better letter fluency - Older musicians showed better semantic fluency
Grassi et al. [37]	2017		N = 40	≥ 65 years	70% men	Musicians (n = 20) Non-musicians (n = 20)	↑ VPTA ↑ LST ↑ sEFT ↑ sMRT	Better central auditory processing Frequency discrimination, gap detection, VPTA, LST and sMRT are good to excellent classifiers for musicians
Hanna-Pladdy & Gajewski [75]	2012		N = 70	≥ 59 years	–	Musicians (n = 33) Non-musicians (n = 37)	↑ LNS ↑ Letter fluency D-KEFS ↑ CVLT-II SDFR ↑ JLO ↑ Tower task D-KEFS (rule violations) Trend in GP	Trends in ROCF delayed recall and D-KEFS letter fluency in currently active musicians (they also have more years of practice) In partition analyses, predictors: JLO - Education ≥ 17 years - In education < 17 years, current practice LNS Age of onset < 9 years
Hanna-Pladdy & MacKay [63]	2011		N = 70	≥ 60 years	40–50% men	High activity musicians (n = 22) Low activity musicians (n = 27) Non-musicians (n = 21)	↑ VRII ↑ TMT-A ↑ TMT-B ↑ BNT Trends in SS and letter fluency	Cognitive performance (VRII, TMT-B and BNT) correctly classifies 57.1% of participants (77.3% of high activity musicians) into the 3 groups. Age of onset is the best predictor of VRI, years of practice of VRII (followed by age of onset), age of TMT-A (followed by years of practice) and TMT-B (followed by current practice), and type of training of BNT
Mansens et al. [71]	2017		N = 1101	≥ 64 years	52% men	Musicians (n = 277) Non-musicians (n = 824)	↑ Alphabet coding Task-15 ↑ Letter fluency ↑ DSF ↑ DSB ↑ AVLT-Learning Trend in AVLT-Delayed recall	Playing an instrument: - > singing and non-musicians in Alphabet coding Task-15 - > non-musicians in DSB - > non-musicians in AVLT-Learning
Moussard et al. [76]	2016		N = 34	≥ 59 years	47% men	Musicians (n = 17) Non-musicians (n = 17)	↑ Go/No-go (Errors)	Overall, more inhibitory ability and more anterior activation:

(*Continued*)

Table 1. (Continued)

			Total sample			Groups	Results	
Authors	Year		Size	Age	Sex	Characteristics	Main	Others
Strong & Midden [64]	2018		N = 58	≥ 65 years	53% men	Active musicians (n = 32) Former musicians (n = 12) Non-musicians (n = 14)	↑ Stroop-1 D-KEFS ↑ Stroop-3 D-KEFS ↑ Stroop-4 D-KEFS ↑ BNT ↑ Letter fluency	–

DSF: Digit Span Forward; **VPTA**: Visual Pattern Test Active; **LST**: Listening Span Test; **sEFT**: short Embedded Figures Test; **sMRT**: short Mental Rotation Test; **LNS**: Letter-Number Sequencing; **D-KEFS**: Delis-Kaplan Executive Function System; **CVLT-II SDFR**: California Verbal Learning Test-II Short Delay Free Recall; **JLO**: Judgment of Line Orientation; **ROCF**: Rey Osterrieth Complex Figure; **GP**: Grooved Pegboard; **VRI &VRII**: Visual Reproduction I & II; **TMT**: Trail Making Test; **BNT**: Boston Naming Test; **SS**: Spatial Span; **DSB**: Digit Span Backward; **AVLT**: Auditory Verbal Learning Test.

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had been made to generate homogeneous groups regarding age, education, IQ, and in certain cases also regarding physical activity [64,71], income [71] and social activity [64]. However, differences between the studies can be observed in age (mean age range: 67 to 74.87 years), level of education (range: 9.4 to 18.3 years of education on average), and in the variables related to musical practice (Table 2).

Meta-analyses of specific cognitive functions. Separate meta-analyses were conducted on each of the cognitive functions in order to explore the cognitive differences associated with musical practice. Eventually, we decided to explore basic domain-general functions (processing speed, inhibition and attention) and complex domain-general functions (verbal and visual working memory, naming, verbal fluency, verbal and visual memory, reasoning, flexibility, visuospatial ability and visuoconstruction) (Figs 4–6; forest plots of non-significant cognitive functions are reported in the S3 File). These cognitive functions were not assessed in all the studies; consequently, the total number of samples for each of the meta-analyses ranged

Table 2. Variables related to the musical practice of participants in the studies included in the systematic review and meta-analysis.

Study	Professional musicians	Groups	Age of onset	Years of training	Years of practice	Current practice (%)	Current practice (h/week)
Baird et al., 2017	Yes	–	–	–	51 (22)	100%	–
Bidelman & Alain, 2015	No	–	10.8 (2.5)	11.4 (5.8)	–	100%	–
Fauvel et al., 2014; Study 1	No	Older musicians	11.2 (4.5)	–	Overall:	100%	9.2 (6.6)
		Middle-aged musicians	8.4 (3.7)	–	38.12 (17.7)	100%	15.3 (12.6)
Fauvel et al., 2014; Study 2	No	Older musicians with early onset	11.2 (4.5)	–	–	100%	9.2 (6.6)
		Older musicians with late onset	42.7 (11)	–	25.8 (12.3)	100%	8.1 (7.2)
Grassi et al., 2017	Yes	–	–	–	60.3 (9.96)	100%	–
Hanna-Pladdy & Gajewski, 2012	No	–	9.3	4	37	51.5%	–
Hanna-Pladdy & MacKay, 2011	No	High activity musicians	9.7 (7.2)	3.5 (0.96)	35.5 (24.7)	45.5%	–
		Low activity musicians	10.4 (5.9)	3.3 (0.95)	3.8 (2.7)	11.1%	–
Mansens et al., 2017	–	–	–	–	–	–	–
Moussard et al., 2016	Professionals and amateurs	–	8.8 (3.8)	27.8 (19.5)	57.2 (8.4)	100%	11 (6.3)
Strong & Midden, 2018	–	Active musicians	8.4 (3.4)	9.5 (6.4)	–	100%	7.9 (6.8)
		Former musicians	8.6 (2.2)	7.9 (5.3)	–	–	–

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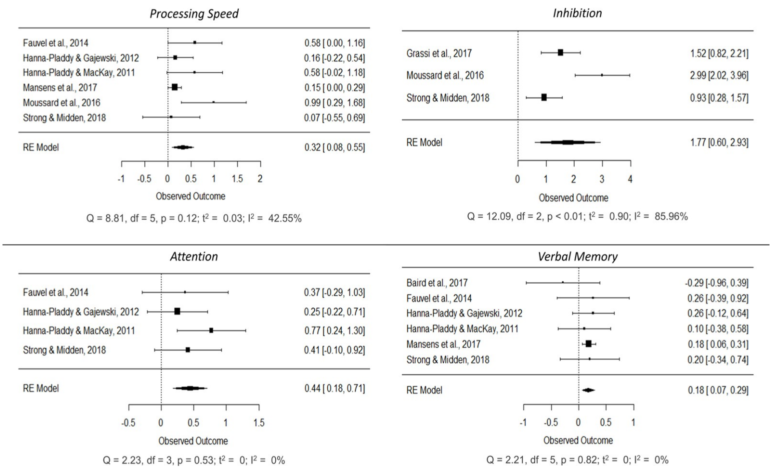

Fig 4. Forest plots showing cognitive improvements in processing speed, attention, inhibition and verbal memory in older adults associated with long-term musical practice.

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between 116 and 1,386 participants (mean = 648, SD = 604.040). Generally speaking, positive mean effect sizes were observed in all functions, although not all of them reached significance. A general improvement was observed in all basic domain-general functions: processing speed (SMD = 0.316, 95% CI [0.082, 0.551], $p < 0.01$; small effect), attention (SMD = 0.441, 95% CI [0.177, 0.706], $p < 0.01$; small) and inhibition (SMD = 1.766, 95% CI [0.601, 2.930], $p < 0.01$;

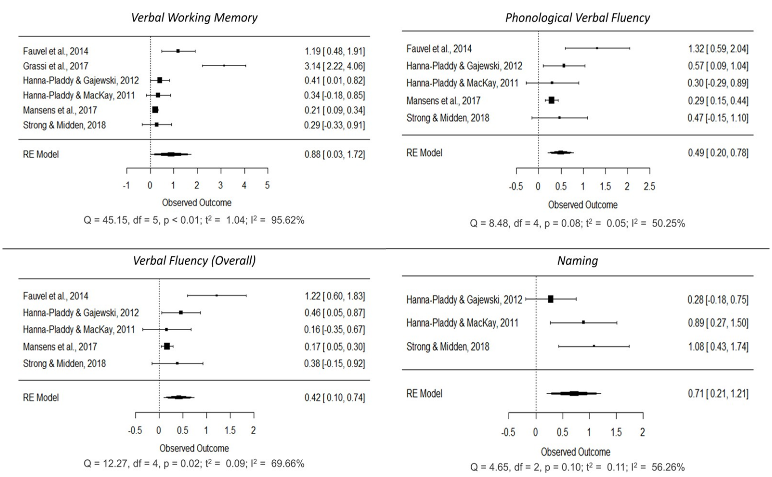

Fig 5. Forest plots showing cognitive improvements in verbal working memory, verbal fluency (overall), phonological verbal fluency and naming in older adults associated with long-term musical practice.

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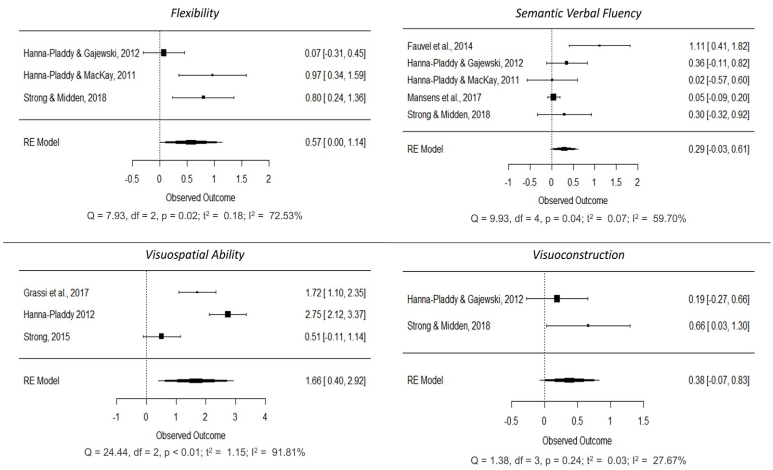

Fig 6. Forest plots showing cognitive improvements in flexibility, visuospatial ability, semantic verbal fluency and visuoconstruction in older adults associated with long-term musical practice.

https://doi.org/10.1371/journal.pone.0207957.g006

large). Additional improvements were observed in complex domain-general functions such as verbal memory (SMD = 0.180, 95% CI [0.070, 0.289], $p < 0.01$; small), verbal working memory (SMD = 0.876, 95% CI [0.027, 1.725], p = 0.043; large), overall verbal fluency (SMD = 0.418, 95% CI [0.096, 0.741], p = 0.011; small), phonological verbal fluency (SMD = 0.493, 95% CI [0.204, 0.783], $p < 0.01$; small), naming (SMD = 0.708, 95% CI [0.206, 1.210], $p < 0.01$; medium), flexibility (SMD = 0.571, 95% CI [0.003, 1.138], p = 0.049; medium) and visuospatial ability (SMD = 1.660, 95% CI [0.397, 2.924], p = 0.01; large). A positive trend was also observed in semantic verbal fluency (SMD = 0.288, 95% CI [-0.033, 0.609], p = 0.10; small) and visuoconstruction (SMD = 0.378, 95% CI [-0.072, 0.829], p = 0.079; small).

Regarding heterogeneity, only processing speed, attention, verbal memory and visuoconstruction showed a low level ($I^2 < 50\%$), whereas verbal fluency measures, naming and flexibility showed a significant medium effect ($75\% > I^2 > 50\%$), and inhibition, verbal working memory and visuospatial ability exhibited a high level ($I^2 > 75\%$).

Other findings of the systematic review. The review of the included articles provided additional evidence of improvements associated with musical practice in auditory skills (i.e., frequency discrimination, duration, gaps and amplitude modulations [37]) and speech perception (i.e., faster speech sound classification and EEG-based evidence suggesting more efficient and robust coding of speech [73]). However, the advantages in perceptual processing were not observed in Moussard et al. [76] with a visual task (no changes were observed in the early components P1 and N170). This suggests that these advantages are more restricted to the auditory modality at early stages of processing. Moreover, Bidelman and Alain [73] pointed out that increases in P3 amplitude may also indicate possible attentional improvements, implying that the advantages of musicians may extend beyond pre-attentive levels.

Additionally, some EEG findings [76] also suggested a greater inhibitory capacity in musicians and a more frontal topography of the effect observed in P3, which was partly interpreted as the development of successful compensatory mechanisms in older musicians. In this regard, Fauvel et al. [74] found that cognitive benefits exhibited a different pattern depending on the specific cognitive function concerned and its sensitivity to age. In fact, the performance of musicians also declined in some tasks (d2 test), although to a lesser extent. By contrast, no decline was observed in other tasks (Digit Span Forward and semantic fluency). Finally, in this cross-sectional study phonological fluency did not show a substantial decline; it even improved with age in musicians. These results indicate that the effects of musical practice may have either a protective or enhancing effect depending on the cognitive function concerned.

The studies included also provided evidence of the relationship between variables associated with musical practice and cognitive improvements. Functions such as phonological fluency [74], visual memory [63] and verbal working memory [75] were associated with the age of onset of the activity, showing better performance with earlier age of onset. The same applied to the amplitude of P3 in no-go trials, which was linked to a higher inhibitory capacity [76]. These relationships suggest the existence of a possible sensitive period during which musical practice is likely to have stronger and more permanent effects. In this regard, Hanna-Pladdy and Gajewski [75] found that an age of onset of less than 9 years predicted a better performance in verbal working memory.

Other variables of musical practice such as the intensity of the activity [63], maintaining the practice during old age [63,75,76], type of training [63] and its duration [76] were also associated with a wide range of cognitive improvements. Finally, older adults who played a musical instrument generally showed greater advantages than singers, especially in processing speed [71].

Experimental studies: Cognitive effects of late-onset and short-term musical practice

Characteristics of the studies. Four experimental studies were included (one of them was a Ph.D. dissertation [77]), forming a total sample of 126 subjects. The main characteristics of these studies are summarized in Table 3. They all covered an age range between 60 and 85 years and showed a similar proportion of men and women across the studies, although with a higher representation of women (between 65% and 78%). As in the correlational studies, the absence of neurological disorders and cognitive impairment was controlled for, as well as other influential variables (e.g., depression, psychoactive treatment and drug abuse). Although the aim was to have homogeneous groups within each study (e.g., age, education, IQ), there were differences between them in the level of education (mean years of education ranged from 13.38 to 18.1 years).

In all the studies, a training program based on piano and musical language teaching was selected, with variations in the total program duration (between 4 and 6 months), type of lessons (3 studies with group lessons, and 1 study with individual lessons), duration of lessons (between 30 minutes and 1.5 hours per session) and autonomous practice time. Differences also existed in the type of control group used: passive control, music listening, or others with workshops involving various leisure activities (all the participants chose at least one physical activity). It should be noted that not all the studies carried out a random assignment of the participants [78]. A follow-up evaluation was conducted in two studies 3 months after the post-test. Lastly, as shown on Table 3, some diversity was also found in the neuropsychological tests used to assess cognitive functions.

Meta-analyses of specific cognitive functions. As with the correlational studies, we conducted independent meta-analyses for each of the functions. Subsequently, we explored basic domain-general functions (processing speed, inhibition and attention) and complex domain-general functions (verbal working memory, verbal fluency, visuoconstruction, reasoning and flexibility), in addition to domain-specific functions (manual dexterity) (Fig 7; forest plots of non-significant cognitive functions are reported in the S3 File). These cognitive functions were

Table 3. Main characteristics of the experimental studies included in the systematic review and meta-analysis.

		Total sample			Groups					Results	
Authors	**Year**	**Size**	**Age**	**Sex**	**Characteristics**	**Random assignment**	**Training program**	**Control group**	**Times of measurement**	**Main**	**Others**
Bugos et al. [36]	2007	N = 31	60–85 years	24% men	Experimental (n = 16): piano training Control (n = 15): without treatment	Yes	6-month piano training. ½ h of individual session and 3 h of autonomous practice per week	No training, only assessment	Pre-test Post-test (6 months later) Follow-up (3 months later)	DSy TMT-B Trend in TMT difference score and DSF	–
Bugos [79]	2010	N = 46	60–85 years	22% men	Experimental (n = 24): piano training Active control (n = 22): musical listening	–	16-week piano training. 45 min. of group session and 15 min. of social activities per week. ½ h of daily practice.	16-week musical listening. 45 min. of group session and 15 min. of social activities per week. ½ h of daily listening.	Pre-test Post-test (16 weeks later)	Both groups, more in musical training: ↑ D-KEFS VF ↑ PASAT ↑ Stroop (Errors)	–
Seinfeld et al. [78]	2013	N = 29	60–85 years	24% men	Experimental (n = 13): piano training Active control (n = 16): leisure activities	No	4-month piano training. 1 and ½ h of group session and 45 min. of autonomous practice 5 days per week (~ 4 h).	4 months of non-musical leisure activities. Everyone chose at least one physical exercise course.	Pre-test Post-test (4 months later)	↑ FTT (D and ND) in both groups In musical training: ↑ Stroop-Color ↑ Stroop-Color-Word ↑ DSF Trend in TMT-A	↑ BDI in both ↑ POMS Total ↑ POMS Fatigue ↑ WHOQOL-BREF Physical ↑ WHOQOL-BREF Psychological
Thorne [77]	2015	N = 20	65–85 years	35% men	Experimental (n = 10): piano training Active control (n = 10): musical listening	Yes	6-month piano training. ½ h of group session per week and ½ h of daily practice.	6-month musical listening. ½ h of group session per week and ½ h of daily listening.	Pre-test Post-test (6 months later) Follow-up (3 months later)	↑ Stroop (Errors) ↑ VBM delayed recall	↑ MOS Energy and Emotional Well-being ↑ MMN amplitude in experimental group after training: better auditory discrimination

DSy: Digit Symbol; **TMT**: Trail Making Test; **DSF**: Digit Span Forward; **D-KEFS**: Delis-Kaplan Executive Function System; **VF**: Verbal Fluency; **PASAT**: Paced Auditory Serial Addition Test; **FTT**: Finger Tapping Test; **VBM**: Verbal Memory; **BDI**: Beck Depression Inventory; **POMS**: Profile of Mood State; **WHOQOL-BREF**: The World Health Organization Quality of Life Brief Questionnaire; **MMN**: Mismatch Negativity.

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not assessed in all of the studies, which caused the number of total samples for each of the meta-analyses to range between 49 and 126 participants (mean = 85, SD = 24,471). Overall, we found positive mean effect sizes in most functions (except verbal working memory), although only reasoning (SMD = 0.436, 95% CI[0.003, 0.869], p = 0.048; small effect) and visuoconstruction (SMD = 0.519, 95% CI[0.015, 1.024], p = 0.044; medium effect) reached statistical significance, and a certain trend was observed in flexibility (SMD = 0.934, 95% CI[-0.026, 1.894], p = 0.057; large effect). This suggests that musical training in older adults can lead to improvements in cognitive functions, especially in high-level functions such as reasoning, and probably in flexibility. Interestingly, verbal working memory exhibited a negative effect (SMD = -0.291, 95% CI [-1.318, 0.736], p = 0.579).

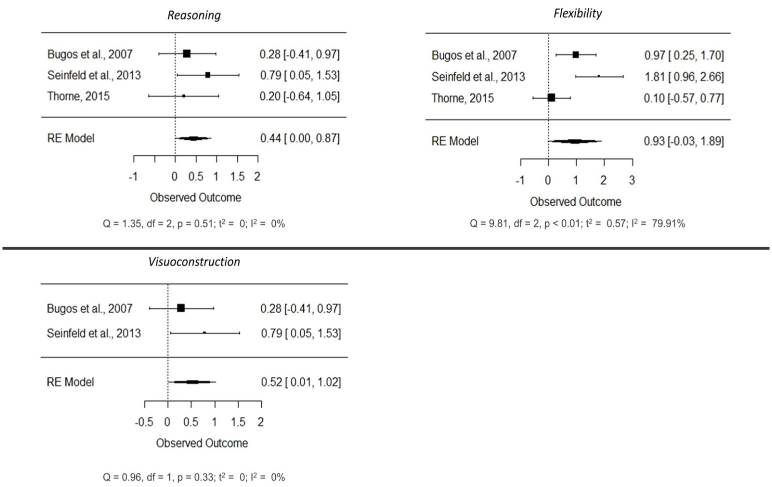

Fig 7. Forest plots showing the effects of short-term musical training on reasoning, visuoconstruction and flexibility in older adults.

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Most functions showed substantial heterogeneity between studies ($I^2 > 50\%$). However, this heterogeneity did not seem to be present in visuoconstruction and reasoning (p-values associated with the Q tests > 0.05; I^2 values of 0% in both), which suggests that the variation observed across studies in the outcomes for this function can only be attributed to chance.

Other findings of the systematic review. In addition to the previous section, the systematic review provided further evidences. Along with the improvements observed in the meta-analyses, the only study in which long-term memory was explored [77] found a significant improvement in the delayed recall of verbal memory. EEG data also showed differences in pre-attentive processing [77]. In the aforementioned study, subjects who had received musical training showed a larger amplitude of the mismatch negativity (MMN) potential associated with sound discrimination. Interestingly, some of the benefits observed after training (in working memory [36] and in inhibition capacity [77]) were not maintained after this training ceased, as shown by subsequent follow-up assessments.

Moreover, some of the improvements observed in the meta-analyses did not consistently reach statistical significance in individual studies. It may be due to small sample sizes (and the consequent low statistical power) or the duration and intensity of the training programs. In fact, Bugos [79] was unable to replicate in 2010 either the significant improvements in divided attention, measured with the Trail Making Test B, or the trend in the B-A score found in the 2007 study by Bugos et al. [36]. In the 2010 study, both a reduction in sample size and a reduction in the number of months of musical training were observed (4 months in Bugos, 2010 vs. 6 months in Bugos et al., 2007).

Discussion

The progressive aging of societies makes it necessary to identify ways to deal with the challenges of aging. In this context, musical practice seems to be a promising tool to reduce the impact of age-related cognitive and brain changes. Despite the increasing interest in music-based interventions nowadays, to our knowledge, this research is the first systematic review and meta-analysis of the available evidence on the effects of musical practice on healthy neurocognitive aging.

Musical practice as a protective factor in neurocognitive aging

Overall, the evidence reviewed suggested a relationship between musical practice and better cognitive functioning in old age. The inclusion of studies with correlational and experimental designs revealed that these benefits were present both in individuals who had engaged in long-term musical practice throughout their lives (correlational studies) and in those who had followed short training programs initiated in later stages of life (experimental studies). These cognitive benefits, which were particularly noticeable in individuals who had engaged in long-term musical practice, were present in both domain-specific and domain-general functions. Specifically, older adults who practiced music showed improvements in the early processing of auditory stimuli; this was to be expected, given that musical training usually involves this type of processing. This had already been observed in studies with adults [39–44,80] and in other studies with older individuals, which could not be included in the current meta-analysis for methodological reasons (mainly due to the age criterion) [81–84]. Moreover, the benefits were also generalized to functions not so closely related to the specific skills trained by musical practice (i.e., domain-general functions), such as naming, episodic memory or executive functions. As happened with auditory processing, these improvements were consistent with research in adults (see Introduction) and other studies with older adults [81,84–87].

Importantly, most of the improvements observed occurred in age-sensitive cognitive functions, protecting or reducing the decline [74]. On the other hand, in functions that are less sensitive to the passage of time musical practice seems to be associated with an enhancing effect. Therefore, cognitive aging is not inevitable, and this variability seems to depend partly on life-long experiences and lifestyle factors.

Moreover, it seems that some tests are more sensitive than others to cognitive differences between older musicians and older non-musicians. Specifically, an individual extreme effect was found in visuospatial ability in the Benton Visual Form Discrimination test (SMD = 5.044; [75]); in the same sample, another visuospatial ability test, the Judgment of Line Orientation test, only found a moderate effect (SMD = 0.508). In this case, a possible explanation could be that the Benton Visual Form Discrimination test requires making fine discriminations between very similar shapes, a skill that professional musicians may train by reading scores with similar-looking stimuli. However, the orientation of these musical symbols does not change, since what is really informative about them is their position (height) on the musical staff. A possibility yet to be confirmed is whether certain position discrimination tests will also show a high sensitivity to the effects of musical practice.

Likewise, larger effects were found in the most demanding tasks within the same function, as happened in working memory (Listening Span Test and Visual Pattern Test Active [37]), naming (with a 30-item version of the Boston Naming Test [64]), verbal fluency (with 2-minute versions instead of the usual 1-minute version [74]), and verbal memory (in the long version of the California Verbal Learning Test-II compared to the short version [75]). This is consistent with the *complexity effect* [11]: just like an increase in the demands of the task is likely to affect older people more than younger people, older musicians may be less influenced by the demands due to their improved cognitive functioning.

As could be expected, the improvements were much more evident in the correlational studies, given that such studies explored older adults with an extensive musical practice and an early onset. However, the correlational evidence cannot be used to identify the directionality of the relationship between musical practice and cognitive functioning. Alternatively, the specific cognitive characteristics of older musicians may have led them to select and maintain this activity throughout their lives (as a predispositional factor); therefore, the fact of choosing groups of musicians may imply selecting a sample with a particular cognitive profile.

However, all the studies attempted to reduce this limitation by controlling for other variables (e.g., education or crystallized cognition). In addition, it appears that variables related to musical experience were also associated with the observed cognitive effects. Although these are correlational findings, the fact that the characteristics of musical practice have a relationship with cognitive performance again supports the idea of possible causality. Among these musical variables, the relationship between the onset of musical practice and age suggests the possibility of a sensitive period during which a long-term enhancement takes place and can be observed even in late stages of life. Specifically, White-Schwoch et al. [88] observed that the neurocognitive effects of early musical practice in older adults were permanent, as they could be observed even when this practice had been discontinued after 25 years.

Nevertheless, the best way to resolve the issue of causal directionality is to use an experimental methodology. Even though experimental studies were few and involved relatively short training programs, the meta-analyses of these works showed an overall positive trend in most of the functions explored, along with clear effects in reasoning and visuoconstruction (significant) and flexibility (marginally significant). This supports the idea that plasticity processes are maintained in the brain of adult and aged individuals [33,34] and that musical activity may continue to stimulate such changes beyond childhood (even with short-term experiences). However, the continuity of these effects is not yet clear, given that some improvements were not maintained in the follow-up assessments.

By contrast, a surprising result was the negative effect observed in verbal working memory in the experimental studies. However, it seems that this was due to the influence of the effect in Seinfeld et al. [78], in which the groups were not equated in the baseline and a highly active control was chosen (i.e., weekly physical exercise workshops, among other activities).

Explanations on the cognitive benefits of musical practice

Although the causal role of musical practice cannot be established yet, a number of findings indicated that some of the differences observed were due to this lifestyle factor. As previously mentioned, musical performance triggers a large number of cognitive processes, which may have a specific impact on each one of these processes by reinforcing their function (*specific training mechanism*). Specifically, musical performance continuously involves both musical listening and sound discrimination (auditory processing) [79], as well as the rapid reading of musical scores and the analysis of the location of notes on the staff (linguistic and visuospatial ability) [86]. This activity also involves many attentional demands: playing in a group requires synchronizing one's own performance (sensorimotor skills) and listening to the musical cues of other instruments (audio-spatial localization) [86], attending to many types of visual stimuli, mainly the score and the body movements of the rest of the musicians and the conductor (divided attention), detecting them and responding appropriately (vigilance and selective attention) over long periods of time (sustained attention) [47]. Regarding the executive functions, musicians must inhibit other information while performing (e.g., other melodies) [37] and must apply monitoring and shifting skills during the performance [89]. Lastly, in many cases musical performance requires the ability to memorize the musical piece and recall it at the time of the concert [71].

However, the improvements observed in our results in older musicians are very broad and cover a wider range of cognitive functions. The findings suggest the existence of a transfer effect of musical practice, which is particularly relevant given the difficulties that many cognitive training programs have obtaining far transfer [36]. In fact, the only cognitive benefits that achieved statistical significance in the meta-analyses of the experimental studies were found in domain-general functions such as visuoconstruction, reasoning and flexibility.

Therefore, improvements in certain functions could have a positive influence on other non-trained processes (*specific compensatory mechanism*). First, it has been noted that improvements in auditory processing are not limited to musical tones but also extend to speech processing. These improvements are likely to affect high-level functions within the verbal context, such as language comprehension in noisy contexts (speech-in-noise; [51,85]). Such linguistic benefits seem to be related to the existence of common brain processing mechanisms for music and language, as proposed in Patel's OPERA hypothesis [90]. Consequently, improvements in one of these two functions can be expected to have a transfer effect on the other function [91]. However, that influence could be specific to some processes instead of general (auditory improvements were not associated with the observed improvements in working memory and visuospatial tests [37]).

Another example can be found in the case of long-term memory. Additionally to the contribution of a higher perceptive ability [92], further evidence suggests that the benefits of musical practice on memory are not due *per se* to improved storage or retrieval capacity, but rather to a more robust and efficient coding (such as an improved rehearsal mechanism [93] or an increased use of semantic information organization strategies [94]).

Finally, an explanation for our results could be drawn from certain aging theories. Just like the decline in certain key functions during aging mediates changes in many other cognitive processes, an improvement or preservation of these key functions may lead to an improved overall functioning (*general compensatory mechanism*). Thus, the presence in musicians of a more efficient processing [8,9] along with a higher inhibitory capacity [10] could be at the root of the other benefits observed. A similar approach has been proposed previously with inhibitory control for adult enhancements [95]. In our opinion, based on the evidence found, attention is also a function that has a crosscutting influence on the rest of the cognitive processes. Attention has been found to be able to contribute to benefits in auditory processing [44,83,96], visuospatial ability [49] and working memory [80] in musicians, among other functions. However, none of the three mechanisms described is exclusive of the others, and they may all occur simultaneously.

Limitations and implications

This review highlights the limited research conducted in this field, even though it is a promising subject. However, the results of our meta-analyses should be interpreted with caution due to the small number of studies included and the amount of heterogeneity observed. Some of this heterogeneity is likely to be due to differences in the tasks used, educational level and age of the samples, differences in musical variables (in correlational studies), and differences in the duration and intensity of scheduled practice, as well as the type of control group used (in the experimental studies). Another difference between the correlational studies was that musicians in some cases were professionals and in other amateurs (although the majority were instrumentalists).

The limitations of our study imply that the evidence provided cannot be considered conclusive. However, the results obtained are positive and consistent with the adult literature. It is therefore essential to conduct new research. Especially, there is a need for further experimental studies involving training programs with a random assignment of the participants, since it is the only way to rule out that the differences found in musicians are due to predispositional factors. In addition, it would be interesting to explore the differential effect on aging in professional versus amateur practice, and in the various types of musical practice (orchestral musicians, jazz, flamenco, singers, composers, conductors, etc.) due to the idiosyncratic cognitive demands that each of them implies. There is also a lack of neuroimaging studies. To our knowledge, the only one conducted [86] showed that musical practice could also have a protective effects on the brain.

Moreover, our results have strong implications in the contexts of education and society. The possibility that early musical practice may produce long-term neurocognitive benefits could lead to rethinking the subject of music in the school context. As shown by this review, intense musical activities during childhood could increase the probability of healthier neurocognitive aging and reduce the risk of neurodegenerative diseases. In addition, musical practice during later stages of life could also be an effective factor to take into account in the design of intervention programs for the prevention of age-related neurocognitive problems.

Conclusions

Age-related cognitive decline does not seem to be inevitable, given that lifestyle factors such as musical practice have been associated with improved cognitive functioning during aging. In this paper, a systematic review and meta-analysis of the impact of musical practice on neurocognitive aging were conducted. Results indicate that an involvement in this activity (particularly early and long-term involvement) is associated with benefits in domain-specific functions (auditory perception) and in a wide range of domain-general functions. Although little evidence is available so far and further research is needed, the findings presented here suggest that musical practice is an effective tool for preventing the declines of healthy aging and making interventions in this regard.

Supporting information

S1 Table. PRISMA checklist.
(DOCX)

S1 File. Search procedures of each database.
(DOCX)

S2 File. Coding sheets for the recording of variables in the studies included in the meta-analysis.
(DOCX)

S2 Table. Cognitive functions explored with independent meta-analyses, including aggregates produced in studies where multiple outcomes existed for the same function.
(DOCX)

S3 File. Forest plots of non-significant cognitive functions in correlational studies.
(DOCX)

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Data and scripts for the conduction of meta-analysis are publicly available via Open Science Framework and can be accessed at https://osf.io/y4w89/.

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Appendix B1

Román-Caballero, R (2023). *Todas las canciones que habitan. Reflexiones desde la psicología y la neurociencia sobre los beneficios de la música.* Capítulos iniciales de un libro de divulgación remitido para revisión.

Todas las canciones que habitan

Reflexiones desde la psicología y la neurociencia sobre los beneficios de la música

Rafael Román Caballero

Índice*

* Junto a los capítulos presentados en esta tesis, está previsto que se les añadan otros cuatro capítulos (con título aún por definir) sobre:

- Los beneficios cognitivos de la música.
- Los beneficios terapéuticos de la música.
- La música en el aprendizaje y la educación.
- La música en la vida cotidiana.

Algo llamado música

Desde la construcción cultural hasta un concepto biológico

Ahora podemos entender el significado de la música. Es la forma de sentirnos al oírla. […] No hay que saber mucho de bemoles, sostenidos, ni nada de eso para entender la música. Si os dice algo, no una historia ni un cuadro, sino un sentimiento; si os cambia por dentro y podéis sentir todo lo bueno de la música, es que la entendéis.

Leonard Bernstein (*Conciertos para jóvenes I: ¿Qué significa la música?*, 1958)

Quizá antes de hablar de los orígenes de cualquier habilidad o de sus funciones, deberíamos definirla. Pero el caso de la música es en sí paradójico. A diario vivimos experiencias musicales en salas de conciertos y la radio, y también en situaciones en las que nos encontramos con ella incidentalmente, como haciendo la compra, en la peluquería o en el dentista. En nuestro mundo la música es tan omnipresente que cualquier actividad podría acabar acompañada de una banda sonora. Con todas esas experiencias musicales, casi de forma instintiva *sentimos* (que no tanto *sabemos*) a lo que nos referimos con la palabra *música*. Parece que el concepto ya nos pertenece. Pero si intentamos definirla y capturar su esencia con palabras, se nos escapa. "Si tienes que preguntar qué es, nunca lo sabrás" es la versión de Louis Armstrong de esta paradoja. La música es más obvia como experiencia que como concepto. De hecho, muchas lenguas, incluyendo la mayoría de lenguas nativas de Norteamérica y lenguas africanas como la basongye de Zaire, solo cuentan con palabras específicas para distintos géneros musicales, pero no disponen de un término global. Por otro lado, la relación tan estrecha que existe entre la música y la danza ha llevado a que muchas culturas utilicen términos que hagan referencia a ambas actividades sin hacer una distinción clara entre ellas, como el término sánscrito *sangıta* o *nkwa* del igbo de Nigeria. El propio origen de la palabra occidental, del griego *mousiké* ("arte de las Musas"), hacía referencia a un conjunto diverso de actividades incluyendo la danza, la poesía y la gimnasia.

Sin duda, la música tiene que ver con el mundo de los sonidos, pero no cualquier clase de sonidos. Cuando hablamos de música, no hablamos del ruido de un motor o el timbre de una puerta. Tampoco nos referimos al lenguaje oral. En general hablamos de sonidos organizados intencionadamente para conformar melodías y ritmos. Habitualmente la estructura musical constituye un plan compuesto minuciosamente por una persona y que otro grupo de personas ejecuta. Es un formato que nos hemos acostumbrado a ver en la música clásica. Por un lado, conocemos el nombre del planificador-compositor (pongamos, Ludwig van Beethoven), y por otro está el nombre de las personas que llevarán a cabo ese plan brillante (la Orquesta Filarmónica de Berlín, por poner un ejemplo). A veces la composición es tan compleja de organizar que es necesaria una tercera persona encargada de dirigir la ejecución de los intérpretes. Y al igual que en la música clásica, también existe un plan musical en las canciones de rock y en muchos otros géneros. Así, sabemos que John Lennon fue quien escribió el *Come Together* de los Beatles. En muchas ocasiones se desconoce el nombre de la persona que compuso la música, como en las canciones populares y en las canciones de algunas tribus norteamericanas, en las que creían que la música emanaba de fuerzas sobrenaturales y se depositaba en la mente de las personas durante los sueños. En otras ocasiones, ni siquiera los intérpretes comienzan a tocar con un plan bien establecido e improvisan. Pero en todos estos ejemplos de autoría diluida, e incluso en el caso de la improvisación, la estructura que surge espontáneamente está muy influida por las estructuras habituales que los intérpretes han escuchado dentro del propio género musical.

Y aquí viene la parte más importante. Toda la música surge de una forma u otra con un propósito. Para Leonard Bernstein "la música son notas, bellas notas y sonidos, unidos de tal forma que disfrutamos al oírlos". Ciertamente, el propósito más habitual es el de producir placer, pero no es la única emoción que la música puede generar. Al Joseph Haydn más anciano le apabullaba el poder de la música, dejando a su merced todo cuanto sentía y todo su cuerpo: "Si la idea es un *allegro*, siento que el pulso se me acelera, o que los ritmos cardíacos se acrecientan; si es un *andante*, todos mis movimientos corporales se ajustan al pausado ritmo de la pieza". Como parte de ese poder, algunas obras pueden contagiar tristeza, miedo, asco, etc., y producir un momento realmente desagradable. Lo hemos vivido muchas veces en las películas de terror: el personaje protagonista se asoma a un pasillo o quizá a una habitación cuya puerta se ha abierto lentamente, y poco a poco mientras avanza en la oscuridad, unas notas muy agudas de instrumentos de cuerda se hacen cada vez más agudas e intensas en un *glissando* ascendente que parece eterno. A veces la música no precede a la aparición del asesino o de la criatura macabra, simplemente el inicio de esa banda sonora consigue convertir un pasillo cualquiera en el más terrorífico de todos. Seguramente habrá quien piense que difícilmente podemos llamar música a ese tipo de sonidos, pero algunas de estas piezas están compuestas por los principales compositores del siglo pasado. ¿Quién le diría a Krzysztof Penderecki que su obra *Polymorphia*, que ha sido utilizada en *El exorcista* y *El resplandor*, no es música? Quizá no sea el tipo de música que escuchamos en los locales de fin de semana o en el gimnasio, pero desde luego son notas minuciosamente escogidas y con un propósito claro en la película.

Volviendo a la paradoja de la música, cada vez que intentamos llegar a una definición con características principales como las que estamos planteando ("sonidos", "intencionalidad", "organización", "placer y emociones") y somos explícitos, nos encontraremos que hemos dejado fuera muchas formas de música. Por ejemplo, existen expresiones musicales de algunas culturas como las documentadas en Papúa Nueva Guinea que no poseen una estructura tonal ni rítmica, compuestas principalmente por sonidos de percusión y vocales. Lo mismo sucede con muchos tipos de música que no tienen un propósito hedónico, sino uno medicinal, como forma de catarsis, o religioso, como vía para congraciar a las divinidades o para influir sobre el mundo espiritual y producir cambios en el mundo físico. En la Antigua Grecia la escuela pitagórica consideraba que la música tenía un papel fundamental en la purificación del alma, en tanto que ambas son armonía. También el mito griego de Orfeo, quien consiguió ablandar al mismo Hades para traer de vuelta a la vida a su amada Eurídice, otorga poderes mágicos a la música como la capacidad de alterar las leyes naturales que rigen la vida y la muerte. Sin embargo, cuando la definición que utilizamos es demasiado vaga, esta podría incluir algunas actividades que intuitivamente no consideramos música pero que están en la frontera por sus similitudes. Es el caso de los recitativos religiosos en el islam y el judaísmo, o los recitales de poesía. Aunque las inflexiones en la entonación dotan a estos textos de una mayor emoción y facilitan su recuerdo, un practicante musulmán rechazaría considerarlos música, sobre todo si proviene de formas estrictas del islam en las que esta se prohíbe. A pesar de las variaciones en el tono, no cabe duda de que son formas de habla en las que la palabra sigue siendo el elemento principal. También en la frontera, y probablemente con un menor acuerdo sobre si es o no música, se encontraría el rap.

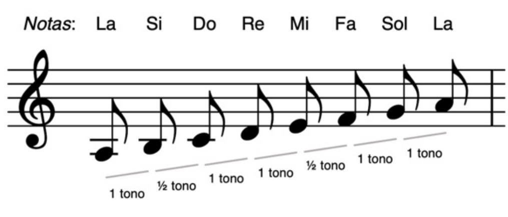
Al llegar a este punto coincidiréis conmigo en que el concepto de música es más escurridizo de lo que pensábamos. La naturaleza esquiva del concepto de música forma parte de su misterio. La música está ahí, siempre compañera de cualquier fiesta, evento deportivo o ceremonia religiosa, pero cada vez que alguien se acerca a ella e intenta recoger su concepto con palabras, se desvanece y solo deja su intuición. Como iremos viendo a lo largo de los capítulos, este es uno de tantos aspectos que han alimentado nuestra fascinación por la música. Sigue siendo misterioso por qué la música tiene un efecto emocional tan intenso y es capaz de comunicar sentimientos con tanta riqueza en matices. ¿Cómo se produce una respuesta así en nuestro cerebro? ¿Cómo un puñado de notas amontonadas en el aire dan lugar a esa explosión de cambios en nuestro interior? ¿Somos el único animal que percibe esa belleza? Y si somos los únicos, ¿por qué evolucionó una cualidad tan insólita? Henry Wadsworth Longfellow dijo de la música que es el lenguaje universal de la humanidad. Quizá esa afirmación pueda sonar muy rotunda, pero algo que sabemos con seguridad es que está presente en todas las culturas humanas. Un fenómeno tan universal dentro de una especie ha sugerido a la comunidad científica un origen innato. Y esto conduce a la pregunta ¿es la música un producto biológico o cultural? ¿Qué conduce a la aparición de las habilidades musicales en una persona, un plan genético o los aprendizajes que conlleva vivir en una sociedad en la que la música está en todas partes? Creo, en este punto, que lo mejor es respondamos a todas estas preguntas desde el conocimiento más consolidado y objetivo; aproximémonos desde la evidencia científica. Para quienes me acompañéis, hacedlo sin la ambición de encontrar respuestas definitivas. Hacedlo por el placer de aprender. Hacedlo solo por la inquietud de saber qué respuestas da la ciencia hoy a todas estas incógnitas.

Una definición universal de la música

Aunque todos los pueblos cuentan en su cultura con manifestaciones musicales, las características de todas ellas pueden ser muy diferentes. Es casi imposible encontrar rasgos musicales que podamos llamar "universales" en un sentido absoluto de la palabra, es decir que siempre y sin excepción estén presentes. Sin embargo, la investigación etnomusicológica (la rama antropológica de la ciencia musical) ha podido identificar algunos rasgos que, si no están en todas las expresiones musicales, son muy frecuentes. Hablaríamos aquí de características "universales" de la música como aquellas que con mucha probabilidad encontraremos en cualquier canción o concierto. Estos universales de la música se han identificado comparando las grabaciones de investigadoras a lo largo de todo el mundo. Muchos de los registros han sido grabados en estudios y posteriormente recopilados, pero otra parte del material son fragmentos que se capturaron *in situ*. Ya os podéis imaginar a nuestra estudiosa conviviendo varios días en una cultura remota y con una grabadora o cámara de vídeo siempre bien a mano, registrando cada segundo de sonido y danza, cada sorbo de esas canciones tan diferentes a todo lo que antes hubiera escuchado. Una de las recopilaciones más completas de este tipo de grabaciones es la *Enciclopedia Garand de músicas del mundo*. Con el análisis de sus fragmentos musicales se han podido identificar un gran número de consistencias a través de las culturas.

Soy consciente de que el bagaje musical de las personas que podrían estar leyendo este libro puede ser muy diferente y no me gustaría dejar atrás a nadie en la descripción de estos universales. Por eso, y dado que los rasgos universales identificados son aspectos comunes a la mayoría de piezas, me ayudaré de una canción que quizá conozcáis, la de *La Tarara*. Para quien no la conozca, es una canción popular española que ha trascendido de la mano del compositor Isaac Albéniz y del poeta Federico García Lorca. El primero utilizó su melodía como motivo principal de su obra *El Corpus Chirsti en Sevilla* de la suite *Iberia* (1906). Lorca también recopiló esta canción en 1931 en un disco grabado junto a la Argentinita. Esta canción, como la mayoría de canciones del mundo, están compuestas por tonos musicales de los que nuestra experiencia auditiva nos permite extraer muchas de sus propiedades físicas. Podremos identificar si los tonos son agudos o graves, si el volumen de su sonido es alto o bajo, y el timbre, o si lo preferís la "personalidad" de ese tono que nos permitirá identificar qué instrumento o persona lo emite. Los tonos se suceden uno detrás de otro y conforman intervalos, es decir distancias entre tonos y tonos. Como en *La Tarara*, gran parte de las melodías están compuestas por intervalos reducidos, con la repetición de la misma nota (intervalo de primera o unísono) e intervalos de segunda y de tercera. En los versos siguientes podemos observar que se componen íntegramente por este tipo de intervalos.

Otro rasgo universal referente a los intervalos musicales es que las notas que forman un intervalo de octava se perciben como equivalentes o con el mismo color, por eso les damos el mismo nombre a ambas aunque su altura sea diferente. Por ejemplo, la nota La que escuchamos en el oboe al comienzo de los conciertos de música clásica para ayudar en la afinación tiene una frecuencia de onda de 440 Hz, mientras que el siguiente La más aguda tiene una frecuencia de 880 Hz (justo el doble). De todos los intervalos posibles comprendidos en una octava como esta, las músicas del mundo generalmente utilizan solo un grupo limitado de tonos, entre cinco y siete. Este grupo escogido de notas es lo que llamamos escala. En general, las culturas adoptan escalas con distancias que no son equivalentes. La escala que estábamos usando para *La Tarara* es la de La menor, donde observaremos que la distancia del La al Si (ambas notas separadas por un tono, o segunda mayor) difiere de la distancia del Si al Do (medio tono, o intervalo de segunda menor). Y como con los intervalos de segunda, el resto de tipos de intervalos que podemos formar con las notas de una escala no son equivalentes; del La al Do existe un tono y medio de separación (tercera menor), mientras que del Do al Mi existen dos tonos (tercera mayor).



El hecho de que cada nota de la escala tenga una separación característica del resto, una especie de "perfil de distancias", nos permite asignar diferentes funciones a cada una de las notas y sentir que existen distintos niveles de relevancia y tensión/relajación entre ellas. Esto se conoce como tonalidad, y la nota que le da nombre, la nota tónica, es la que percibimos como más estable. Por eso, la tónica suele ser una de las notas más utilizadas a lo largo de la pieza y la que concluye la pieza. La tonalidad no solo se manifiesta en un predominio de la tónica, también se expresa en la percepción de una estructura de tensiones y resoluciones. El desplazamiento desde la tónica a la llamada dominante, a una distancia de quinta ascendente (La → Mi), se percibe como consonante, como un movimiento que "suena bien". Pero una vez en la dominante, la música se ve casi imantada a volver a la tónica (Mi → La). "Tónica" y "dominante" puede que os sean dos términos bastante ajenos, pero si pensáis en el clásico "chin-pon" que se utiliza como onomatopeya del final de una canción o, por extensión, de cualquier cosa, la sílaba "chin" tiene el sonido de la dominante y "pon" es la tónica. Tensiones y tendencias similares se experimentan cuando estamos en Sol, que pide subir hacia la tónica La; o en Fa, que nos mueve descendentemente hacia la dominante Mi. Además, este festival de tensiones y atracciones se ve envuelto en otros rasgos de la música, como aumentos o descensos en el volumen, y que acaban incendiando aún más esas dinámicas.

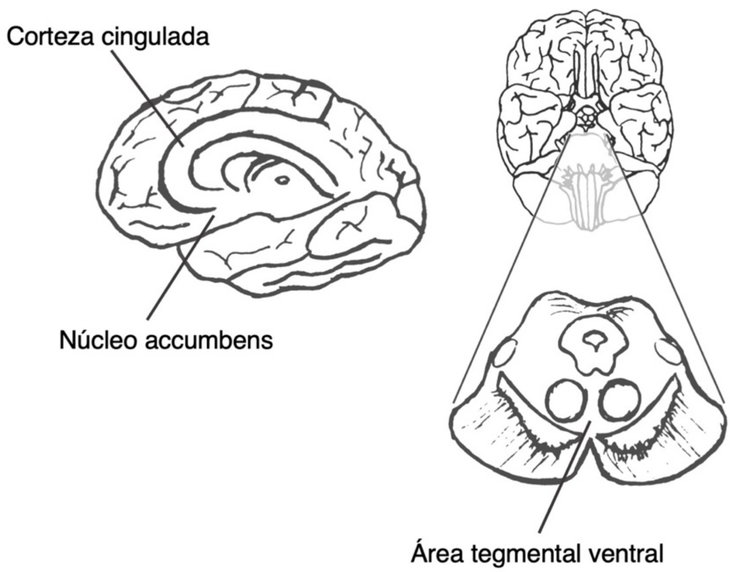
Con la tonalidad como contexto, como si fuera el fondo de un cuadro, las notas se suceden y conforman una secuencia característica de intervalos: la melodía. En todas las culturas, las melodías suelen ser motivos no muy largos, de unos cuantos segundos, que a menudo se repiten. La repetición es uno de los rasgos que distinguen a la música del lenguaje. Mientras la mayoría de canciones tienen un estribillo (por ejemplo, *La Tarara sí, la Tarara no, la Tarara madre que la bailo yo*), cuando hablamos, esa repetición de ideas no es habitual. Tendría el efecto de hacernos parecer demasiado insistentes, quizá hasta impertinentes. Es en la poesía y en algunos recitativos religiosos donde se evoca esta propiedad musical para embellecer el lenguaje. Lo vemos en la anáfora poética, en la que se repite la parte inicial del verso, como en la del Romance Sonámbulo de Lorca: *Verde que te quiero verde. / Verde viento. Verdes ramas*. O en los salmos responsoriales de la eucaristía católica, donde una sección de versos o antífona se intercala en la lectura del salmo. También, las melodías poseen un contorno característico de notas que ascienden hacia el agudo y, acto seguido, descienden. El contorno melódico nos permite abstraer la trayectoria de las notas y distinguir las melodías a pesar de los cambios acústicos. Así, no importa que una persona cante *La Tarara* una octava más aguda, seguiremos percibiendo que es *La Tarara*. Y lo mismo sucede si alargan la duración de las notas o si un piano toca la melodía en lugar de cantarla, como en la versión de Albéniz.

Esta identidad de la melodía con independencia de las pequeñas variaciones que se den en la versión se debe a nuestra propia forma de percibir la música. En general, los seres humanos percibimos las melodías de una forma relativa, donde las relaciones entre las alturas de los tonos, los intervalos y el contorno melódico, son más importantes que las alturas individuales de cada una de las notas. Por eso, decimos que tenemos un *oído relativo*. Lo contrario, la capacidad de identificar la altura exacta de cada nota sin ventajas al presentar otra nota de referencia con la que relacionarla, es una habilidad rara conocida como *oído absoluto*. Se estima que tan solo una de cada diez mil personas la poseen, o si vivís en una ciudad de unos 200.000 habitantes, os encontraréis con unas escasas 20 personas con esta habilidad. Aprovechando que estamos hablando de verde con el vestido de la Tarara y en el Romance de Lorca, imaginad que queremos comprar una tanda nueva de baldosas verdes igual a las que tenemos en la pared de un baño. Por supuesto, queremos que el color de las nuevas baldosas sea idéntico y si tenemos alguna baldosa antigua la llevaremos de tienda en tienda para comparar su color. Sin esa muestra, estaréis de acuerdo conmigo en que estamos perdidos. Somos capaces de distinguir una baldosa verde de una marrón o beige, incluso podemos distinguir sin la muestra si era un verde más pistacho, oliva, esmeralda, etc. Pero dentro de cada categoría de verde necesitaremos una referencia para encontrar el nuestro, de otra forma tendríamos que tener una categoría para cada tonalidad. Lo mismo sucede con los tonos musicales. Somos capaces de distinguir si un sonido es bastante agudo, muy agudo, medio agudo medio grave, etc., pero dentro de esas categorías no sabemos ser más precisos sin una referencia. Para ello necesitaríamos disponer en una memoria con un número muy grande de asociaciones nombre-nota (recordad que la afinación puede variar y podemos encontrar muchas frecuencias absolutas para la misma nota: La 440 Hz, La 442 Hz, La 436 Hz, etc.). Esta es la habilidad poco frecuente de las personas con oído absoluto. En la práctica no necesitan baldosa de muestra. Solo con escuchar una nota, aunque sea de forma aislada, no tienen problemas para identificarla.

Junto a la organización tonal, también existen rasgos de organización temporal que son universales en la música. Las notas se producen de una forma rítmica, manteniendo un pulso más o menos constante. Ese pulso podemos sentirlo y, escuchando muchas canciones, es casi inevitable sincronizarnos con él golpeando con nuestros pies o moviendo la cabeza. Cuando lo hacemos, podemos observar fácilmente que el intervalo de tiempo entre un golpe de pie y el siguiente es constante en toda la canción. A su vez, ese pulso principal marca el inicio de cada compás o grupo rítmico de notas, que se subdividen habitualmente en dos, tres o cuatro pulsos. Veámoslo en nuestro fragmento de *La Tarara*, donde he marcado con círculos el inicio de cada compás, justo donde coincidiría con el movimiento más impetuoso de cabeza si fuera una canción de rock: *LLE-*

va mi ta-RA-ra un ves-TI-do VER-de. Los compases se subdividen en dos pulsos, que he marcado con triángulos: *LLE-va MI ta-RA-ra UN ves-TI-do VER-de*. El primero de ellos coincide con el inicio del compás, lo que hace que su acentuación sea mayor y, en cierto sentido, lo convierten en más relevante que el segundo pulso de la subdivisión. Más aún, las notas forman grupos o patrones rítmicos en torno a esos dos pulsos, en este caso siguiendo un patrón también binario (que he marcado con líneas finas y gruesas). El resultado final es que en cada compás escucharemos la mayoría de veces cuatro sonidos iguales en duración, pero diferentes en acentuación y relevancia en el ritmo. Otras veces, como en el tercer y cuarto compás, se producen silencios, pero el flujo rítmico no cesa en nuestra cabeza puesto que forman parte de una estructura superior, la canción. A pesar del silencio, podemos seguir sintiendo el pulso de la música y los instrumentos o voces pueden tocar *a tempo*.

Con estas bases, la música es uno de los estímulos más placenteros que existen. Nos hace llorar, nos recorre la espalda con escalofríos y nos pone la piel de gallina. La investigación en el laboratorio demuestra que todos esos cambios de éxtasis emocional se acompañan de cambios fisiológicos como consecuencia de la activación del sistema nervioso simpático, dilatando las pupilas, aumentando la frecuencia cardiaca, la tensión arterial, la frecuencia respiratoria y la tensión muscular. También se activan otras partes más centrales del cerebro, aquellas que se ven implicadas en situaciones emocionales y de euforia, como el área tegmental ventral en el mesencéfalo, el núcleo accumbens, la ínsula o la parte anterior de la corteza cingulada. Así, en general, todas las personas experimentan esta respuesta orquestada de todo el organismo y acaban disfrutando de la música. La respuesta a la pregunta "¿te gusta escuchar música?" es casi obvia. Las estadísticas de Spotify, la plataforma de reproducción más importante en este momento, son demasiado claras: en todos los continentes sin excepción, sus usuarios escuchan una media de entre 100 y 140 minutos de música al día. Obviamente, mucha de esa música la reproducimos de fondo mientras hacemos otras actividades y quizá solo un pequeño porcentaje la escuchemos de forma atenta, pero cuesta pensar otra actividad que no sea vital y que repitamos con esa frecuencia.



La sensación placentera de escuchar música universalmente proviene de diversas fuentes. Así lo recoge uno de los cuestionarios más relevantes en el área de estudio, el *Cuestionario de Recompensa Musical de Barcelona* (BMRQ, en sus siglas en inglés). Como os imaginaréis lo de

Barcelona se debe al ser la ciudad en la que se desarrolló, en el grupo de investigación de Antoni Rodríguez Fornells. El cuestionario contempla cinco fuentes principales de placer con la música, la evocación de cambios emocionales (con preguntas como *Puedo llorar cuando escucho algunas melodías que me gustan mucho*), la tendencia a inducir movimientos, que contagian el entusiasmo o que implican secuencias motoras de tensión-relajación muscular y producen alivio (*Cuando escucho una melodía que me gusta mucho no puedo evitar mover el cuerpo*), la capacidad para regular nuestras emociones, sobre todo las negativas (*Con la música me puedo desahogar*), la propia necesidad de escuchar música y de satisfacer la ansia de conocimiento por ella, que algunas personas experimentan como un impulso (*Busco novedades musicales continuamente*), y la sensación de pertenencia y conexión con un grupo (*La música me hace conectar con la gente*).

Con respecto a la última fuente de disfrute, parece que universalmente el placer de escuchar música se intensifica al hacerlo en grupo, y mucho más si es activamente, cantando, tocando, añadiendo sonidos de percusión a la música o bailando. En todas las culturas, la mayoría de manifestaciones musicales se realizan en grupo, en conjuntos que incluyen cantantes, instrumentos musicales, y personas que se mueven y bailan al ritmo de la música. Debido a la abundancia de la expresión grupal, algunos rasgos que permiten mantener sincronizado al conjunto están muy presentes en las músicas del mundo: el uso de instrumentos de percusión, la existencia de un pulso principal constante y no *ad libitum* (como sucede en muchas piezas de solista), la repetición de motivos rítmicos y melodías en forma de estribillos, y el uso de un canto silábico en el que a cada sílaba le corresponde una sola nota. No es casualidad que una canción como *La Tarara*, creada para acompañar el baile del corro, tenga todas estas características. Por encima de la expresión y la inventiva, quienes cantan *La Tarara* cumplen con un plan musical diseñado para que el grupo encuentre la unidad a través del baile.

¿Unos universales culturales o innatos?

La música como fenómeno surge en el seno de una cultura, y de ella adopta muchos rasgos distintivos, como el tipo de escala, los ritmos o los instrumentos que se utilizan. Para el compositor Pierre Boulez "las preferencias musicales son en su mayoría un resultado arbitrario de la historia". Y Arnold Schönberg, célebre por alejarse de la tonalidad con su sistema dodecafónico, dio un paso más allá defendiendo que con la exposición suficiente, la música atonal se volvería tan popular como la música tonal. Estas palabras resuenan a las ideas del padre del conductismo, John B. Watson: "dadme una docena de niños sanos, bien formados, para que los eduque, y yo me comprometo a elegir uno de ellos al azar y adiestrarlo para que se convierta en un especialista de cualquier tipo que yo pueda escoger —médico, abogado, artista, hombre de negocios y, sí, incluso mendigo o ladrón— independientemente de su talento, inclinaciones, tendencias, aptitudes, vocaciones y raza de sus antepasados." Esta es una cita célebre dentro de la psicología que refleja, en la misma línea que Boulez y Schönberg con la música, una corriente de pensamiento del siglo XX que defendió un potencial radical de la cultura y de las experiencias vitales para determinar aspectos tan profundos como los gustos.

Sin embargo, la existencia de unos rasgos comunes a todas las culturas, junto a otras evidencias biológicas que trataremos a continuación, sugiere que los mecanismos que permiten la percepción y la producción de la música son "universales", variando solo en su adaptación a las convenciones de cada cultura. O, dicho de otra forma, parece que existe una distinción entre *musicalidad* y *música*. Por un lado, están las capacidades biológicas que nos permiten ser seres musicales (*musicalidad*), que tienen que ver con la evolución de nuestro sistema auditivo y nuestro cerebro, y, por el otro, los productos surgidos de la interacción de esas habilidades con una cultura que las moldea: preferencias musicales, canciones, bailes, etc. Antes de surgir la *música* como la conocemos, heredamos un conjunto, vamos a decir inaugural, de habilidades con el que interactuamos con la cultura musical de nuestro entorno. Con esa caja de herramientas iniciales que es la *musicalidad* y todas las experiencias musicales como materia prima, construimos desde muy temprano lo que entendemos por *música* en este momento de nuestra madurez.

De cómo evolucionan nuestras habilidades y nuestra percepción de la música hablaremos en los siguientes capítulos. Ahora solo daremos unas pequeñas pinceladas sobre esas habilidades fundamentales. Por ejemplo, el hecho de que las culturas escojan escalas con un número reducido de tonos, entre cinco y siete, en lugar de las doce notas posibles en el sistema occidental (como proponía el dodecafonismo de Schönberg) no es arbitrario. En general, las personas, que disfrutan con la música pero que no se han dedicado profesionalmente a la música como Schönberg, les resulta más sencillo percibir y memorizar las melodías cuando el número de notas es reducido. Cuando la canción solo utiliza siete notas y todas ellas ocurren en un contexto tonal estable, en el marco de una tonalidad, es muy sencillo distinguir la tónica de la dominante, si estamos al final o en la mitad de una frase y, en general, toda la música se organiza de forma sencilla en nuestra cabeza. Por tanto, el uso de escalas y tonalidades parece ser la consecuencia de unos sistemas de percepción y de memoria con limitaciones. Estos sistemas tienen sede en nuestros oídos y cerebro, que como cualquier otro órgano, tienen límites biológicos. Nuestros brazos tienen una amplitud máxima de movimiento, la vejiga tiene un volumen máximo, y para nuestra capacidad para discriminar sonidos y memorizar melodías sucede lo mismo.

Las notas que forman un intervalo de octava se perciben con una sensación de correspondencia, como la misma nota a diferentes alturas.

Sobre el origen de esta percepción se ha especulado que quizá surgiera del canto habitualmente al unísono de hombres y mujeres, en el que las voces de mujeres tienden a acomodarse mejor a una octava más aguda que la nota de los hombres. Pero no hay ninguna razón por la que esperar que sea a una distancia de octava, en lugar de una sexta o un séptima. Simplemente, cualquier sonido lo suficientemente agudo en comparación a la nota que cantan los hombres vendría mejor para la tesitura de voz de las mujeres. Parece más bien que es al contrario, el hecho de que exista una correspondencia en nuestra percepción de las dos notas motiva que muchos de los cantos al unísono de hombres y mujeres se hagan a una distancia de octava, a la distancia donde más se "siente" que están cantando a la par. Parece que un origen más plausible para esa sensación de octava se debe al análisis que realiza nuestro propio sistema auditivo de los sonidos que nos llegan. Sabemos que los sonidos que producimos con la voz y los instrumentos musicales son tonos complejos que están formados por una combinación de frecuencias componentes o armónicos. Cuando tocamos un La, cuya frecuencia fundamental es de 440 Hz, en esa nota también hay sonidos de frecuencias superiores resultado de multiplicar la frecuencia fundamental por un número entero ($440 \times N$), de ahí su nombre de armónicos. Los primeros armónicos de la nota La son un La una octava por encima ($440 \times 2 = 880$ Hz), un Mi ($440 \times 3 = 1320$ Hz), otro La aún más agudo ($440 \times 4 = 1760$ Hz) y un Do sostenido ($440 \times 5 = 2200$ Hz).

Todos estos sonidos se combinan en una onda compleja que, a su vez se suma a la del resto de sonidos de otros instrumentos y ambientales (uno de los clásicos es una persona tosiendo). Esta única onda amalgamada es la que llega a nuestros oídos y en la cóclea este barullo se disecciona en sus frecuencias esenciales. El cerebro debe posteriormente unir todas esas piezas acústicas y uno de los trucos que utiliza para recomponer la escena auditiva es usar la relación armónica de las frecuencias. Puesto que en la realidad las frecuencias que provienen de un mismo emisor, como acabamos de ver, suelen tener una relación armónica, esta es una buena pista para el cerebro auditivo para separar las piezas que pertenecen a unos sonidos y a otros (algo así como lo que hacemos con los puzles, que empezamos agrupando por regiones más o menos seguras, las piezas con azules para el cielo, las verdes para el césped, las ocres para las baldosas del camino, etc.). Años antes de que la ciencia tuviera estas respuestas, Leibniz expresaba una intuición similar: "La música es un ejercicio aritmético inconsciente en el que la mente no sabe que está contando. [...] En efecto, se equivocan los que piensan que nada sucede en el alma de lo que ella no sea consciente". Hoy sabemos que el cerebro realiza todo un mundo de operaciones que permanecen fuera de nuestra experiencia, pero que tienen el resultado final de poder distinguir el sonido de unos emisores y de otros. Lo más importante es que al tocar una nota La una octava más aguda (con frecuencia fundamental de 880 Hz) a la vez que una nota La de 440 Hz, estamos ejecutando una nota cuya frecuencia fundamental es consonante con el primer armónico del La 440 Hz. Otros intervalos que percibimos como consonantes o que "suenan bien" son la quinta (La-Mi o, como ya vimos, la secuencia tónica-dominante) y la tercera mayor (La-Do sostenido). Todas esas notas consonantes forman parte del repertorio de armónicos. En cambio, otros intervalos producen disonancia, como la segunda menor (La-Si bemol) o el tritono o cuarta aumentada/quinta disminuida (que puede tomar la forma de una cuarta aumentada, La-Re sostenido, o de una quinta disminuida, La-Mi bemol). ¿Y cómo suenan esos dos intervalos disonantes? En el famoso *Maria* de *West Side Story* que compuso Leonard Bernstein, las sílabas "Ma-ri" forman un tritono que sucede a una segunda menor en las sílabas "ri-a". Y la misma configuración (tritono-segunda menor) se repite en la apertura de Los Simpsons, con un tritono entre las notas "The-Simp", y una segunda menor en "Simp-sons". En todos estos intervalos los armónicos de las dos notas no coinciden, y generan una sensación de "vibración" o "batida" auditiva que nos mueve a deshacernos del acorde lo antes posible. Por tanto, el gusto de las culturas musicales por la octava y por la consonancia de la tercera mayor y la quinta emana de nuestra propia arquitectura biológica. La forma en la que nuestro sistema auditivo decodifica y recompone los sonidos inclina nuestras preferencias. No es una preferencia arbitraria como Boulez y Schönberg plantean. Y esto no excluye que seamos capaces de disfrutar con una segunda menor o un tritono. Como planteaba Leibniz, las disonancias pueden ser "sombras sobre orden y luz", un elemento que inyecte aún más placer en nuestra experiencia de la consonancia. Sea como sea, en la medida en la que nuestro sentido del oído es universal e innato, estos rasgos de la música también lo son.

Todas estas razones no son exclusivas de la biología humana. Los sistemas perceptivos y de memoria de otras especies animales también tienen limitaciones similares. De hecho, como en la música humana, el canto de las aves suele construirse con tonos discretos. No hablaremos de escalas, pero igualmente producen secuencias no muy extensas de tonos ascendentes y descendentes, y para ellas utilizan principalmente intervalos poco distantes como el de segunda o tercera. También, muchas especies de aves y mamíferos con aprendizaje vocal, la habilidad para controlar la laringe o la siringe para producir vocalizaciones, como las cacatúas y los leones marinos, son capaces de sincronizar el movimiento de su cabeza y de sus patas al ritmo de la música como hacemos los humanos. Y se han documentado formas de comunicación en primates a través del uso de herramientas como instrumentos de percusión. No es momento para entrar en el debate de la experiencia musical que viven todos estos animales, profundizaremos en ello en el siguiente capítulo. Pero el hecho de que manifestaciones así existan en otras especies y que tengan una forma similar a los rasgos "universales" de la música humana sugiere que existen condicionantes biológicos y que no son rasgos tan arbitrarios.

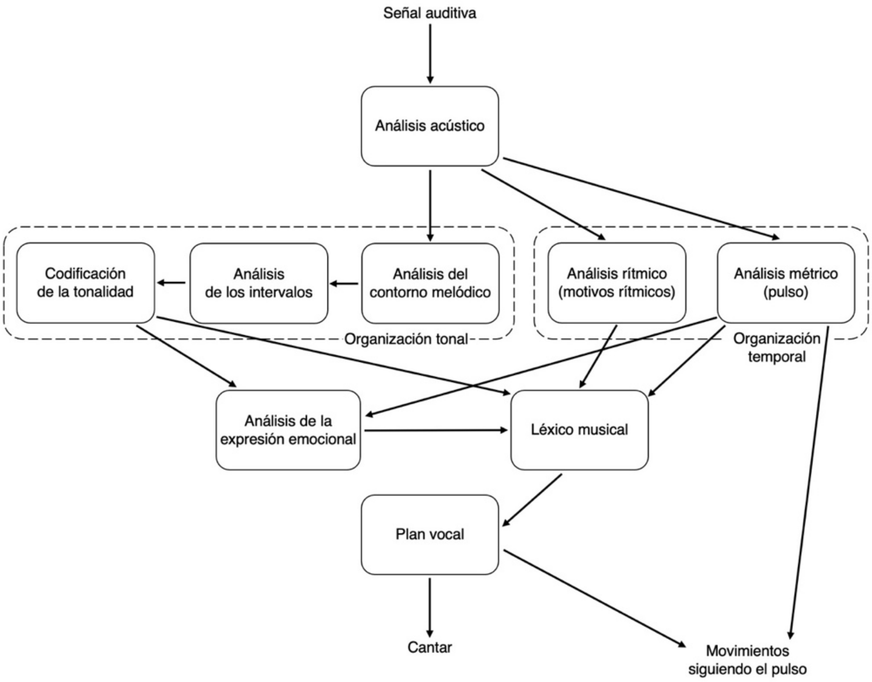
El origen está en el cerebro

> *Damos nuestros sentidos por sentados. Nos parece que el mundo visual, por ejemplo, se nos presenta con toda su profundidad, su color, movimiento, forma y significado, que todo casa perfectamente y está sincronizado. Dada esta aparente unidad, a lo mejor no se nos ocurre que hay muchos elementos distintos que componen una sola escena visual, y que todos ellos han de ser analizados por separado y luego combinados.*

Oliver Sacks (*Musicofilia: Relatos de la música y el cerebro*, 2007)

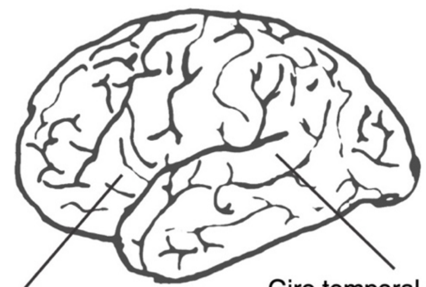
Estas palabras con las que el neurólogo Oliver Sacks describe nuestra percepción del mundo visual sirven también para comprender cómo nuestro cerebro construye la experiencia musical. La investigación en neurociencia poco a poco nos ha enseñado que la música que escuchamos, aquella que parece un único fenómeno en nuestra cabeza, en realidad se procesa parte a parte. La experiencia musical que vivimos es un mosaico visto desde la distancia, tan lejos como para que no podamos apreciar todas las pequeñas teselas que lo componen. Sabemos que algunas partes de nuestro cerebro se encargan de codificar los cambios en la altura de los sonidos, el contorno melódico, los intervalos y la tonalidad, de forma independiente a otro conjunto de áreas que se encargan de extraer el pulso y segmentar la pieza en unidades o motivos rítmicos. Os preguntaréis, ¿cómo hemos sido capaces de saber todo esto? Dos tipos de evidencia han sido fundamentales para que la neurociencia haya podido adentrarse de esta forma en la arquitectura del cerebro. La primera, y la más antigua, ha sido el estudio de pacientes con lesiones cerebrales. Como Sacks nos plantea, vivimos nuestro día a día como una experiencia fluida, donde todo se conecta, lo que vemos con lo que oímos, nuestros recuerdos con el presente, lo que somos y lo que no somos, si somos la misma persona que hace un tiempo o si hemos cambiado. Pero como neurólogo, Sacks trató a personas que desafortunadamente sufrieron un daño en su cerebro por una contusión en un accidente de tráfico, un ictus o la aparición de un tumor, entre otros. Estas lesiones con frecuencia merman algunas de nuestras capacidades mentales. El mosaico que conocíamos se desmorona y pierde algunas de sus teselas. Nos sonará la pérdida de memoria en la enfermedad de Alzheimer, o la pérdida de movilidad de un brazo o de una mano en algunos pacientes de ictus. Cuando podemos acotar bien las regiones del cerebro afectadas en la lesión, esto nos permite establecer relaciones entre la habilidad mental disminuida y las estructuras biológicas que están dañadas. El otro tipo de evidencia son los resultados de las técnicas de neuroimagen que han ido surgiendo a lo largo del siglo XX. Una de las que más ha revolucionado la comprensión del cerebro ha sido la resonancia magnética. Su exquisita resolución espacial permite reconstruir milímetro a milímetro el tejido neuronal. Y más aún, los avances de esta técnica hacen posible hoy no solo reconstruir la anatomía del cerebro sino también conocer cómo funciona y cómo responde a los estímulos del entorno.

En el caso de la música, la alteración neuropsicológica que más nos ha revelado sobre el cerebro musical ha sido la *amusia*. Quienes la padecen pierden la capacidad de percibir e imaginar ciertos aspectos de la música. Para las personas con amusia una pieza de piano puede sonar como una secuencia arbitraria de sonidos, o como un barullo de ruidos sin sentido y por eso ser irritante, puede que no sean capaces de identificar el pulso o quizá no reconozcan una melodía familiar como *La Tarara*. Son muchas las formas de amusia, pero el resultado es que, de una forma u otra, la música se desvirtúa, se transforma en un estímulo completamente diferente a lo que conocemos. El estudio de los casos de *amusia adquirida*, la que aparece en personas que habían vivido una vida plenamente musical hasta el momento de la lesión, muestra que la experiencia musical surge como consecuencia de la actividad de dos sistemas cerebrales diferentes, un grupo de áreas del cerebro dedicadas a la percepción del tono y de la melodía, y otro conjunto de regiones encargadas de la organización temporal de las notas. La investigadora Isabelle Peretz ha documentado casos de pacientes con un daño cerebral cuya capacidad para percibir el ritmo está alterada, pero su percepción del contenido melódico permanece intacta. Y, al contrario, algunas lesiones disminuyen las habilidades tonales, sin rastro de problemas en las habilidades rítmicas. Oliver Sacks cuenta en su *Musicofilia* dos episodios personales de *amusia al tono pasajera* que vivió durante unas crisis de migraña. Sacks estaba escuchando obras de piano de Chopin cuando de repente los tonos "empezaron a perder afinación y carácter, y en un par de minutos quedaron reducidos a un aporreamiento carente de tono con una desagradable reverberación metálica, como si tocaran la balada con un martillo sobre una plancha metálica". Algo muy importante de estos dos episodios es que su sentido rítmico permaneció intacto en todo el suceso ("me permitía reconocer la balada por su estructura rítmica").



Modelo de percepción musical de Peretz y Cotheart (2003)

Traslademos este modelo al cerebro. Con los casos de amusia adquirida, hoy sabemos de la existencia de un área del hemisferio derecho (ya sabéis que gran parte del cerebro se encuentra divido en dos grandes porciones o hemisferios) que trabaja especialmente en elaborar las relaciones entre tonos: el giro temporal superior derecho. En concreto, la llamada corteza auditiva secundaria. Y los estudios de neuroimagen han confirmado posteriormente que esta región responde intensamente a pequeños cambios en lo agudas o graves que son las notas y, a un nivel superior, a los cambios que aparecen en el contorno melódico, es decir la abstracción de la trayectoria ascendente y descendente de las notas. Curiosamente, un menor tamaño en esta parte del cerebro es una de las principales diferencias en las personas con oído absoluto. Al contrario que en la amusia, la percepción de la música en las personas con oído absoluto no está alterada. Pero una configuración distinta del cerebro musical tiene como consecuencia inevitable una experiencia de la música diferente.



El contorno melódico se matiza, además, con el análisis exacto de los intervalos. Esta operación es consecuencia de la cooperación de la corteza auditiva de ambos hemisferios. Por ejemplo, si entono la melodía de *La Tarara* como *mi-mi-mi-re-DO-mi-re-do* en lugar de *mi-mi-mi-re-FA-mi-re-do* (*lleva mi taRAra*), simplemente con el cambio en el contorno identificaríamos que algo ha cambiado en la melodía, que la música que antes ascendía en un punto y luego bajaba (*re-FA-mi*), ahora de repente es al contrario, baja y sube (*re-DO-mi*). Pero si el contorno no se ve modificado y solo cambia el intervalo entre las notas (*re-SOL-mi*: dos tonos y medio de ascenso frente a un tono y medio ascendente en el original), nuestro cerebro debe realizar un análisis más preciso para detectar el cambio. En ese caso, necesitamos una estimación exacta de la distancia entre las notas. Los pacientes con daños en la corteza auditiva derecha tienen especial dificultad para percibir el cambio en las melodías que se mueven con cambios pequeños, en intervalos de segunda y de tercera. Para ellos, todo se vuelve una "ruidosa confusión global". El problema es que la mayoría de las melodías se componen de estos intervalos, así que inevitablemente las personas con amusia se perderían una parte central de la música.

Cambio en el contorno melódico

Cambio en el intervalo

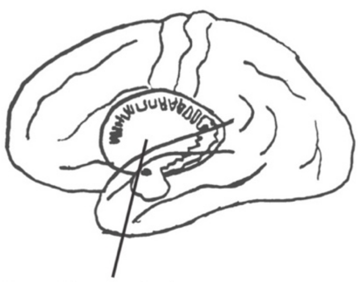
Cambio en la tonalidad

Es importante resaltar aquí que las dos desviaciones de la melodía original que hemos visto no suponen ninguna amenaza para la tonalidad; las notas que han cambiado en estos dos ejemplos, Do y Sol, son notas que la escala de La menor utiliza. ¿Y si fueran tonos fuera de esa escala, como por ejemplo un La bemol? Está claro que igualmente percibiríamos un cambio en la melodía. Pero esta vez algo más ha cambiado. Ahora el orden tonal, los cimientos sobre los que se está construyendo toda la canción, se balancean. Alteraciones de este tipo, sobre todo si no son accidentales y se prolongan en el tiempo, nos hacen sentir un cambio de la tonalidad en la que está escrita la música. De hecho, estos periodos de tránsito entre tonalidades son una parte fundamental de la música clásica, dado que generan una sensación de movimiento, de inestabilidad o, incluso, de tensión. En el periodo del Clasicismo musical, al que se adscriben figuras como Franz Joseph Haydn o Mozart, era muy habitual comenzar las obras estableciendo un tema en una tonalidad y acto seguido enlazar con un fragmento de inestabilidad o tránsito para dar paso a melodías en otra tonalidad diferente. La percepción de ese sentido de tonalidad parece depender de la comunicación de la corteza auditiva secundaria con regiones del cerebro más cercanas a la frente, la parte inferior del lóbulo frontal. Peretz documentó el caso de G. L., un hombre con amusia tras sufrir un daño en el lóbulo temporal izquierdo y el giro frontal inferior derecho. Como consecuencia de estas lesiones, G. L. tenía dificultades para sentir la tonalidad, como se manifestaba en su incapacidad para percibir las cadencias finales ("chin-pon") y las notas que no pertenecen a la escala. Sin embargo, su habilidad para percibir intervalos y el contorno melódico no estaba tan afectada.

Quizá la sensación de tonalidad sea una de las más únicas en la música, puesto que no aparece en otras formas de percepción auditiva como el lenguaje o los sonidos del ambiente. En general, las personas con amusia no tienen problemas para comprender las palabras en las conversaciones. Cuando Sacks vivió uno de sus episodios de amusia pasajera cuenta que bajó a hablar con su casero, y se dio cuenta que su voz y la de su casero sonaban perfectamente normales. El lenguaje suele estar tan preservado que muchas veces es la única vía para que las personas con amusia reconozcan la canción. "Todo lo que tenga palabras me va bien" decía D. L., otra paciente con amusia de Isabelle Peretz. Pero, incluso cuando la comprensión del lenguaje está mayoritariamente intacta, hay aspectos que la percepción de la música y la percepción del habla podrían compartir. Desde luego no la tonalidad, que hemos visto que es una de las propiedades más distintivas de la música. Sin embargo, nuestras preguntas o exclamaciones tienen una entonación diferente a cuando simplemente afirmamos. O muchas de las intenciones y emociones que expresamos se manifiestan a través de la prosodia. Estos rasgos de contorno melódico en el habla podrían también verse afectados en la amusia, aunque en muchos casos no suponen un problema reseñable dado que el contexto de la conversación ayuda muchas veces a que la comprensión sea igual de buena. Pero en otros casos la desventaja no es tan sutil, como en de las lenguas tonales como el chino mandarín. En estas lenguas la entonación de las sílabas tiene un papel central para distinguir las palabras. El uso de diferentes tonos con la misma sílaba cambia por completo la palabra: *mā* (madre), entonada con una altura aguda y sostenida, o *mǎ* (caballo), con una entonación grave al principio que ligeramente desciende y luego asciende al agudo. En estos casos, las personas con amusia tienen problemas más notables en la percepción del lenguaje.

Sobre la independencia de la música del lenguaje, también encontraremos el caso contrario a la amusia, pacientes con problemas en la comprensión del lenguaje o para hablar que disfrutan sin cambios de la música. A esta condición se la conoce como afasia y, como una especie de reflejo en el espejo de la amusia al tono, aparece con lesiones en el lóbulo temporal izquierdo. Y lo que puede ser más interesante, muchas personas con afasia pueden haber perdido la capacidad para hablar de forma fluida pero no tienen problemas para cantar canciones. En otro de sus libros, Oliver Sacks confronta esta disociación en música y lenguaje en un relato en el pabellón neurológico de afasia, donde un grupo de pacientes con afasia estaban "riéndose a carcajadas convulsivas" mientras escuchaban el discurso del presidente (parece que Ronald Reagan). Aunque su condición neurológica les dificultaba la comprensión pura del lenguaje, no podía parar de reír con la impostura y la falsedad que estaban percibiendo. "Eran, pues, las muecas, los histrionismos, los gestos falsos y, sobre todo, las cadencias y tonos falsos de la voz, lo que sonaba a falsedad para aquellos pacientes". Y del otro lado, Sacks cuenta la reacción contraria de una paciente con problemas en la percepción de la prosodia tras un tumor en el lóbulo temporal derecho, lo que se conoce como agnosia tonal o aprosodia. Como imaginaréis, agnosia al tono y amusia rara vez suelen ir por separado, mientras que la comprensión estricta del habla, la que se refiere al sentido expresado por las palabras, suele estar intacta. Por eso, esta paciente no se reía, estaba perpleja: "—No es convincente —dijo—. No habla buena prosa. Utiliza las palabras de forma incorrecta. O tiene una lesión cerebral o nos oculta algo." Por tanto, hay rasgos de la música como la tonalidad que son completamente únicos. Pero, en general, la música y el lenguaje se relacionan de una forma paradójica: mientras mantienen su identidad como capacidades diferentes, al combinarse dan lugar a experiencias mentales de una cualidad distinta.

Pero no solo nos quedemos en la percepción de la melodía y la tonalidad. La experiencia del ritmo musical depende de dos operaciones que se realizan más o menos con independencia en nuestro cerebro: la extracción del pulso y la identificación de los motivos rítmicos en la pieza. De nuevo, los estudios con pacientes han sido muy esclarecedores. Nos han enseñado que los daños en la corteza auditiva derecha pueden alterar la capacidad para mantener el pulso, mientras que los daños en el hemisferio izquierdo afectan especialmente a la percepción de los patrones rítmicos. Y, junto a las cortezas temporales, el cerebelo y los ganglios de la base también parecen contribuir a estas operaciones de organización temporal.



Una vez que nuestro cerebro ha elaborado todo el contenido tonal y rítmico, entra en juego la memoria musical y la extracción de las emociones. Todas las experiencias musicales que hemos vivido, una vez percibidas, se almacenan para poder reconocer si la melodía que estamos escuchando es nueva o no. Así, generamos reproducción tras reproducción, concierto a concierto, un *léxico musical*. A diferencia de otros tipos de memorias, las representaciones musicales son en esencia perceptivas. Las melodías, en sí, no tienen un significado como lo tienen las palabras. Aunque, por supuesto, se almacenan asociadas a más información: con emociones, con información del contexto de la música, como el título, el nombre de la cantante, la letra, etc. Como diría Bernstein, "si hay una historia, de acuerdo, a veces es bueno, aporta un significado extra. Pero es extra, no lo olvidéis". En todas estas operaciones cerebrales, la parte anterior del lóbulo temporal derecho, la que está más cercana a la punta de este lóbulo con forma alargada, parece que cumple el rol de léxico musical. Por otro lado, la música tiene ciertas características que son las responsables de provocar en nosotros cambios emocionales. Cuando la canción es lenta y está compuesta en una escala en modo menor causa sensaciones de tristeza, mientras que un ritmo rápido y escalas mayores conducen a la alegría. Una clasificación en alegre o triste es reduccionista en exceso, es solo un ejemplo al que debemos añadir la enorme gama de emociones. Como con el tono y el ritmo, la amusia ha mostrado que nuestra memoria y emoción para la música tienen sede en nuestro cerebro separadas del resto de operaciones. Pero, solo tras todos estos pasos, la música se convierte en música en nuestra cabeza. Porque el mosaico al completo es lo que nos conmueve, su historia y su diseño, que solo nos llegan una vez que cada tesela ocupa su lugar.

¿Cerebro cultural o cerebro genético?

Hasta ahora os he hablado de unas estructuras biológicas que imponen sus propias limitaciones sobre la forma final que adopta la música (los "universales") y que, si fallan, todo se desmorona. Nos podríamos preguntar ¿toda esa arquitectura estaba tal cual en los planos de la genética? Hablando sobre la música y el talento artístico, Fran Lebowitz cuenta esta anécdota:

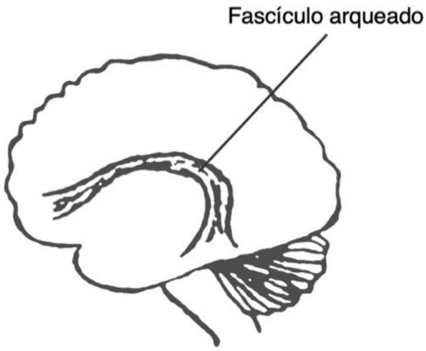
> *Recuerdo muy bien cuando les dije a mis padres: "tenemos que devolver el chelo [al colegio] y comprar uno". […] Y los oí pensando formas de pagar un chelo. Así que fui a la cocina. Supuestamente yo no los estaba escuchando, pero les dije: "No me compréis un chelo. No se me da bien. La verdad. No vale la pena. No os gastéis el dinero". Y mi madre dijo: "Bueno, eso es porque no estudias lo suficiente. Si estudiaras más, serías buena". Y yo le dije: "No, si estudiara más, sería mejor, pero buena no seré nunca".*

Este pasaje contiene la respuesta personal de Lebowitz a la pregunta de antes: el talento, o también la capacidad musical, "no depende de nada; no se puede comprar, no se puede aprender". El investigador Steven Mithen también pensó lo mismo durante décadas. Desde muy pequeño se sentía incapaz de entonar melodías sencillas, ni siquiera de mantener el ritmo con la mano. Después de varias humillaciones en el colegio con profesores de música que le hicieron cantar solo delante del resto de la clase, decidió abandonar cualquier expresión musical para siempre. Esta no es una historia poco frecuente. De hecho, se parece mucho a la de Lebowitz, pero la diferencia es que Mithen quiso dar una segunda oportunidad a sus habilidades musicales y, después de 35 años, volvió a recibir clases de canto. Para su sorpresa y la del neurocientífico Lawrence Parsons, quien escaneó su cerebro con resonancia magnética mientras cantaba, varias regiones de las que ya hemos hablado (los giros frontal inferior y temporal superior derechos) habían aumentado su actividad. ¡Las clases de canto habían cambiado la respuesta del cerebro musical de Mithen! Y junto a este estudio, la evidencia científica apunta a que el cerebro se reorganiza y cambia con la práctica musical. Por ejemplo, quienes aprenden a tocar un instrumento, tras horas y horas de práctica, acaban desarrollando una sensibilidad especial a los sonidos de ese instrumento. Así, la respuesta del cerebro de una violinista es más intensa a las notas de un violín que a las de una trompeta, y al contrario para una trompetista. También se puede estudiar cómo el cerebro representa el tacto rozando suavemente los dedos de las manos de una persona y observando su respuesta. En el caso de las violinistas, guitarristas y otras instrumentistas de cuerda, el rango de corteza que el cerebro utiliza para representar la información táctil de los dedos de la mano izquierda, justo la mano que usan para cambiar de nota al tocar, es mayor. Pero no encontraremos diferencias en el espacio de corteza cerebral que representa los dedos de la mano derecha y el pulgar izquierdo, que solo se utiliza para agarrar el instrumento. O cuando los músicos escuchan obras muy conocidas de su instrumento, muchas veces sienten como si sus dedos "se dispararan" a tocarlas en el aire. Este fenómeno no es solo una sensación, también las áreas motoras del cerebro están activas a pesar de que los músicos no estén moviendo las manos.

Por tanto, el cerebro es un órgano plástico, un órgano que se construye y reconstruye de mano de la experiencia. No puedo avanzar sin resaltar antes algo sobre el cerebro. El hecho de que sea un órgano biológico no lo convierte en una estructura determinada por la genética, como muchas veces se interpreta. Como vemos, su arquitectura es la consecuencia de la interacción entre las experiencias vitales y nuestro linaje genético como especie. Por supuesto el tejido neuronal no es plastilina. La experiencia no puede moldear a placer un cerebro humano y convertirlo en un cerebro de otro mamífero, por poner un ejemplo radical. Es una materia prima que tiene sus propias limitaciones e, incluso, sus propias tendencias. El oído absoluto tiene un componente hereditario y esto produce una tendencia: esas personas y sus familiares tienen una mayor probabilidad de desarrollar un cerebro que percibe la música con un oído absoluto. Pero de todas aquellas personas que tienen una predisposición genética, quienes comienzan su formación musical antes de los 6 años son las que realmente tienen una probabilidad alta de tener oído absoluto (hasta el 50%). Por tanto, el cerebro es el embudo; el punto en el que se encuentran experiencia y predisposición, cultural y genética. Desde este momento, si escuchamos "un mayor tamaño en una cierta área del cerebro se asocia con…" o, si nos vamos al nivel más molecular, "una disminución en un cierto neurotransmisor se relaciona con…", nos daremos cuenta que, a la base de los cambios neuronales de los que hablan, podrían estar tanto la genética como la cultura. Como diría Ted Gioia, "la biología reparte las cartas, pero son las condiciones sociales las que determinan cómo se juegan".

Pero si la cultura tiene tanta influencia en nuestro cerebro, ¿qué nos garantiza que existe un plan genético para la musicalidad humana? ¿No podrían los estudios de resonancia magnética estar analizando solo los cambios culturales en el cerebro? ¿Y si la amusia adquirida solo afecta a unas habilidades que son puramente aprendidas? Estas son preguntas de una gran profundidad, de ese tipo de interrogantes que necesitan mucha evidencia para llegar a una respuesta realmente convincente. A lo largo de los capítulos iré presentando muchos de los datos en los que la neurociencia se basa para afirmar que efectivamente, no existen dudas, somos una especie musical desde nuestras raíces genéticas. Aquí solo mencionaré un caso especial de amusia hereditaria que aparece desde el nacimiento: la amusia congénita. Este tipo de amusia se caracteriza por una alteración en la parte tonal de la música, en la percepción de la tonalidad, de los cambios en el contorno melódico, reconocer melodías y, como consecuencia, la incapacidad para disfrutar de la música. La paciente D. L., de la que hemos hablado, tenía amusia congénita y describía la música como "si estuviera en la cocina y tirara todas las sartenes y ollas al suelo". Los conciertos para D. L. eran aburridos, incluso un "sufrimiento", a los que acababa asistiendo solo por cortesía. Pero no tenía problemas para bailar con los chavales en la calle, para disfrutar del claqué y del sonido de las conversaciones. Lo que más nos interesa ahora del caso de D. L. es que provenía de una familia muy musical en la que a todas horas había música a su alrededor, si no era su padre tocando un instrumento, era su madre, si no, eran los discos de música. Y a pesar de todo el ambiente musical y del esfuerzo de su familia por estimular la pasión de su hija por la música, D. L. nunca pudo vivir un mundo musical. Pudo adquirir el ritmo, la destreza sobre los pies para bailar, la lingüística para comunicarse. Pero la música nunca llegó a su mente.

La herencia genética en este tipo de amusia produce un subdesarrollo en una de las principales vías de comunicación del giro temporal superior y del giro frontal inferior: el fascículo arqueado. Así, el origen de la amusia congénita no es un daño en estas dos áreas del cerebro, sino un problema de desconexión hereditario. Es paradójico, porque al disponer de una corteza auditiva secundaria funcional, el cerebro de las personas con amusia congénita puede detectar cambios en las alturas de los tonos, pero solo a nivel cerebral. Esto lo sabemos porque la corteza auditiva secundaria se sigue activando ante los cambios de tono. Sin embargo, la falta de comunicación con las regiones del lóbulo frontal impide que el cambio detectado a nivel cerebral, o la "diferencia cerebral", se convierta en una diferencia en la sensación consciente. ¿No es fascinante? ¿Cómo un cerebro que discrimina en la trastienda no consigue que sus hallazgos se hagan conscientes? Parece que para las operaciones tonales más complejas (generar un contorno melódico, la sensación de tonalidad, etc.), la información auditiva se amplifica y se reelabora en la corteza frontal. Pero al interrumpirse esa comunicación temporal-frontal, ninguna de esas operaciones complejas se lleva a cabo y lo que queda es una masa arbitraria de sonidos, un "ruido de ollas al caer".



Por lo tanto, la mayoría de nosotros nacemos al mundo como seres musicales. La pérdida innata de musicalidad en la amusia nos lo recuerda. Es cierto que aún no hemos sido capaces de definir qué es exactamente la música, y quizá nunca lo seamos, pero no hemos parado de usarla. Allá donde hemos ido, la música nos ha acompañado en nuestras ceremonias, en la privacidad del hogar, con nuestra pareja, nuestra bebé o en soledad. Y sus extraños efectos no dejan de fascinarnos. Tan etérea en forma (es solo una onda en el aire) y tan sólidas sus consecuencias sobre la materia. Cuando esa onda nos alcanza, nuestra sangre líquida fluye a una velocidad distinta, moviliza nuestro cuerpo y, con la emoción, nuestros deseos, prioridades, pensamientos… Todo cambia. Tras este breve recorrido por el concepto de la música, respondamos al resto de preguntas. Adentrémonos un poco más en su misterio.

El comienzo de la sinfonía

Sobre los albores de la música

Tierra seca,
tierra quieta
de noches
inmensas.

(Viento en el olivar,
viento en la sierra).

Tierra
vieja
del candil
y la pena.
Tierra
de las hondas cisternas.
Tierra
de la muerte sin ojos
y las flechas.

(Viento por los caminos.
Brisa en las alamedas).

Federico García Lorca (*Poema de la Soleá, 1931*)

Para hablar de los orígenes de la música, tendremos que imaginarnos un paisaje muy diferente al que vemos en nuestras calles. Tendremos que alejarnos de las salas de conciertos y deshacernos de todo el ladrillo, todo el asfalto y todo el hormigón de nuestra vista. Incluso los árboles. Imaginémonos un paisaje inmenso de hierba, un horizonte con pocas fracturas, algunas rocas, algunos arbustos. Imaginémonos grandes estepas como las de la Patagonia o las de Rusia. Para hablar de las primeras músicas conocidas tenemos que trasladarnos al último periodo glacial, no muy lejos del momento en el que las capas de hielo comenzaron a crecer antes de extenderse por la Tierra, aproximadamente 30.000 años atrás. En este periodo, Europa estaría viviendo un descenso radical en sus temperaturas (hasta 8–10 ºC menos en Europa central). La aridez y la falta de lluvias formarían grandes estepas-tundra que irían desde España hasta Canadá atravesando Europa, Asia y Norte América por el puente de Beringia. Un horizonte poblado de manadas de bisontes y mamuts lanudos con un cielo sin nubes, completa y eternamente despejado. Visualizad la noche, gélida y oscura, más inmensa que de costumbre sin el relieve de las nubes y ante la linealidad imperturbable de la llanura.

En este paisaje veremos a nuestros antepasados *Homo sapiens* cobijarse del frío y de la vista de los depredadores en cuevas. Los veríamos allí, aprovechando la existencia de una de las grandes salas con una hoguera iluminando sus rostros mientras trabajan. Algunos *sapiens* estarían calentando carne en el fuego, mientras otros estarían limpiando la piel del animal cazado con una piedra a modo de raspador. El suelo lleno de utensilios de madera, hueso y piedra. El filo de roca lascada atraviesa y trocea la carne. Un punzo fino atraviesa la pieza de piel ya limpia y la une a otra. Y de fondo, desde el otro lado de la hoguera proviene un sonido rítmico, la percusión recurrente de dos *sapiens* más que trabajan piedra contra piedra para elaborar algunas herramientas. Incluso imaginaría que entonan sílabas sin significado, el sustrato vocal justo y necesario para hacer nacer una melodía. Y por debajo, el acompañamiento de las lascas, de la colisión constante de las piedras. No tengo duda que ya en ese momento de la historia la música estaría muy presente en las jornadas de los *sapiens*. Y os preguntaréis, ¿cómo podemos saber de los hábitos musicales de los humanos de hace 30.000 años?

Los primeros instrumentos musicales

Conocer los hábitos de vida de los *Homo sapiens* de aquel momento de la historia es una tarea difícil. Con tantos miles de año de por medio y con la degradación de gran parte de los registros, hechos en maderas y materias orgánicas que se descomponen fácilmente, apenas quedan vías para conocer cómo fuimos y qué hicimos. Lo que más nos ha enseñado sobre la vida musical de los humanos de antaño han sido los hallazgos arqueológicos de instrumentos musicales primitivos. Independientemente de la complejidad de la técnica, por definición, un instrumento musical es todo objeto que se usa para producir música y alterar las emociones a través del sonido. Puede ser un hueso para generar ritmos o una caracola a través de la que soplar. No importa que parezca muy simple o que no se parezca nada a los instrumentos de elaboración sofisticada que tenemos hoy. Con solo demostrar que la finalidad principal de ese objeto fue la de producir ritmos o melodías, nos indica que la música podía ser ya una costumbre bien arraigada en esas sociedades primigenias. Los *Homo sapiens* aparecieron en África hace 300.000 años atrás y desde allí se lanzaron a explorar el mundo. Poco a poco fueron habitando Asia (desde 130.000 años atrás) y Oceanía (65.000 años atrás). Pero el tiempo cubre y degrada, y convierte en una auténtica hazaña que nos llegue cualquier rastro de la vida de aquellos *sapiens*. Tantos miles de años de distancia es una travesía larga que debilitaría hasta la voz más fuerte. Por eso, puede que no sea casualidad que los primeros instrumentos hallados daten de la llegada de nuestra especie a Europa (45.000 años atrás) en lo que se conoce como el Paleolítico Superior. Son flautas hechas de hueso sobre las que no existe duda de que su función fue musical. Las primeras de estas flautas se encontraron en los yacimientos de la sierra del Jura de Suabia, en el sur de Alemania, un área llena de grutas y cuevas ricas en hallazgos arqueológicos. Esos objetos, conservados a lo largo del tiempo, nos hablan de la cultura de aquellas sociedades paleolíticas. Las cuencas y colgantes de las cuevas del Jura de Suabia indican que utilizaban ropas con piezas ornamentales. Y la gran cantidad de figurillas de animales y hombrecillos nos abren la puerta a su representación del mundo. La mayoría de figurillas son de animales que habitaban la zona, caballos y bisontes, pero sobre todo de animales con una gran fuerza y peligro, los mamuts y los leones de las cavernas. Algunos de estas figurillas tienen agujeros, por lo que quizá acabaran utilizándose como colgantes o piezas de embellecimiento de la vestimenta. Pero dos de las figuras más fascinantes del conjunto sugieren algo más que un gusto por la ornamentación. La Venus de Hohle Fels, una figura de una mujer con un desproporcionado énfasis en los atributos femeninos. El segundo es el Hombre león, una figura antropomorfa con cabeza y brazos de león, y cuerpo y piernas humanas. Los rasgos de estas estatuillas y su descubrimiento en lugares destacados de las cuevas han llevado a pensar que son figurillas de dioses y más que un uso estético, serían unas de las primeras evidencias de un pensamiento religioso en nuestra especie.

Entre todos estos objetos, bellos y espirituales, estaban las primeras flautas inequívocamente musicales. La mayoría de ellas estaban hechas de los huesos cúbitos y radios de las alas de aves como buitres y cisnes. Hay muchos rasgos de estas flautas que hacen evidente que no fueron objetos improvisados, como el limado de su superficie, las líneas a modo de marca para localizar la posición de los agujeros, y la práctica de agujeros con una hendidura con forma cónica que facilitaría la oclusión con los dedos. Estas características hablan de una cultura longeva de construcción de este tipo de instrumentos. Puede que sean los más antiguos que se hayan preservado, pero esa elaboración planificada sugiere que la experiencia en el uso de flautas era una costumbre implantada en aquellos grupos de *Homo sapiens*. A esto hay que añadir el hallazgo de una flauta de marfil en la cueva de Geissenklösterle y algunos fragmentos de otras. Sus características son muy similares al del resto de flautas de huesos de ave, con la excepción de que hacer una reproducción así en marfil de mamut no es una tarea tan sencilla. En primer lugar, los huesos cúbitos y radios de aves están naturalmente huecos, son de un tamaño apropiado y su material se trabaja con facilidad. El marfil de mamut, al contrario, crece en capas, como las anillas de los troncos de los árboles y para crear de ahí una flauta se requiere aserrar el marfil por la mitad, eliminar las capas internas y volver a unir las dos piezas con algún tipo de material adherente, como resinas. Resulta inverosímil pensar que quien hizo esta flauta no conocía muy bien lo que quería construir exactamente. En un objeto de esta complejidad, hasta improvisar con los detalles (dónde posicionar los agujeros, cómo hacer la embocadura, etc.) parece osado.

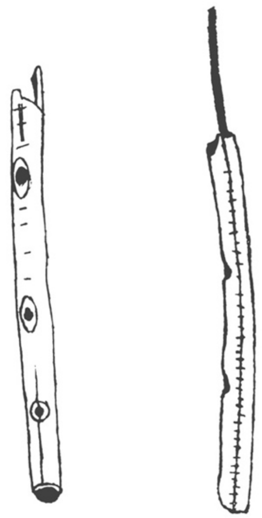


Imagen de dos flautas paleolíticas halladas en Geissenklösterle, la de la izquierda hecha de hueso de cisne y la de la derecha de marfil de mamut

Ante la flauta de marfil de mamut, también de 43.000 años atrás, es fácil pensar que en el momento en el que se hizo ya existía una cultura musical bien desarrollada. Es probable que quienes hicieron la flauta de marfil también exploraran con otro tipo de materiales para fabricar flautas, muchos de ellos más sencillos de manipular, como la madera. Junto a los instrumentos de viento, que requieren de un estudio sofisticado para controlar la posición de los agujeros y las notas que producen, quizá también fabricaran instrumentos de percusión, como maracas, instrumentos de raspado parecidos al güiro moderno o bramaderas. Sin embargo, la madera, las membranas y pieles animales, las telas de araña, los frutos, las semillas, etc., todos ellos son materias degradables que difícilmente nos llegarían desde aquel tiempo. Así, lo más probable es que en la misma época de estas flautas paleolíticas ya existiera todo un mundo de objetos musicales que no hemos podido conocer. Y lo que es más importante, aunque las flautas del Jura de Suabia son los instrumentos musicales más antiguos que se hayan descubierto, todo lo que las rodea sugiere que la música ya existía miles de años atrás. No olvidemos que la voz y el propio cuerpo humano son excelentes instrumentos musicales. Es incluso posible que los *Homo sapiens* hubieran tenido una extensa vida musical antes de recurrir a cualquier objeto fabricado. De hecho, las formas de música más frecuentes en muchas tribus recientes fueron predominantemente música vocal con ciertos acompañamientos de percusión sobre el cuerpo o pequeños instrumentos de materiales degradables. Es lo que justo sucede con las tribus norteamericanas de los pies negros y los siux, y con los yupik del sudoeste de Alaska. En mi mente imagino los grupos de *sapiens* paleolíticos cantando, entonando al unísono melodías repetitivas, o incluso estructuras musicales más complejas de pregunta-respuesta. Mientras, algunas personas acompañarían con ritmos o marcando el pulso con los golpes de dos piedras. A día de hoy no conocemos exactamente cómo fueron esas expresiones musicales y creo que es muy probable que nunca lo sepamos. Pero me gusta pensar que detrás de los huesos de cada *Homo sapiens*, allí, ocultos a quien sea que los observe, se encuentran los instrumentos musicales primigenios. Como una realidad que sugiere, pero no se revela. Como el hueco de algo que se fue, ¿qué sería? Como el sobre de una carta que, solo quizá, existió.

Un comportamiento moderno

Las primeras flautas paleolíticas son solo la punta del iceberg de una industria de objetos que han aparecido en los yacimientos arqueológicos en la Europa de 40.000 años atrás. Creaciones como los abalorios, colgantes e instrumentos musicales de las cuevas del Jura de Suabia hablan de humanos que no solo estaban preocupados por comer y resguardarse del frío. Son objetos propios de culturas desarrolladas, que ornamentaban su cuerpo y embellecían con música el ambiente de la cueva. Probablemente cantando y bailando, en una especie de rito religioso, buscarían influir en el mundo espiritual o conseguir el favor de dioses como la Venus y el Hombre león. La moda, el arte, la música, la religión. Estos comportamientos, cada vez más cercanos a lo que hacemos hoy, se los ha llamado *modernos*, en contraposición a las conductas de nuestros antepasados homínidos: las *conductas modernas* del *Homo sapiens*. *Modernas*, también, en la medida en la que expresan una capacidad inédita de comprender el mundo de una forma abstracta y simbólica. Las figurillas y pinturas que nos han llegado de aquel tiempo son evidencias de una habilidad para representar realidades del mundo con otros objetos. Lo relevante no es el trozo de marfil o la mancha de pigmento sobre la pared, sino la realidad a la que sustituyen. Con la figurilla de un león de las cavernas, los *Homo sapiens* podían interactuar con un sustituto de esa criatura sin poner en riesgo su vida. ¡Ya veo a los niños paleolíticos huyendo de ese falso león, lo suficientemente real en sus mentes para justificar una buena carrera, pero lo suficientemente inofensivo como para hacerlo entre risas y empujones con el resto de la pandilla! Bajo esta comprensión del mundo, lo que vemos y escuchamos dejan de ser solo realidades sensoriales para convertirse en realidades que se entrelazan unas con otras y crean un mundo que es etéreo, que es semántico. Cuando podemos utilizar símbolos de esta forma, al igual que en el presente se distribuyen carteles que hacen aparecer a los grupos de música en cualquier lugar y a todas horas, el león de las cavernas pudo trasladarse en el tiempo y en el espacio en forma de figurilla. ¿No es curioso que la representación haya prevalecido a lo representado, que ya no haya leones de las cavernas, pero perdure su símbolo en las vitrinas de un museo? Lo más interesante de aquellos objetos es que no eran siempre realistas, podían ser una transfiguración de la realidad, como con el cuerpo de la Venus; una ficción, como una criatura mitad hombre mitad león; y hasta formas abstractas sin conexión alguna con lo representado. La capacidad de representar dio paso a los símbolos, y algunos de esos símbolos se convirtieron en palabras. Cada página de este libro es solo una evolución sofisticada de aquella capacidad para intercambiar una realidad por otra y operar sobre un mundo más manipulable.

Pero no solo el razonamiento de los *Homo sapiens* era moderno. También lo era todo el desarrollo tecnológico que ha aparecido en los yacimientos. Los tipos de herramienta se diversificaron y se volvieron cada vez más especializados (punzones, proyectiles, cuchillas de piedra, etc.), la dieta y los materiales de fabricación se ampliaron, y el uso de pigmentos permitió pintar tanto las paredes de cuevas como el propio cuerpo. Hoy sabemos que todos estos desarrollos son el resultado de una acumulación de conocimiento generación a generación, milenio a milenio. Aunque los objetos que evidencian la modernidad de la conducta son especialmente numerosos en la Europa de 40.000 años atrás, no significa que las conductas modernas surgieran en aquel momento. A nivel anatómico, los *Homo sapiens* eran ya modernos desde 100.000 años atrás cuando aún solo vivían en África y Oriente Medio. Y en esas regiones también se han encontrado objetos de una "modernidad" clara, como las piezas de ocre grabadas de 77.000 años atrás encontradas en la cueva de Blombos, en Sudáfrica. Lo interesante de esos grabados es que son completamente abstractos, con patrones de líneas entrecruzadas que no hacen referencia a ningún animal o planta existente. Por tanto, los utensilios encontrados en Europa, en todo caso, pertenecieron a una fase avanzada de una cultura que surgió en África mucho antes de que los *Homo sapiens* se lanzaran a explorar otros continentes. Así, la música, junto a todas las conductas modernas, probablemente surgieron en África y desde ahí se expandieron a cada rincón del planeta acompañando a los *Homo sapiens*. Pero lo relevante para mí no es el lugar, sino el momento. De nuevo, no es descabellado pensar que la musicalidad ya existía muchos miles de años antes de las primeras flautas, casi con los albores de los *Homo sapiens* modernos. Quién sabe si incluso antes.

Música, que no sonido

Por supuesto, las flautas de las que hemos hablado no fueron los únicos objetos que los *Homo sapiens* paleolíticos fabricaron para producir o amplificar sonidos. Pero de nuevo nos topamos con la difícil tarea de decidir cuándo el sonido se convierte en música, y si un objeto que se usó como *instrumento sonoro* fue, a su vez, un *instrumento musical*. Además de las sofisticadas flautas de hueso, en los yacimientos europeos abundan los silbatos de falanges de animales, habitualmente de reno. Estos pequeños tubos de hueso tienen un único agujero por el que, al soplar sobre él, emana un tono agudo (entre 1500 y 4000 Hz, entre cuatro y nueve octavas por encima del La que se utiliza como referencia en la afinación de la orquesta). Muchos aspectos convertirían a estos silbatos en un instrumento musical rudimentario, comenzando por su limitación a la hora de producir melodías con un solo tono o, a lo sumo, varios al modificar la embocadura. Quizá este obstáculo pueda salvarse con un poco de ingenio, cuando combinamos varios de estos silbatos con diferente tamaño en una especie flauta de pan. Sin embargo, es más plausible que los *Homo sapiens* no pretendieran fabricar un instrumento melódico, sino una herramienta útil para la comunicación lejana y en la coordinación de la caza. Esta no es una hipótesis descabellada sabiendo que su sonido es audible a más de un kilómetro de distancia y que, usado con destreza, permite mantener conversaciones a largas distancias parecidas a las que tienen los pastores de la Gomera o del pirenaico Valle de Aas con sus lenguajes silbados. Más curioso aún, los experimentos modernos con estos silbatos, y otros similares de los pueblos nativos de Canadá de principios del siglo XX, demuestran que sus sonidos no alteran ni ahuyentan a las manadas de renos.

Al igual que los silbatos de falange, lo que aparentemente fueron rocas o huesos para la percusión podrían haber sido simplemente percutores para la talla de piedras. ¿Y si los dientes de los güiros paleolíticos sirvieron para mejorar el agarre del objeto o como una especie de ábaco? ¿Y si las supuestas bramaderas fueron en realidad pesos de pesca o colgantes? Es difícil responder sin haber sido testigos de cómo se usaron. Solo el hecho de que algunas piezas con marcas de percusión hayan aparecido junto a las famosas flautas hace volar nuestra imaginación hacia escenas orquestales. Pero tenemos que ser conscientes de que nuestra mente está ávida de música y, a veces, los pasajes de piedra son solo eso, de piedra; no tienen mayor pretensión artística. Una de las excepciones es un conjunto de huesos de mamuts encontrados dentro de una choza también construida con huesos hace 20.000 años atrás en Mezin, Ucrania. La conocida como "orquesta de huesos" es una rica colección de piezas decoradas con pinturas y grabados, con signos de raspado, golpes, sonajeros, mazos, conchas marinas, etc. Aunque tampoco hemos sido testigos del uso que se le dio a este ajuar de instrumentos, su abundancia casi clama una escena de varios *Homo sapiens* creando música con el conjunto orquestal más antiguo de la historia.

En un mundo plenamente tecnológico como el nuestro, los problemas prácticos reciben sus soluciones a base de diseño, energía y dispositivos. En un mundo así, la música habita el rincón de los placeres y emociones. Pero en el Paleolítico, la recreación en el sonido se mezcló con la subsistencia. El goce quedaba al amparo de la funcionalidad de la música. La tribu de los pies negros de Norteamérica practicaba una técnica, digamos, “musical” de caza que ya se usaba antes en la Prehistoria. Consistía en atraer a las manadas de animales a un desfiladero con canciones que simulaban el mugido de un carnero, para después hacerlas caer despeñadas. También, todo indica que los *Homo sapiens* prestaron mucha atención a la acústica de los sitios que habitaban. Por lo general, las grandes pinturas rupestres, las de los grandes bisontes y las figuras humanas con arcos que se nos vendrán a la cabeza, suelen concentrarse en los espacios con mejor resonancia dentro de las cuevas. ¡Es fascinante cuán matemático es! Cuanto mayor sea el número de ecos y su duración dentro de una de las salas de la cueva, mayor cantidad de arte rupestre alberga. Por un lado, la resonancia tiene la virtud de amplificar la voz e, incluso, de convertirla en un sonido completamente diferente. Aquellos *sapiens* paleolíticos descubrieron que al golpear algunas de las estalactitas y estalagmitas, se convertían en auténticas arpas naturales en el interior de aquellas salas, como sucedió con los pliegues de una de las paredes rocosas de la cueva de Nerja conocida como el *Órgano*. Sin duda se deleitaron con las impresionantes posibilidades acústicas que ofrecían aquellos sitios. Las pinturas de algunos de los recesos de las cuevas, pequeños agujeros donde apenas cabe el cuerpo de una persona, delatan la inquietud sonora de estas primitivas sociedades. ¿Por qué pintar una procesión de humanoides junto a un agujero cercano al suelo, como en la cueva noruega de Solsem? En esos interiores, las notas graves entonadas con la boca cerrada se apoderan de todo el espacio y se transfiguran en sonidos animalescos. Es tan sencillo imitar allí el sonido de un bisonte, que se le ha dado este nombre al fenómeno: *efecto bisonte*. Conociendo el estrecho vínculo entre las pinturas de las cuevas y la sonoridad, la presencia aislada de puntos rojos en las paredes de algunos túneles ha resultado especialmente intrigante. El estudio de la acústica ha confirmado que esos puntos coinciden con las zonas de máxima resonancia de aquellos pasillos de piedra. ¿Tal era su obsesión por la música que hasta en los oscuros túneles buscaban los recodos más sonoros? Lo más probable es que, además de placentera, la entonación fue una parte fundamental de la exploración a oscuras dentro de las cuevas. Quizá utilizaran algunas lámparas pequeñas, pero serían insuficientes para iluminar aquella inmensidad de roca. Sin embargo, con el sonido podrían orientarse a ciegas. Si el sonido se amplificaba, era la señal de una gran sala. Si el suelo no devolvía pronto el sonido, significaba que había un agujero y que el siguiente paso no sería tan firme. Al final, existen pocos testimonios de aquel momento, algunas piedras y algunos huesos que han sobrevivido a la erosión del tiempo. Por eso, nuestra idea sobre las primeras músicas solo puede ser vaga. Pero todo lo que nos queda habla fuerte y claro de un ser humano que colmó desde un principio todas las actividades, desde las espirituales hasta las de subsistencia, de una exuberante sonoridad.

Música animal

Los *Homo sapiens* se despertarían en su amanecer como especie siendo seres musicales y, en aquel amanecer, contemplarían de una forma renovada los sonidos de la estepa. Escucharían el ritmo continuo de las gotas de nieve derretidas al calor de la mañana, o el *crescendo* y el *diminuendo* del viento surcando la llanura. Pero también advertirían el canto de los pájaros y el relinchar de los caballos, los coros de las ranas y los rotundos barritos de los mamuts. Envueltos en tanta música, ¿no nos preguntaríamos si llegábamos a una sinfonía ya en movimiento? ¿Y si no somos la única especie animal con una sensibilidad musical? ¿Y si solo somos una voz más de toda la orquesta? Determinar el grado de musicalidad de otras especies es apasionante, a la vez que una labor extremadamente compleja, dado que conlleva entender desde fuera la mente de animales que no comparten con nosotros ni siquiera los órganos sensoriales. Lo primero es que, no todos los sonidos animales que parezcan musicales a nuestros oídos humanos provienen de mentes musicales. Los patrones del aire pueden ser muy melódicos, hasta inspiradores (que se lo digan a Vivaldi en el primer movimiento de su *Invierno*), pero no estamos hablando de un ser musical. Sucede lo mismo cuando percibimos caras en las manchas del mármol o en el gotelé de las paredes, las llamadas pareidolias. Y es que somos seres ávidos de rostros, de vida social y, de la misma forma, de música. Por otro lado, las canciones animales como tal, como las de pájaros cantores y ballenas, son señales de comunicación esenciales para la supervivencia. Con estas canciones, los animales alteran el estado emocional de quienes las escuchan, pero no por puro disfrute, sino para defender su territorio o atraer a una pareja sexual. Es cierto que a veces veremos a pájaros jóvenes cantando a solas, como en una especie de práctica en privado de los motivos que luego exhibirán en la temporada de cortejo, lo que se ha conocido como *subcanciones*. Este *sottovoce* puede que no tenga interlocutor, pero no es una actividad recreativa. Su función es la de ensayar un comportamiento clave para el cortejo. Si me apuráis, esta puede ser la mayor diferencia entre la "música animal" y "la música humana". Sin canciones, los humanos perderíamos una valiosa fuente de placer, pero la supervivencia de nuestra especie no estaría gravemente comprometida. Los *Homo sapiens* vivirían una existencia más gris y solitaria, seguro, pero no dejarían de existir. Sin embargo, las expresiones musicales para los animales cantores son un elemento crítico, independientemente de lo que disfruten con ellas.

Como veíamos en el capítulo anterior, la musicalidad humana es el resultado de todo un mosaico de habilidades. Aunque, por separado, muchas de las teselas de ese mosaico están presentes en otras especies. Por ejemplo, los macacos Rhesus, una especie del sudeste asiático de cara rosada, interpretan que dos melodías son iguales cuando una de ellas es justo un intervalo de octava más grave o agudo que la otra, pero se comportan como si fueran dos melodías diferentes cuando el intervalo de la trasposición es otro distinto. Esto sugiere, una vez más, la singularidad con la que los primates experimentamos el intervalo de octava. Los macacos Rhesus tampoco perciben la semejanza entre las dos melodías cuando son atonales, quizá porque la ausencia de escala las hace difíciles de memorizar o reconocer. Así, los Rhesus tienen una vaga habilidad para reconocer el contorno melódico, que en otros primates está definitivamente ausente, como en los monos capuchinos, que escuchan las melodías fundamentalmente con oído absoluto. También compartimos con muchos monos la capacidad para distinguir entre sonidos consonantes y disonantes, pero parece que ellos no experimentan la tensión emocional de los intervalos disonantes o el placer con los intervalos consonantes. Es lo que hemos aprendido de una serie de estudios con titís cabeciblancos, un mono que debe su nombre a la cresta de pelos blancos estilo David Bowie, en los que se manipulaban el sonido de fondo de los dos espacios de un laberinto en V. Los titís pasaron más tiempo en el espacio con ruido suave al espacio con ruido fuerte, o prefirieron el espacio con el sonido de otros titís comiendo a gritos de titís estresados. Sin embargo, no tuvieron una preferencia clara entre acordes consonantes (de octava, cuarta, quinta) y acordes disonantes (acordes de segunda menor o tritonos). Solo algunos de nuestros parientes más cercanos, como los chimpancés, comparten nuestra preferencia por la música consonante. Por tanto, aunque la diferencia entre acordes consonantes y disonantes existe a lo largo de muchas especies de primates, los conceptos de consonancia y disonancia expresan una experiencia humana. Solo quienes percibimos placidez con el intervalo de octava podemos utilizar el calificativo *consonante* (del latín *consonare*, estar en armonía), o solo cuando el tritono tensa nuestras emociones llamaríamos a este intervalo *disonante* (con el prefijo *dis-*, lo contrario).

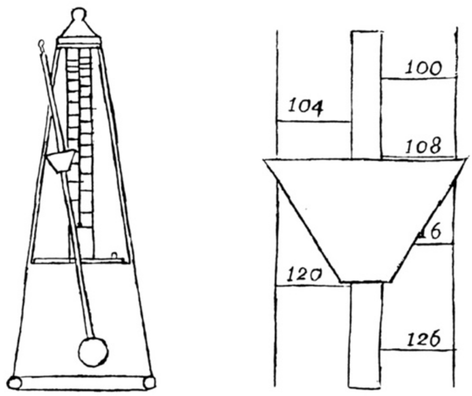
Con nuestros parientes los primates no solo compartimos rasgos a la hora de percibir la música. También ellos usan la percusión y otros objetos a modo de instrumentos musicales. Veremos a muchos simios golpeando con las manos su propio cuerpo u objetos resonantes, como los troncos huecos y hasta los cubos y los barrotes de las jaulas cuando están en cautividad. Es uno de los gestos más idiosincráticos de los gorilas, alzado, golpeando con agresividad y entre bramidos su pecho. Pero los gorilas no siempre lo hacen siendo feroces. A veces percuten sobre el suelo, los troncos o el cuerpo de otros compañeros a modo de juego. Por su parte, un hábito entre los chimpancés es percutir sobre las raíces de árboles, a lo que muchas veces sigue un grito de llamada, el primero que se nos viene a la cabeza de tantas veces escucharlo en la televisión o el cine. También los chimpancés han llamado mucho la atención con sus "danzas de la lluvia" y "de las cascadas", en las que expresan con balanceos rítmicos su inquietud ante las imponentes fuerzas de la naturaleza y sus sonidos. En la cima de lo instrumental se sitúan los orangutanes, que colocan hojas de plantas en frente de su boca para hacer más graves sus sonidos y dar la sensación de que son orangutanes de un mayor tamaño. Así, hay mucho del placer que sentimos al escuchar y hacer música que hunde sus raíces en nuestros rasgos ancestrales de primates. Hay cierta esencia de simio en los *riffs* de batería del jazz. Las palmas del flamenco, antes de acompañar a la madera de la guitarra, resonaron en su origen en unas manos más peludas, entre la madera de África millones de años atrás.

Las habilidades musicales no son un monopolio de los primates. Quizá sea atrevido equiparar a las arañas tañendo sus redes con un instrumento de cuerda. Pero los golpes que realizan las ratas canguro con sus patas para ahuyentar a los depredadores o los chasquidos de los pájaros carpintero sobre los árboles defendiendo su territorio son ejemplos sin fisura de percusión. Y cuando vemos el cortejo de las cacatúas negras tamborileando en los árboles con palos entre los dedos, ¿cómo no iba a evocarnos a los ritmos de las baquetas? El reino animal habla rotundo. Aunque algunas de las habilidades musicales de los *Homo sapiens* son únicas dentro de la familia primate, su utilidad las ha hecho irresistibles en otras especies. La naturaleza ha sido reincidente, y ha desarrollado una y otra vez la misma capacidad en linajes lejanos. Por supuesto, sin ninguna finalidad musical. Las canciones son el ejemplo más claro. Controlar nuestro aparato fonador para imitar las vocalizaciones de nuestro grupo o inventar las nuestras propias es una habilidad fascinante que muy pocas especies poseen. Nuestros parientes primates son incesantes vocalizadores y las llamadas de algunos de ellos, como los gibones, tienen una riqueza melódica y una belleza que difícilmente nos dejan indiferentes. Pero todas esas vocalizaciones son sonidos completamente innatos, esenciales para expresar sus emociones, aunque adquiridos sin aprendizaje. Entre los pocos animales capaces de aprender vocalmente y construir canciones están las ballenas, las focas y los pájaros (¡cómo no!). De las ballenas jorobadas sabemos que cantan siguiendo estructuras jerárquicas, de notas que se combinan en frases de unos 15 segundos, con las que a su vez construyen temas de varios minutos. Al final, las canciones de las ballenas contienen varios de estos temas, con una duración de unos 12 minutos (la mitad de una cara de un LP), y pueden repetirse en bucle durante horas. ¡Se han registrado ciclos de canciones de ballena de hasta 21 horas ininterrumpidas! Una expresión del aprendizaje vocal de las ballenas es la rapidez con la que las canciones evolucionan, en un proceso de continua creación. Así, poco a poco han ido desarrollándose dialectos que varían de un lugar a otro, de Australia a Hawái, del Caribe al Mediterráneo. Ante una riqueza de motivos tan amplia, la construcción en bloques de las canciones (frases < temas < canciones) y la repetición del final de las frases a modo de rima son una ayuda muy valiosa para recordar estas complejas secuencias. Las canciones animales, como las canciones humanas, son el producto de la interacción entre la genética y la experiencia. Una biología que viene determinada, en parte, por nuestra condición como especie (¡una ballena es una ballena!), pero que se alimenta y crece de las creaciones y de la cultura del grupo del que somos parte. En nuestra especie, el gen FoxP2 es especialmente importante para el control vocal, hasta el punto de que sus mutaciones desencadenan alteraciones graves en el desarrollo del habla y de la pronunciación. Y junto a nosotros, el FoxP2 se expresa en regiones del cerebro de los pájaros cantores que son relevantes para el control motor y el aprendizaje de canciones. Pero esa base genética es solo el sustrato que hace posible la imitación, la práctica, la innovación, y el ensayo y error. Las canciones que escuchamos en los bosques no son la expresión de genes, en todo caso estos serían solo sus raíces. Independientemente de si es justo o no equiparar las canciones animales con las humanas, hay una gran belleza en observar que el mismo diálogo entre predisposición y experiencia se extiende por todo el reino animal.

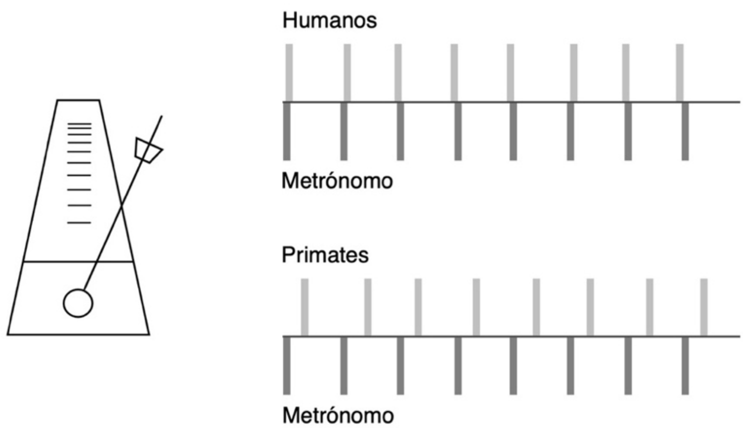
¿Por qué los monos no bailan flamenco?

La sincronización es la última de las habilidades musicales sobre la que hablaremos. Los fundamentos del ritmo están presentes en muchas especies. Ratas, palomas, periquitos y macacos Rhesus, por nombrar algunos ejemplos, son capaces de percibir la duración de los sonidos y de segmentar los cantos en grupos rítmicos. No puedo hacer que las páginas de este libro alberguen sonidos, pero seguro que me entenderéis con el siguiente ejemplo. Imaginad que canto dos sílabas "la", una más corta que la otra: "laaaa" y "laaaaaaaa". Una forma de saber si habéis percibido la duración de las sílabas sería pediros que me digáis cuál es la sílaba larga y cuál es la corta. También, podría pediros que me reproduzcáis las dos sílabas tratando de que se ajuste a la duración que habéis percibido en ambos sonidos. Es fácil, ¿verdad? Con procedimientos tan sencillos como este sabemos que la capacidad para estimar duraciones en muchos animales no tiene nada que envidiar a las destrezas humanas. Como hacemos los humanos, el sistema auditivo de estas especies utiliza, además de la duración de los sonidos, su intensidad, la altura de las notas y los silencios para segregar un motivo rítmico de otro. Sin embargo, para sincronizar nuestros movimientos y bailar con la música necesitamos, además, extraer el pulso y hacer que nuestros pies coincidan con él a tiempo. Habitualmente realizamos este tipo de *sincronización auditivo-motora* con música, que es un estímulo complejo con una estructura rítmica que sigue una extensa jerarquía de pulsos (pulso, compás, subdivisión del compás, etc.). Pero no necesitamos contextos musicales tan sofisticados para estudiarla. Las bases de esta capacidad ya afloran solo con pedir a las personas que sigan con el dedo el pulso de un metrónomo. Cualquiera puede hacerlo. Es una tarea tan sencilla que no importa si hemos aprendido a tocar un instrumento o no. La sensación del pulso es invasiva, recorre todo nuestro cuerpo de una forma casi evidente (digo casi porque todo se vuelve más ambiguo con algunos ritmos más complejos; ¿qué me decís del pulso de *Pyramid Song* de Radiohead?). Lo normal es que os sorprenda si os digo que, entre los animales, esta es una habilidad realmente exótica. La presencia del pulso es tan intuitiva que el propio Charles Darwin, sin muchas pruebas, pero tampoco dudas, planteaba que "la percepción, incluso el disfrute, de las cadencias musicales y del ritmo es común probablemente a todos los animales, y sin duda depende de la naturaleza fisiológica común de sus sistemas nerviosos". En esencia, Darwin nos dice con estas palabras: ¿cómo algo que sentimos tan profundamente va a ser único en los *Homo sapiens*? El biólogo Tecumseh Fitch no daba crédito a la paradoja de que el ritmo sea omnipresente, no solo en la música, sino en actividades tan esenciales como el desplazamiento animal (de nuevo vuelvo al ejemplo de los caballos galopando) y, sin embargo, que nuestra habilidad para extraer y sincronizar los movimientos con el pulso pueda ser algo tan raro. Si es una cuestión de experiencia, los perros llevan miles de años a nuestro lado escuchando canciones, lista de reproducción tras lista de reproducción. "¿Por qué no bailan los perros?" se pregunta Fitch. ¿Qué es lo que impide a la mayoría de animales bailar?

En la extensa familia de los primates, solo algunas especies han demostrado algunas formas bastante limitadas de sincronización con el pulso. En la tarea de seguir el metrónomo, los humanos de una forma espontánea y sin mucho esfuerzo son capaces de reproducir la secuencia y, lo que es más interesante, sus golpes de dedo se desvían poco con respecto al pulso, 10 o 20 ms antes. Esto es una evidencia de que el cerebro humano guía los movimientos siguiendo un modelo del tiempo, generando su propia expectativa de cuándo va a aparecer el próximo clic de metrónomo. Aunque también podemos seguir metrónomos visuales (un ejemplo fácil son las secuencias de parpadeos en los semáforos), los humanos hemos desarrollado característicamente estas habilidades con una predilección hacia los ritmos sonoros. Además, el cerebro trabaja de forma flexible para poder seguir el ritmo de pulsos rápidos o lentos (desde 200 ms hasta 1000 ms de separación entre pulso y pulso) o para no quedarse atrás cuando el pulso se acelera o desacelera dinámicamente en la misma canción. Quizá por eso hayamos tardado tantos siglos en descubrir por qué las indicaciones de *tempo* de Beethoven eran exageradamente rápidas. Hasta Beethoven, los compositores indicaban la velocidad del pulso con indicaciones generales (*presto*, *allegro*, *adagio*, etc.), pero todo cambió cuando el ingeniero Johann Maelzel regaló al compositor alemán el primer metrónomo industrial de la historia. Desde ese día, Beethoven comenzó a especificar la velocidad exacta que quería para sus obras ("♩ = 120", es decir, en un minuto deben caber 120 negras). O así habría sido de no ser porque leyó las indicaciones del metrónomo al revés. Beethoven interpretó la pesa con forma de trapecio como una flecha, tomando la indicación de *tempo* justo por debajo, cuando tendría que haber seguido el valor que indicaba la base mayor. Los 120 de Beethoven podrían haber sido 108 (en la primera página de su novena sinfonía hasta el compositor dudaba: “108 o 120 Maelzel”), algo que sería un enorme alivio para los intérpretes. Pero para la audiencia de la novena sinfonía, un *tempo* u otro no cambiaría nada, el pulso perduraría tan intenso a 108 como a 120.

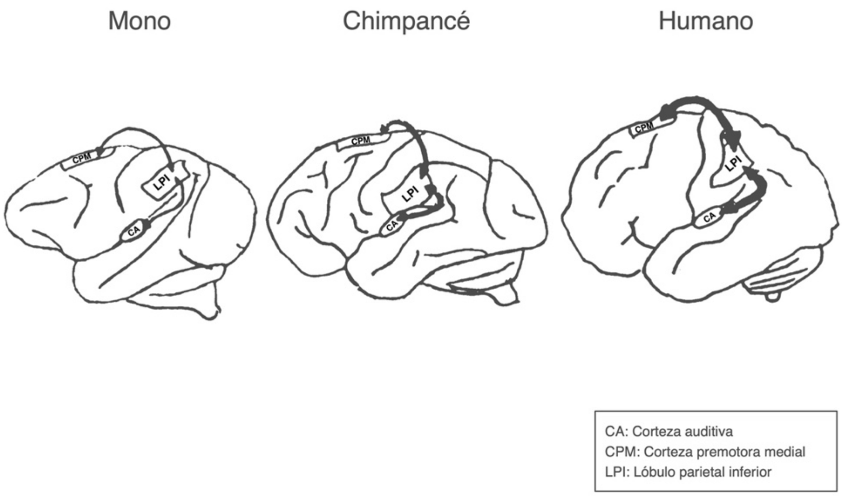


Mientras, la mayoría de primates tienen grandes dificultades para sincronizar su cuerpo con el ritmo. Por un lado, primates como los macacos Rhesus muchas veces no prestan una especial atención a sonidos de este tipo y cuando al final las investigadoras consiguen despertar su interés por los metrónomos, hace falta un largo entrenamiento hasta que al final consiguen que los Rhesus reproduzcan la regularidad de los metrónomos. Puede ser un proceso de uno o dos años de práctica intensa, con varias horas de entrenamiento al día, y el resultado la mayoría de las veces es un macaco golpeando a rebufo del metrónomo, siempre bastante por detrás. Al contrario que los humanos, el orden de los primates expresan una preferencia por los ritmos visuales; en la práctica, los ignoran menos y los reproducen de una forma más precisa. El grupo del investigador mexicano Hugo Merchant ha demostrado que la respuesta de los Rhesus puede ser anticipada como en los humanos, milisegundos antes del siguiente clic, pero esto solo sucede cuando, además del extenso entrenamiento, los macacos reciben recompensas por anticiparse. Con esas condiciones tan específicas incluso son capaces de seguir los ritmos en *ritardando* y *accelerando*, es decir, cuando se hacen progresivamente lentos o rápidos. Pero nada hace pensar que la sincronización sea instintiva en la mayoría de primates. Más bien, solo aparece en el repertorio de conductas del animal tras un largo aprendizaje. ¿No es esto lo que sucede con la habilidad de tocar un instrumento musical? ¿Quién diría que tocar el piano es un comportamiento espontáneo?



Merchant ha demostrado que el cerebro de los macacos Rhesus es incapaz de sentir el pulso tal y como lo percibimos. Para el ser humano el pulso es donde sentimos que el peso de nuestro cuerpo debe caer, donde debemos marcar con nuestra cabeza y nuestros pies. El pulso es donde cantaríamos la sílaba acentuada de la palabra más importante. Al pulso lo imaginamos antes de que suceda y también cuando no sucede. ¡Qué se lo digan al flamenco!, donde la mayoría de voces, a contratiempo, se acompasan gracias a la idea del pulso en su cabeza. Es un punto en el tiempo que imanta toda nuestra atención y movimientos. Por eso, si alguien desafina en ese momento o alguien da una palmada inexacta, no pasará inadvertido. Es un punto demasiado central. Pero no lo es para los Rhesus. Su cerebro al menos no reacciona diferente cuando los errores ocurren justo en el pulso. Sin el pulso, por mucho que un Rhesus practicara, jamás podría hacer flamenco, de organizar sus palmas a contratiempo. Sin pulso, no hay compás ni son.

Tras décadas de estudio, solo algunas especies de simios, como los chimpancés y los bonobos, han demostrado una capacidad de sincronización auditivo-motora más cercana a la humana. En estas especies no es necesario un régimen de entrenamiento, su incorporación al ritmo es espontánea. En el caso de los chimpancés, algunos ejemplares parecen experimentar una predilección por sincronizar su cuerpo con el sonido, no necesitan recompensas externas para hacerlo e incluso cantan acompañando sus balanceos [z]. También los chimpancés son los únicos primates conocidos que han demostrado seguir el ritmo de forma predictiva como en los humanos, anticipándose con un modelo mental. Pero parecen ser poco flexibles, siendo capaces solo de seguir el ritmo a velocidades muy restringidas. Sea como sea, esta cierta progresión en las habilidades rítmicas de nuestros parientes primates ha despertado la idea de una evolución gradual de la capacidad para sentir el pulso. En concreto, Merchant propuso junto al investigador holandés Henkjan Honing que la clave de esta habilidad está en la interacción entre las áreas auditivas y motoras del cerebro (el giro temporal superior que ya nombraba en el capítulo anterior y la corteza premotora medial), que están fuertemente conectadas en el ser humano a través del lóbulo parietal inferior.



Recordemos de nuevo que la evolución sensorial de los primates ha potenciado un predominio de lo visual. ¡Los primates nos enamoramos en la contemplación y en el tacto! En comparación con otros mamíferos arborícolas como las ardillas, los primates han experimentado cambios profundos en su visión: una expansión de las áreas visuales del cerebro, visión en color, ojos más frontales, y no en los laterales de la cabeza, que comparten gran parte de su área visual (campo de visión binocular), etc. Estos avances han sido importantes para la vida entre árboles de los monos, permitiendo que sus saltos de rama en rama sean impecables. El hecho de poseer dos ojos ligeramente separados en nuestra cara nos otorga una capacidad exquisita de percibir la profundidad y la tridimensionalidad del espacio. Además, incrementó la agudeza visual y la capacidad para detectar siluetas en la maleza, como la de los pequeños insectos, manjar para los primates primigenios, o la de una serpiente. Dado este curso evolutivo, es comprensible que en muchos de nuestros parientes la sensorialidad que mejor se integra con la faceta motora sea la visual. Para Merchant y Honing, solo los simios más cercanos al ser humano, los chimpancés y los bonobos, disponen de una mayor integración auditivo-motora a nivel cerebral lo suficientemente avanzada como para permitir cierta sensación del pulso. Todos los demás primates, incluyendo a los macacos Rhesus, pueden percibir la regularidad en los clics del metrónomo, pero no su pulso. Los Rhesus percibirán el intervalo entre los clics ("ahora viene un intervalo de 500 ms, otro de 500, otro, otro…"), pero no percibirán un orden de acentos ni el compás ("UN-dos-tres-cuatro-UN-dos-tres-cuatro…").

Fuera del orden de los primates, tan solo encontramos sincronización auditivo-motora en algunas especies de las familias con aprendizaje vocal, como el león marino de California, y muchos loros y cacatúas. El vídeo de la cacatúa Snowball bailando a los Back Street Boys ha dado la vuelta al mundo. También, hemos podido ver en vídeos al león marino Ronan marcando con su cabeza el ritmo de canciones de varios géneros. El hecho de que la capacidad de aprendizaje vocal esté presente en los linajes de estas especies sugiere que la sincronización motora es una condición biológica. Por muchas listas de reproducción a las que sometamos a nuestras mascotas caninas, nunca acabarán bailándolas mientras que los circuitos cerebrales sean los mismos.

La sincronización permite una escalada de complejidad de la comunicación, desde la creación de coros, grupos grandes de animales entonando a la vez, hasta diálogos turnados, con una estructura de "preguntas y respuestas". Hacer que todo un grupo de personas sienta un pulso común es lo que permite en la música que cada voz pueda hacer su entrada en momentos diferentes del compás, deslizarse, sincopar, enmudecer y volver al primer plano sonoro desde la nada. El metrónomo interno de las especies sincronizadoras es la base para tejidos sonoros complejos. ¡Quién escucha con frecuencia a Bach sabe a lo que me refiero! Y, ¿no son hipnotizantes los entramados de palmas en el flamenco, cada par de manos siguiendo un patrón diferente, casi todos a contratiempo! Los gibones protagonizan uno de los duetos más bellos entre los primates. Pero, además de ser vocalizaciones innatas, la estructura "pregunta y respuesta" del dueto se produce como a continuación de las entonaciones de la pareja. Como sucede en la tarea de sincronización con el metrónomo, los primates producen sus vocalizaciones como una reacción, sin un modelo de pulso o de compás. Los pájaros cantores exhiben duetos de una complejidad aún más avanzada gracias a sus habilidades rítmicas y de sincronización. Ejemplares como los cucaracheros colilisos, que habita los Andes, producen formas de canto con más de dos integrantes. El cucarachero suele vivir en grupos extensos de machos y hembras, y entre su repertorio cuentan con precisos cantos corales, con secciones alternantes de coros de machos y coros de hembras. Los integrantes de estos coros no cantan en todo momento, entran y dejan de cantar en sincronía, lo que hace más formidable esta forma de canto. Como en la música humana, estas obras corales de los cucaracheros demandan más que un simple "cantar como reacción al canto de los otros" para lograr que todas las voces del mismo coro produzcan sus sonidos a tiempo y coordinadas. Es ineludible. Si nos fundimos con el grupo bailando y siguiendo el ritmo es porque somos seres en sincronía. El pulso habita en nuestro interior y, desde ahí, en nuestras canciones.

Una canción solitaria

Lo que acabamos de ver es un baño de realidad. No somos los únicos animales en sentir el pulso en la música, sincronizar nuestro cuerpo con él, percutir, cantar, diferenciar la consonancia de la disonancia o experimentar la octava como algo singular. No nos pertenecen solo a nosotros. Lo que nos pertenece es la exclusiva combinación de todas ellas. Lo especial, lo que con gran probabilidad motiva que estéis leyendo estas páginas, es la propiedad emergente de todas esas capacidades musicales. En las especies que cantan, el cortejo y la defensa territorial depende de esa habilidad. En los animales que practican la percusión, el ahuyento de los depredadores o la comunicación social se ve comprometida sin esa conducta. Pero lo que fascina de la música humana es que ha adquirido un valor que trasciende a la subsistencia: el placer. Nos deshacemos emocionalmente de una forma casi inmediata desde los primeros acordes de nuestra canción favorita y no es por la razón terrenal de encontrar una pareja o proteger nuestro salón. Simplemente nos deshacemos. Y no necesitamos más de esa canción. Que esté ahí, que siga siempre ahí cuando la volvamos a buscar. Todavía hoy no sabemos cómo las teselas dan paso a un mosaico con valor propio. Pero lo que la investigación ha dejado claro es que, al contrario de lo que pensaba Darwin, la música no es una capacidad bien repartida entre las especies animales. Nada más lejos de la realidad. La música es un mosaico exclusivamente humano.

Entre ocho y diez millones de años atrás, el antepasado común de los *Homo sapiens* y simios africanos como los chimpancés adquirió la capacidad de percutir y de sincronizarse. Aunque nuestros antepasados los australopitecos disponían de una anatomía vocal y neurológica no muy diferente a la de los simios de hoy, muchos de los rasgos que hicieron posible el aprendizaje vocal y el canto en los *Homo sapiens* surgieron en especies más antiguas del género *Homo*. Por ejemplo, hace dos millones de años el área de Broca, una región del cerebro en el giro frontal inferior izquierdo (que ya hemos situado en el capítulo anterior) muy vinculada a la habilidad de producir secuencias musculares complejas y del control fino de las vocalizaciones, vivió un notable crecimiento con el *Homo habilis*. Con el *Homo ergaster*, hace 1,8 millones de años atrás, se produjo el descenso de la posición de la laringe en el cuello, lo que facilitó desde entonces la movilidad de la lengua y amplió el rango de vocalizaciones posibles. Y en torno al *ergaster* siguieron apareciendo rasgos que acercaron más y más la capacidad de vocalizar de los *Homos* a las de la actualidad: un aumento de las inervaciones neuronales de los músculos torácicos, esenciales para controlar a placer la presión del aire que sale de los pulmones; cambios en los circuitos cerebrales que controlan la planificación y el control fino de los músculos orofaciales; las mutaciones del nombrado gen FoxP2, etc. Milenio a milenio, especie tras especie, la música fue llegando a nosotros entre los murmullos del bosque, como un susurro entre la maleza que poco a poco se va desvelando. Desde que la melodía llegó a nosotros ya no hubo fin. La escalada de géneros, instrumentos, contextos en los que hemos utilizado la música solo demuestra que su valor no ha dejado de crecer. Pero, si la música humana no es trascendental para la defensa territorial, para encontrar pareja o nuestra alimentación, ¿por qué este *crescendo*? ¿Por qué está cada vez más y más presente en nuestra vida? ¿Qué nos regala, que no es esencial para la vida, pero provoca que Nietzsche sintiera que "la vida sin música sería un error"? En este capítulo os he hablado de cómo comenzó la sinfonía. Permitidme ahora que hablemos de su por qué. Permitidme que os hable de los primeros regalos de la música.

Seres musicales

¿Por qué la música nos acompaña?

Si pensamos que un enigma no tiene una respuesta nunca la encontraremos.

Para explicar pautas culturales diferentes tenemos que empezar suponiendo que la vida humana no es simplemente azarosa o caprichosa. […] *Solo pido un favor, tened presente que al igual que cualquier científico, espero presentar soluciones probables y razonables, no certeras. Sin embargo, por imperfectas que puedan ser, las soluciones probables deben tener prioridad sobre esa inexistencia de soluciones*.

Marvin Harris (*Vacas, cerdos, guerras y brujas*, 1974)

Solo tenemos que situarnos frente al espejo para empezar a escuchar aquellos relatos que están inscritos en nuestro cuerpo. Al mirarnos quizá nos preguntemos si hay rincones que han cambiado. ¿Cómo los han tratado los años? ¡Ah, esa cicatriz! Fue de aquella caída tan absurda. ¿Disimulará hoy nuestra cara el sueño que tenemos? De todas las inquietudes que despierte esa imagen, no creo que vuestras primeras preguntas sean sobre el origen de las partes de nuestro cuerpo o la función de los órganos que lo habitan. Quizá eso solo suceda una tarde nublada, una de esas en las que escucharíamos a Miles Davis y solo nos apetece movernos despacio. Pero si indagamos en la imagen que tenemos delante no tendremos ninguna duda en adivinar por qué la naturaleza nos ha dado unos brazos, esos ojos o tales dientes. Sabemos la respuesta a por qué late en nuestro pecho un corazón que nunca hemos visto. También podemos observar sin misterio cómo nuestro torso se infla y desinfla, al empuje de unos pulmones que nos hacen respirar. ¿Os imagináis el susto de algo que crece y mengua en nuestro interior y no supiéramos por qué? Sin embargo, nos costará pensar con nitidez los propósitos de la naturaleza para dotarnos de muchas de nuestras capacidades mentales, sobre todo en aquellas que son únicas en los seres humanos. Por ejemplo, los animales son capaces de aprender y almacenar sus experiencias en la memoria. Pero los recuerdos humanos son diferentes, contienen imágenes de un tiempo y un lugar en el pasado, que nuestra mente recobra en el mismo presente. No es solo que las experiencias que vivimos influyan en nuestras decisiones o en el futuro. Como señalaría el psicólogo Endel Tulving, el misterio de nuestra memoria se encuentra en la capacidad para viajar atrás en nuestra mente. En los recuerdos, los minutos caminan de espaldas, y con su paso logramos revertir la flecha del tiempo. De un vistazo ante el espejo no comprenderemos cómo la naturaleza ha diseñado habilidades de esta complejidad. Pero si nos tomamos algo más de tiempo para reflexionar, esbozaremos algunas hipótesis razonables. ¿Recordamos para no cometer los mismos errores? ¿Para permitirnos viajar por los posibles futuros?

De entre todas esas rarezas mentales del ser humano, el caso de la música es incluso más esquivo. Por un lado, la disfrutamos mucho y no queremos separarnos de ella, pero nos cuesta pensar en la verdadera utilidad que desde hace miles de años (ya hemos visto que podrían ser cientos de miles) permitió una mayor supervivencia de los *Homo sapiens*. Desde los trabajos de Darwin sobre la evolución de las especies, la comunidad científica busca, detrás de cada rasgo animal, los beneficios sobre la supervivencia que explican que se haya preservado. Una característica como la musicalidad, que se ha reproducido a lo largo de miles de generaciones y por todos los territorios en los que ha vivido el ser humano, es una gran sospechosa de cumplir una función adaptativa. Ha recorrido demasiado tiempo y demasiados lugares en el mundo como para ser azarosa. Pero, ¿y si la música nunca tuvo una función en la evolución de nuestra especie? ¿Podría ser tan solo el resultado de haber adquirido otras habilidades mentales, que unidas dan lugar a nuestra capacidad para apreciar la música? En definitiva, ¿y si la música siempre fue (y será) puro placer? Esta es la idea que el psicólogo Steven Pinker lleva defendiendo desde el siglo pasado. Para Pinker, el ser humano está dotado con una capacidad de razonamiento que ayudó en la obtención de alimentos, de garantizar nuestra seguridad y de potenciar los avances tecnológicos. Si las frutas estaban en ramas muy altas, razonaríamos que alcanzarlas con una vara larga era más eficiente que escalar el árbol. Pero, además, podemos utilizar el razonamiento para completar un puzle una tarde de domingo sin ningún beneficio evolutivo. En una de sus citas más célebres, Pinker comparaba la música con una tarta de queso auditiva:

> Nos gusta la tarta de queso, pero no porque hayamos desarrollado un gusto especial por ella. Evolucionamos con circuitos neuronales que nos brindaron chorros de placer ante el sabor dulce de la fruta madura, la sensación cremosa en la boca de las grasas y aceites de las nueces y la carne, y la frescura del agua fresca. La tarta de queso tiene un toque sensual que no se parece a nada en el mundo natural porque es una mezcla de megadosis de estímulos agradables que cocinamos con el propósito expreso de

> pulsar nuestros botones del placer. […] Sospecho que la música es una tarta de queso auditiva, un dulce exquisito elaborado para estimular los puntos sensibles de al menos seis de nuestras facultades mentales.

Pinker habla del lenguaje como una de esas adaptaciones humanas (las que sí fueron importantes en nuestra supervivencia) que permitieron que la música se desarrollara. Y es cierto que el lenguaje oral comparte mucho con las canciones. Hay mucho de contorno melódico en la prosodia, con la que distinguimos una afirmación de una pregunta ("es eso" o "¿es eso?"), y también hay mucho ritmo entre las sílabas, agrupadas en palabras, con sus acentos y sus partes débiles, conformando una cantinela semejante al pulso musical. ¿Recordáis la letra de *La Tarara* ("Lleva mi Tarara un vestido verde…") con todos los acentos dispuestos en un mismo patrón: UN-dos-UN-dos-UN-dos? El mensaje de Pinker es célebre porque es rotundo. Con su tarta de queso nos dice que la música no es necesaria, lo es el lenguaje. La música es una casualidad muy placentera de la evolución que proviene de otras facultades que verdaderamente han sido adaptativas.

Por un lado, no parece que haya una función obvia de la música más allá del placer. Y por otro, la idea de que la música sea únicamente una fuente de goce ha incomodado a muchas personas. Por ejemplo, Platón pedía en su tiempo desterrar *la música por la música*, la música debía tener siempre un fin educativo:

> La armonía, cuyos movimientos son de la misma especie que las revoluciones regulares de nuestra alma, de ninguna manera se aparece ante el hombre que tiene una relación inteligente con las Musas como simplemente buena para procurarle un placer irracional, tal como parece creerse actualmente. Por el contrario, las Musas nos han dado la armonía como un aliado de nuestra alma, ya que ella

> intenta llevar al orden y al unísono sus movimientos periódicos, que en nosotros se han desafinado.

Así, como instrumento educativo, la música podía aportar armonía al equilibrio turbado del alma y estimular el intelecto. También para san Agustín, quien definía la música como la ciencia de medir bien ("*Musica est scientia bene modulandi*"), el placer no debería ser un fin en sí mismo, sino una forma de estimular la fe y la devoción religiosa: "Pues aquel que canta alabanzas, no solo alaba, sino que también alaba con alegría; aquel que canta alabanzas, no solo canta, sino que también ama a quien le canta". Sin embargo, el placer puro era para san Agustín un instrumento sensual y de perdición: "Esto no obsta para que, cuando comprendo que me ha emocionado más el canto que las palabras que se cantaban, confiese que he cometido un pecado que habré de expiar, prefiriendo entonces no haber oído cantar nada".

Llegados a este punto, podríamos preguntarnos: ¿nos habremos obsesionado con encontrar una función evolutiva a la música? Para Pinker llevamos milenios inventando funciones para actividades "simplemente porque queremos ennoblecerlas con el visto bueno de la adaptabilidad biológica". ¿Se equivocaron Platón y san Agustín, entre otros, en buscar la trascendencia en la música? Voy a dedicar este capítulo a ofrecer las respuestas de la ciencia a estas preguntas. Si en el capítulo anterior resultó resbaladizo ofrecer respuestas al origen de la música, sobre todo por la escasez de evidencias que nos han llegado, intentar explicar el porqué de ese origen será un viaje completamente a lo desconocido. Sin ser testigos directos de aquellos primeros momentos de nuestra especie y viviendo ahora una realidad tan diferente, es muy difícil dar respuestas rotundas. Pero, siguiendo la filosofía de la cita de Marvin Harris del principio, las empresas difíciles no deben enmudecernos. Aunque no alcancemos soluciones certeras, vale la pena buscar respuestas probables y razonables al enigma. Y así haremos.

Una tarta de queso musical

Hay que admitir la fuerza de la metáfora de Pinker, tan sensorial que invoca sin barreras (¡en nuestra mente y en nuestro paladar!) el concepto que desea transmitir. Nos dice: los seres humanos hemos nacido para escuchar la naturaleza y comprender el lenguaje, lo de la música es una sofisticación. Pero la idea detrás de esta metáfora es tan antigua como las modernas teorías de la evolución humana. En 1844, un libro anónimo titulado *Vestigios de la historia natural de la Creación* sacudió la sociedad británica, sembrándola de un relato de evolución del universo que también incluía a los animales y al propio ser humano. El planteamiento de que las especies cambiaban con el tiempo y que las formas de los animales actuales eran diferentes a las formas primitivas era todo un desafío para el pensamiento cristiano más ortodoxo, que defendía que cada especie era ya perfecta cuando Dios la creó. Los *Vestigios* fue un superventas internacional que se infiltró rápidamente en las mesitas de noche de la aristocracia y la burguesía, aunque su autor, el periodista escocés Robert Chambers, no fue revelado hasta 1884 en la primera edición del libro tras su muerte, todo por temor a las represalias. Pero para ese momento las ideas evolucionistas ya habían inundado el pensamiento científico. Cuando el biólogo Alfred Russel Wallace leyó por primera vez los *Vestigios* quedó tan fascinado que desde 1845 se embarcó en varios viajes por el Amazonas y el archipiélago malayo para probar aquellas ideas en las especies exóticas de lugares remotos. Fruto de estas travesías, Wallace escribió en 1858 un ensayo sobre el origen de las especies con ideas muy similares a las que Charles Darwin ya llevaba años compilando en un monumental libro, titulado *Selección natural*, y que aún no había visto la luz. Pero nunca la vería. La coincidencia atemorizó tanto a Darwin que se apresuró a escribir un libro mucho más breve que el anterior, el famoso *El origen de las especies*, que se publicó en 1859. Y de nuevo un libro de la evolución se convirtió en un superventas internacional; las más de 1000 copias de la primera edición se vendieron en tan solo un día. Las teorías de Darwin y Wallace llegaban a una cultura preparada para aquellas ideas tras el antecedente de los *Vestigios*. Los *Vestigios* fue el relámpago de un enorme trueno. Ambas teorías ponían frente al espejo a toda una sociedad en su forma de comprender al ser humano como descendiente de los primates. Los científicos comprendieron que los principios que explicaban por qué somos como somos eran los mismos que para el resto de animales y se lanzaron a especular sobre el origen de cada rasgo humano.

En ese clímax evolucionista, el científico Herbet Spencer defendió en un artículo de 1857 que las raíces de la música estaban en el mundo de las emociones. Para Spencer, al igual que los perros mueven su cola como expresión de la alegría o los gatos ronronean de placer, las vocalizaciones musicales, que para Spencer eran la música primigenia, son la consecuencia muscular de una emoción. Como todo lo que existe, Spencer creía que la música más sofisticada en su tiempo, la de Beethoven, Mendelssohn y Chopin, era el culmen de un proceso evolutivo que se inició con formas musicales simples y muy similares, y progresivamente fueron diversificándose y ganando complejidad. Y desde Spencer hasta hoy, muchas otras figuras de la ciencia han defendido esta postura contraria a un origen adaptativo de la música. Entre ellas, uno de los padres de la psicología contemporánea, William James, quien entendía la música como "una mera peculiaridad" y como un rasgo "sin utilidad zoológica". Según James, la música era una reacción no pretendida en el diseño de nuestro sistema nervioso, que trata de resolver otro tipo de problemas realmente útiles. Como Pinker, él también utilizó comparaciones llamativas, equiparando "el amor por la música" con "el mareo a bordo de un barco" y "una intoxicación alcohólica", reacciones para las que sería absurdo, según James, suponer un origen que no sea accidental.

Por tanto, Pinker y su tarta de queso se han convertido en portavoces de una idea tan antigua como el debate de la evolución. Una idea que da una solución sencilla a la ausencia de una función evidente: puesto que la música es un accidente no es necesario buscarle una utilidad originaria. De este modo, se entiende que la música, como pura creación social, es un fenómeno en continuo cambio y con tanta diversidad de géneros. Sin embargo, la hipótesis de la "tarta de queso" tiene problemas para explicar algunas partes de esta historia. Por un lado, hacer música en el Paleolítico podía ser una osadía, cuando los *Homo sapiens* vivían rodeados por depredadores que podían atraer con sus cánticos. Y un ritual musical, con baile, percusión y todo al completo, es una ceremonia con un alto gasto energético. A ese precio, la música sería un lujo mayor al de una habitual tarta de queso. Quizá sería un lujo a la altura de un plato de langosta de alta cocina. Con unos costes tan altos y si realmente su utilidad hubiera sido tan reducida, la música sería un comportamiento que no podríamos permitirnos con frecuencia. Unos costes así, incluso, justificarían que la música, por muy accidental que fuera su origen, hubiera desaparecido, que tan rápido como hubiera llegado a nosotros se esfumara. Pero la historia ha sido justo la contraria. Como vimos en el capítulo anterior, las habilidades musicales han escalado rápidamente en las especies de primates y en nuestra especie, después de cientos de miles de años, ha seguido refinándose hasta niveles insospechados. Así, uno de los primeros argumentos en contra de la "tarta de queso" es la antigüedad de la musicalidad humana y su expansión por todas las culturas. La universalidad de la música sugiere que todos los seres humanos necesitan de ella. Seguramente los "tartistas" dirían que, en la medida en que la música emana de nuestra arquitectura cerebral diseñada para la emoción y el lenguaje, la música también debe de serlo. Para los "tartistas" la omnipresencia de la música y todo su refinamiento desde los primates sigue siendo el efecto colateral de un desarrollo en nuestras habilidades emocionales y lingüísticas.

Lo que no puede explicar Pinker es la independencia entre musicalidad y lenguaje a nivel cerebral. Ya veíamos que ambas capacidades comparten rasgos (la melodía y la prosodia, el ritmo y los acentos en las sílabas, etc.), pero en nuestro cerebro no son la misma cosa. Decíamos que la amusia es un problema neurológico que devasta de forma específica el mundo musical de la persona, pero no afecta a su lenguaje. Y, al contrario, en los trastornos cerebrales del lenguaje, la musicalidad humana se mantiene intacta. Tampoco, esta hipótesis explica que la musicalidad humana disponga de rasgos únicos, que ni la emoción ni el lenguaje pueden utilizar, como es la tonalidad. Solo en la música tiene sentido una organización de los sonidos en estructuras jerárquicas y complejas como la tonalidad. ¿Qué haría el lenguaje con esa habilidad? Se vería como cuando nos regalan un utensilio de cocina extraño de dudoso provecho. ¿Cómo funcionan estas tijeras para hacer croquetas? ¿Una "croquetera"? La tarta de queso o el plato de langosta son metáforas llamativas, pero, a la luz de las evidencias, resulta difícil creer que la selección natural no haya favorecido específicamente la música. Quizá su función no sea evidente, pero tampoco creo que sea una capacidad "sin utilidad zoológica".

Around the world, parents sing to infants and children sing songs*

Una de las principales fisuras en el modelo de la "tarta de queso" se encuentra en el hecho de que la musicalidad es una de las habilidades que se desarrollan más temprano, más incluso que el lenguaje. El feto empieza a escuchar en el segundo trimestre de embarazo y a partir del octavo mes de gestación responde de forma coherente a los sonidos que escucha. Así, el feto pasa meses escuchando la voz de su madre desde el interior de su útero y tras el nacimiento, aunque solo lleve unos cuantos días de vida, ya es capaz de reconocer su voz. Junto a las conversaciones de la madre, desde el útero también escucha la música de la televisión, las canciones en la ducha, los hilos musicales de las tiendas, etc. Aunque lo llamemos "recién nacido", el bebé viene a este mundo con una mochila repleta de experiencias sonoras. Por ejemplo, diversos estudios han demostrado que el bebé prefiere las nanas y cuentos que su madre ya les ha cantado o narrado repetidamente en los últimos meses de embarazo, es decir cuando aún habita en su barriga, a otras nanas y narraciones nuevas. Estas investigaciones muestran nuestra especial sensibilidad a las características musicales y que, incluso desde el útero, somos capaces de aprender y recordar melodías. En el caso de las narraciones de cuentos, no es el significado lo que el bebé memoriza, sino los aspectos acústicos de la voz, la entonación, los tonos que suben y bajan, el ritmo, las respiraciones y las pausas. Antes de comprender el contenido verbal del cuento, el recién nacido ya es capaz de acceder a la música que hay en esas palabras y

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* En todo el mundo, los padres cantan a los bebés y los niños cantan canciones (trad.).

recordarla. Como anécdota científica, un estudio de la década de 1990 aprovechó que la BBC emitía diariamente la telenovela australiana *Neighbours* para investigar el aprendizaje prenatal. Muchas de las embarazadas de esos años veían regularmente la serie y, por tanto, sus bebés habían escuchado la sintonía de cabecera cientos de veces durante el embarazo. Varios días después de su nacimiento, el estudio comprobó que los recién nacidos de estas madres reducían sus movimientos y su ritmo cardiaco al escuchar la sintonía de *Neighbours*. Esa exposición masiva a una canción en concreto, en general, tenía un efecto calmante en los bebés, algo que no sucedía con otras sintonías como la de *Coronation Street*.

A los seis meses de edad, los bebés ya perciben el contorno melódico, ese perfil de tonos arriba y abajo que decíamos en el primer capítulo que identificaba a cualquier melodía. Cuando un bebé ha aprendido una melodía como la del *Cumpleaños feliz*, no importa si la cantamos más lento, si en lugar de cantarla la tocamos al piano o si la entonamos muy grave. Ninguno de estos cambios impedirá que el oído relativo del bebé pueda reconocer la melodía. También, desde los dos meses de vida, los bebés prefieren los sonidos consonantes a los disonantes, expresando desagrado cuando las melodías están construidas con intervalos disonantes. Sorprendentemente, muchas de las habilidades musicales de los bebés prelingüísticos son similares a las de los adultos o en algunos casos incluso las superan. Todos los bebés nacen en una cultura con predilección por ciertas características musicales. Al exponernos de forma selectiva a un tipo de escala, nos volvemos menos sensibles a los cambios cuando las canciones están escritas en otras escalas. Al igual que los japoneses adultos tienen dificultades para distinguir los fonemas "l" y "r" en otros idiomas, los adultos occidentales tienen problemas para percibir alteraciones en las notas de melodías escritas en escalas diferentes a las occidentales. Sin embargo, antes de completar el proceso de culturalización, los bebés son igual de sensibles para las músicas de su propia cultura como a la de otras.

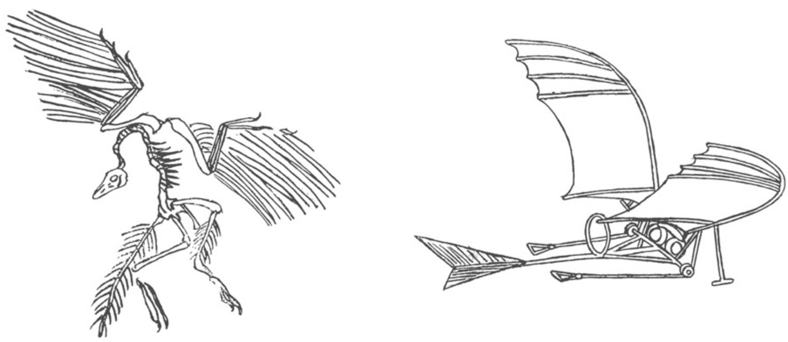
Al año de vida, los niños empiezan espontáneamente a cantar y a seguir con su cuerpo el ritmo de la música. No sé si habéis tenido la oportunidad de ver las reacciones de un niño de esa edad con el *Baby shark*, pero el despliegue de movimientos y vocalizaciones que desencadena es algo que merece la pena contemplar. Y entre los dos y los tres años los veremos reproduciendo canciones completas y marcando el pulso con las manos. En una etapa en la que sus construcciones verbales se limitan a frases de una o dos palabras, los niños de dos años son capaces de cantar melodías de decenas y decenas de compases, sin errores en la entonación y respetando el ritmo. A esa edad, el contraste entre la expresión verbal y la expresión musical del niño es demasiado evidente. Mientras las limitaciones lingüísticas obligan a estos niños a concentrar toda la expresión de ideas complejas en solo una o dos palabras ("aba" o "quero aba", para indicar que le demos agua), en el mundo de lo melódico ya se desenvuelven con fluidez pasando de una frase a otra sin titubear.

Entre las primeras experiencias musicales que vive un bebé sobresale especialmente un género, el de las nanas. Todas las culturas las utilizan para entretener a sus recién nacidos, jugar con ellos o calmarlos hasta que se duerman. Más aún, el estilo con el que se cantan las nanas está adaptado a las preferencias musicales con las que nace el bebé. No es algo que tampoco pensemos mucho, una vez que tenemos en brazos a un bebé y empezamos a cantarle siempre, sea cual sea nuestra cultura, la forma en la que lo hacemos es peculiar. De repente nuestra voz se vuelve cálida y aterciopelada, entonamos más agudo y con un *tempo* lento. A nivel de la estructura, las nanas son extremadamente sencillas y repetitivas, lo que hace que sea un género fácil de distinguir. No importa si desconocíamos la nana o no dominamos el idioma de la letra. Es un estilo tan propio y universal que reconoceremos rápido lo que estamos escuchando. A las nanas tenemos que contemplarlas con curiosidad. Cómo no hacerlo cuando las primeras canciones de nuestra historia pertenecen a uno de los primeros géneros de la historia de la música. Uno al que muchos consideran como el único verdaderamente innato.

Una excelsa exaptación

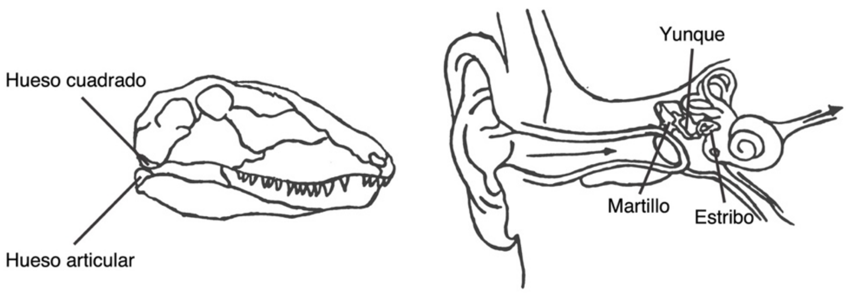
En paralelo a Spencer, James, Pinker y quienes han negado una utilidad biológica de la música, otros científicos han defendido múltiples razones por las que la música sería un rasgo adaptativo. En breve os contaré un poco más sobre estas hipótesis. Pero no quiero que nos adentremos en ellas con la idea de que defender una función para la música solo puede significar estar en contra del modelo de la "tarta de queso". Para una postura "adaptacionista" radical, sí que es incompatible: la música al completo cumple un papel evolutivo esencial, y por lo tanto nada es accidental en ella. Pero ni siquiera el propio Darwin fue tan radical. Él dejaba espacio para gamas de grises en la evolución: "Estoy convencido de que la Selección natural ha sido el principal pero no el único medio de modificación". La reconciliación más inteligente entre "adaptacionismo" y "no adaptacionismo", y probablemente una de las explicaciones más razonables, nos la ha dado la neurocientífica Laurel Trainor. Para esta investigadora, las bases de nuestra musicalidad (la percepción del ritmo y de las melodías) surgieron de la evolución del sistema auditivo para poder llevar a cabo sus dos funciones principales: identificar *qué* objetos nos rodean y *dónde* están situados en el espacio. Sin embargo, una vez adquiridas esas capacidades musicales por accidente, nuestros antepasados puede que descubrieran nuevos beneficios y usos que favorecieran su desarrollo. La música, tan inesperada como útil, adquirió un nuevo valor y se refinó desde ese momento. Este es el concepto de *exaptación*. Probablemente nunca hayáis escuchado esta palabra, pero es la causa de muchos de los "artilugios" biológicos más comunes y útiles del reino animal. Por ejemplo, las plumas, ese prodigio que ha permitido a las aves surcar el cielo y que ha incendiado la curiosidad de mentes como la de Leonardo da Vinci.

Pero su origen no está ligado ni a las aves ni a las alturas. Las plumas aparecieron en algunos dinosaurios pequeños que cambiaron parte de sus escamas por estas estructuras que funcionaban mejor como abrigo. Sí, al principio las plumas actuaban más como chaquetón impermeable que como ala de avión. Sería después cuando las plumas se extenderían accidentalmente y permitieron algunas maniobras aéreas como el planeo, similar al de las ardillas voladoras. Este nuevo uso celeste de las plumas favoreció un desarrollo en esa dirección y dio lugar a especies como el *Archaeopteryx*, un dinosaurio con aspecto de ave capaz de volar, un *protopájaro*.



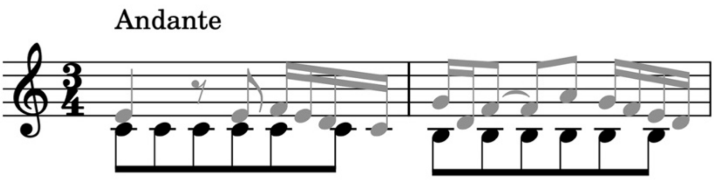
Fósil de Archaeopteryx y diseño de una máquina voladora de Leonardo da Vinci

Hablando de exaptaciones ilustres, hay una que está especialmente relacionada con este libro. Es la de la formación de los huesecillos del oído medio, aquellos que conducen las oscilaciones membranosas del tímpano hacia nuestra central de transducción auditiva, la cóclea. Mientras en los reptiles, anfibios y aves la comunicación entre el tímpano y el oído interno se produce gracias a un huesecillo fino y alargado, un homólogo de nuestro estribo, en los mamíferos dos de los huesos de la articulación de la mandíbula, el articular y el cuadrado, migraron al oído medio para convertirse en nuestro martillo y yunque. Con esta modificación, la audición de los mamíferos se hizo más sensible a una gama más amplia de sonidos, sobre todo a los sonidos agudos. Así, unos huesos con una función en la apertura de la mandíbula encontraron un nuevo papel al incorporarse a nuestro sistema auditivo.

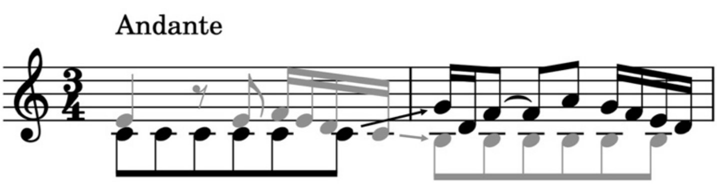


Laurel Trainor nos propone que la habilidad para percibir y distinguir entre diferentes timbres sonoros no es un desarrollo de nuestro cerebro para que digamos "¡es impresionante la entrada del chelo entre el resto de cuerdas!". Ni la recomposición que hace el sistema auditivo de los sonidos en función de sus armónicos ha surgido para que admiremos la belleza de las notas graves y agudas, o de la consonancia y disonancia. Nuestro cerebro elabora de esa forma la ensalada de sonidos que le llegan para identificar que en la escena hay un chelo y unas cuerdas, que hay diferentes emisores a nuestro alrededor, unos graves y otros agudos. Es de vital importancia que sepamos quién y cuántos nos merodean, y para ello nuestro cerebro empleará toda clase de trucos. Otra técnica para segregar los distintos emisores es utilizar la *proximidad de los tonos*. Puesto que los tonos que emite una fuente de sonido (puede ser la voz de una persona, pisadas, un instrumento musical, etc.) se mueve la mayor parte del tiempo dentro de un rango limitado de sonidos, nuestro cerebro tiende a agrupar los sonidos que son más o menos cercanos en altura como obra de la misma fuente. Y, al contrario, si escuchamos a la vez un grupo de sonidos muy graves y cercanos junto a otro grupo de sonidos agudos y próximos percibiremos que hay, como mínimo, dos emisores en la escena. Los compositores de música clásica eran muy conscientes de este principio de agrupamiento de nuestro cerebro y lo utilizaron para sorprender a sus audiencias con ilusiones auditivas. Dos de los ejemplos más exquisitos son las sonatas n.ᵒˢ 2 y 3 para violín solo de Johann Sebastian Bach. Estas obras barrocas albergan en su interior dos de los movimientos más mágicos de la historia de la música: el tercer movimiento de la sonata n.º 2 y el segundo movimiento de la sonata n.º 3. En estos movimientos, Bach aprovechó la capacidad del violín de hacer sonar varias cuerdas a la vez para crear la ilusión de que la música que escuchamos procede de dos violines y no de uno. Dos voces, una más grave que la otra, que en el aire se cruzan, se preguntan y se responden, coinciden y se separan. ¿Cómo dos entidades con tanta independencia podrían provenir de una sola persona? Bach eligió meticulosamente las líneas de estos movimientos para crear un trampantojo sonoro que ni el oído más entrenado pudiera diluir. Lo que no estaba en sus planes era que su ilusión sería aún mayor en el siglo XXI, cuando la mayoría de las veces que se escucha es solo en discos y reproducciones de audio, sin la referencia visual de la violinista. No tengo dudas de que serán muy pocas las personas que adivinen la realidad detrás del audio la primera vez que escuchen estas dos obras.

Sonata n.º 2 para violín de J. S. Bach
Tercer movimiento



Por la misma razón que Bach utilizó este truco del cerebro para producir ilusiones, las normas de composición más clásicas aconsejaban tenerlo en cuenta para evitar la confusión en los oyentes. Por ejemplo, en las normas de composición occidentales recomendaban formar los acordes con los cambios de notas lo más reducidos posibles en las voces y eludiendo saltos de grandes intervalos. Pero, sobre todo, aconsejaban evitar los cruces entre las voces, por ejemplo, permitiendo que la voz aguda cantara en algunos momentos por debajo de las notas de la voz grave. Imaginaos el fragmento de arriba interpretado por un violín y un chelo, en el que de repente el chelo saltara a interpretar en el segundo compás las notas agudas y que el violín se quedara en el bajo. Estas encrucijadas sonoras desdibujan la trayectoria de cada voz generando una sensación ambigua para el oyente.



Por tanto, una parte importante de la musicalidad no surgió para llenar nuestro mundo sonoro de sinfonías, conciertos y canciones de baile. En aquel momento eso no era urgente. Lo relevante era desarrollar un sistema auditivo capaz de identificar, cuantificar, segregar, localizar, etc. Sin embargo, otras facetas de la música no aportan nada a nuestro sentido básico del oído. ¿Qué creéis que añade la tonalidad, la percepción del pulso o la tendencia a sincronizar el cuerpo con el ritmo? La forma de emocionar de la música también es inédita en todo el reino animal. Nuestros parientes los primates directamente la ignoran o la acogen con indiferencia. De hecho, puestos a escoger, elegirán el silencio o la música con un volumen más bajo. En cambio, los bebés humanos exteriorizan una sensibilidad privilegiada desde el primer mes de vida. Resuenan las palabras de Darwin: "En una sola nota musical podemos concentrar una intensidad del sentimiento mayor que en páginas de escritura". Para Laurel Trainor, estas facetas únicas son el signo de que el origen de la música no fue totalmente secundario. La música pudo surgir como una creación cultural aprovechando las habilidades auditivas más básicas. Pero el hecho de hacer música, o más bien una forma de *protomúsica*, tuvo ventajas importantes para nuestros antepasados y presionó para que las habilidades musicales se expandieran. Aquellos beneficios inesperados promovieron una transformación de nuestro cerebro que conectó los circuitos auditivos con los motores en busca del ritmo, y la música con los centros del placer y la emoción. Como las plumas o los huesecillos del oído medio, unas habilidades adquiridas por accidente comenzaron a ser útiles y presionaron para extenderse.

El verdadero enigma es: ¿cuál fue la nueva utilidad de la *protomúsica*? Y la respuesta más correcta, por paradójico que resulte, podría ser otra pregunta: ¿realmente creemos que solo una única función pudo explicar la complejidad y el desarrollo de tantos componentes como hay en la música? Pensad en lo absurdo que sería la disyuntiva: ¿la visión evolucionó para detectar depredadores o encontrar alimentos? ¿Para esquivar obstáculos o para encontrar una pareja deseable? Probablemente todas estas ventajas a la vez condicionaron la evolución de nuestra capacidad visual. Si nos centramos en una de ellas correremos el destino inevitable de poder comprender solo una parte, quizá extremadamente reducida. Creo que ha llegado el momento para hablar de las funciones evolutivas que los científicos han propuesto para la música. Desde la elección de una pareja, fomentar la cohesión de grupo, regular las emociones y fortalecer el vínculo madre-hija. Estas son solo las ventajas sobre las que más se ha investigado. Pero en lugar de enumerarlas, profundicemos en lo que se ha dicho de ellas.

En busca de una función I: elige bien a tu pareja

Ni siquiera el propio Darwin tenía respuestas claras para la música. Cuando se aventuró a hablar de ella reconoció que "ni el goce ni la capacidad de producir notas musicales son facultades con la menor utilidad para el hombre en referencia a sus hábitos de vida cotidianos, por lo que deben figurar entre las más misteriosas de las que está dotado". Pero los enigmas alimentan las mentes curiosas. Los antiguos mapamundi señalaban lo desconocido con la inscripción *hic sunt dracones* ("aquí hay dragones"), una marca del terror para muchos y el destino de los espíritus exploradores al mismo tiempo. Y por su parte, Darwin, como buen explorador de la ciencia, se enfrentó a muchos de los "dragones" del conocimiento de su época. En otro de sus libros (quizá el más atrevido), *El origen del hombre y la selección en relación al sexo*, trató sin tapujos al ser humano como a un animal más que habría vivido miles de años de evolución enfrentándose a las presiones del ambiente. Para Darwin, las fuerzas de la naturaleza no solo favorecen las anatomías fuertes y veloces, las de mayor éxito esquivando peligros y consiguiendo alimento (su *selección natural*). También las figuras atractivas y sugerentes influyen en la competición por encontrar pareja, lo que llamó *selección sexual*. En algunos casos como el de las plumas de los pavos reales, los reclamos amorosos van en contra de la supervivencia del animal: tener el cuerpo recubierto de los colores más insólitos de la manzana puede convertirte en el macho más exótico a los ojos de todo el mundo, de tu amada y también de tus depredadores. Pero en la batalla del amor no solo cuentan las apariencias, hay que pasar a la acción. La competición por conquistar a la pareja deseada lleva a muchos animales a realizar costosos rituales de cortejo. Por ejemplo, los pingüinos machos dedican mucho tiempo y energía para regalar a su hembra preferida una piedra meticulosamente elegida. Todas estas peculiaridades no son vitales para afrontar las batallas de la vida, las hembras de pavo real o del pingüino sobreviven en las mismas condiciones que los machos. Unos atributos así solo sirven para exhibir un buen estado físico y cautivar.

En *El origen del hombre* Darwin planteó que la música, y en concreto el cante, son comportamientos que forman parte del ritual de cortejo humano. A través de las canciones y del baile, nuestros antepasados expresarían su destreza y su buen estado de salud para conquistar a sus amadas. Y, como consecuencia de la competición cada vez más exigente por demostrar quién cantaba y bailaba mejor, la música habría adquirido formas más y más elaboradas. ¡Qué mayor proeza que los solos de batería del jazz, como el de Joe Morello en *Castilian blues*, desafiando el tiempo y el espacio, creando mil y un ritmos con los que completar el mismo compás! O el magistral control de la voz que nos regala el flamenco. En saetas como las de Fosforito, cada sílaba se extiende en un melisma interminable y el cante, en lugar de extinguirse en cada segundo que pasa, se hace más presente. O, ¿quién es capaz de seguir los dedos de virtuosos de la guitarra o del violín como Itzhak Perlman? Para Darwin, todas ellas son formas sofisticadas de un arma diseñada para el amor. Aunque la Biblia cuenta que Josué, el sucesor de Moisés, consiguió conquistar Jericó derrumbando sus murallas con el sonido de siete trompetas, el poder de la música parece que no reside tanto en la fuerza como en la sensualidad. Aunque la música occidental separe casi por norma a la audiencia de los intérpretes, la música de las culturas más tradicionales se vive como un evento inclusivo, donde todas las personas que asisten acaban participando de una forma u otra. Es un espectáculo en el que cada asistente tiene la oportunidad de juzgar y ser juzgado por sus habilidades musicales. En tan solo unos minutos decenas de personas expresan su mundo emocional y observan el del resto de asistentes. Según esta teoría, los momentos al abrigo del fuego y las canciones eran trascendentales para nuestros antepasados en las decisiones amorosas que tomaban después del baile.

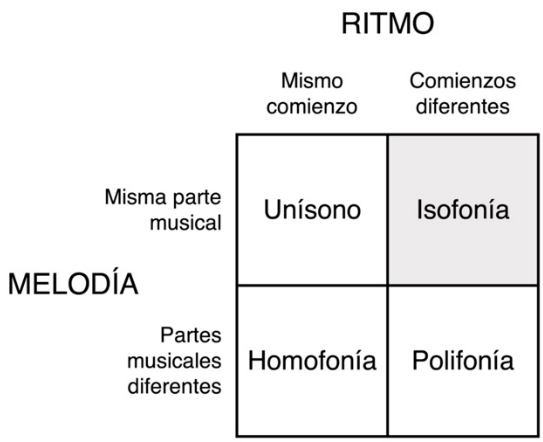
"Quiero que sepas, Sancho, que todos o los más caballeros andantes de la edad pasada eran grandes trovadores y grandes músicos, que estas dos habilidades, o gracias, por mejor decir, son anejas a los enamorados andantes". Si las palabras de don Quijote son ciertas, es fácil comprender la fiebre que desatan las figuras del rock. Se desvelaría el éxito amoroso del vocalista de los Rolling Stones, Mick Jagger, con ochos hijos y más de 4000 amantes. Cobraría sentido el éxtasis fan de los Beatles, siempre rodeados de miles y miles de chicas capaces de cualquier cosa para verlos, desde pedalear 30 kilómetros en bicicleta hasta gatear por el alcantarillado. Sus canciones nos lo cuentan: *She came in through the bathroom window* (es decir "ella entró por la ventana del baño"), en honor al allanamiento de la casa de Paul McCarney de un grupo de admiradoras. Estocolmo, París, Chicago… cada concierto de la banda británica era sinónimo de caos, disturbios y ambulancias. La fiebre era tal que la periodista Sandy Gardiner definió la "beatlemanía" como "una nueva enfermedad que los doctores son incapaces de detener". Pero quizá los casos de Mick Jagger y los Beatles estén más cerca de la anécdota que de ser representativos. Por cada Johann Sebastian Bach con veinte hijos habrá un Beethoven sin descendientes. Por cada roquero famoso existirán cientos de músicos de orquesta discretos, trompistas, oboístas, etc. Y la vida itinerante de los músicos dista mucho de ser fácil de conciliar con la paternidad. Si analizamos individualmente las canciones, es cierto que la temática amorosa predomina en las letras. Pero esto no es siempre así. Existen muchos contextos en los que la música se utiliza para amenizar el trabajo, tranquilizar al bebé o como forma de juego. Aunque la teoría de la música como filtro amoroso resulta intuitiva, al menos viendo el éxito de algunos músicos, no es una explicación redonda. Es más probable que la música tenga otros poderes. Entonces preguntémonos: si no es un elixir de fuerza o de amor, ¿cuál es su otro embrujo?

En busca de una función II: la vida emocional de la mayoría de las personas

Vivir significa enfrentarse a muchas realidades. Con algunas de ellas cumplimos nuestros deseos y no podemos evitar sonreír, ni siquiera cuando el día había comenzado con el ceño fruncido. Cuando la alegría nos inunda, nuestra fisiología se modifica y se vuelve más tolerante al dolor, al sueño, de repente experimentamos un torrente de energía y todo nuestro ser se prepara para seguir con la acción. Nada tiene que ver con las noticias tristes, con las que todo se ralentiza, el tiempo, nuestro cuerpo, nuestras ganas, etc. No somos capaces de parar de pensar en todo lo que hemos hecho mal, cómo hemos llegado hasta ese punto, qué cosas tenemos que cambiar… Las emociones son todo eso. Expresiones faciales, cambios corporales, pensamientos, sensaciones. Cuando lo que sucede es algo que nos afecta, nuestro organismo toma las riendas y reacciona a todos estos niveles para que sigamos con nuestros anhelos o nos alejemos de lo que nos duele. La biología irrumpe y provoca un punto de inflexión en nuestro día llamado emoción.

Si la música es el lenguaje del amor, es porque pocos estímulos son capaces de provocar emociones tan intensas. Este es uno de los grandes misterios de la música. ¿Cómo consigue contagiar emociones tan diversas y de una forma tan irreprimible? Es imparable. Por eso no solo escuchamos música cuando estamos enamoradas. El dolor de la voz de Chavela Vargas nos reconforta cuando estamos abatidas, y la música de fondo para meditar rompe con el bullicio de la calle y resetea nuestro estado. A través de la música somos capaces de sentir las consecuencias de situaciones que quizá nunca hayamos vivido, como la muerte de un ser querido o la devastación de la II Guerra Mundial. Decía Leonard Bernstein "la música puede dar nombre a lo innombrable y comunicar lo desconocido". Vista así, la música es un simulacro de la vida, un escenario teatral donde hacemos asomar las tragedias y lo burlesco de nuestra existencia para reflexionar sobre ellas. Puede que ese sea el sentido de las palabras de Leonard Cohen: "La música es la vida emocional de la mayoría de las personas".

Llevamos siglos debatiendo cuál fue, al principio, la relación de la música con el lenguaje, nuestra otra gran herramienta para recrear escenarios y comunicar sentimientos. Desde Spencer hasta Pinker, para quienes defienden la teoría de la "tarta de queso", la música es un accidente del lenguaje. Por tanto, el lenguaje fue primero. Es justo la postura opuesta a la de Darwin, quien defendió que la *protomúsica*, las vocalizaciones ancestrales con las que nuestros antepasados excitaban a sus parejas, precedieron a otras formas de comunicación lingüística. Pero ya sabemos lo difíciles que resultan estos debates del "¿qué fue antes, el huevo o la gallina?", sobre todo en cuestiones que tienen que ver con la evolución. El investigador Steven Brown reconcilió ambas versiones plateando que la música y el lenguaje surgieron a la vez de un mismo sistema de comunicación primitivo, un *musicolenguaje*. Cuando todavía no existían las canciones ni el habla, Brown imaginó a nuestros antepasados utilizando las vocalizaciones para comunicar sus emociones. Debían de ser sonidos con un escaso parecido al lenguaje o a la música. Se aproximarían más a un coro de lobos aullando. Un miembro de la manada comenzaría con un motivo breve que se expandiría por el resto de miembros en una oleada de variaciones (rítmicas, en la entonación, del timbre, etc.). Sería un jaleo entonado, el contagio caótico de una melodía, una *isofonía*.



Pero el incremento en el tamaño de las comunidades de humanos hizo necesario que los métodos de comunicación fueran más eficientes. Por un lado, era importante construir explicaciones ricas en detalles, pero sin margen para la ambigüedad. Narrar los hitos de la tribu, describir el terreno o transmitir las enseñanzas sobre los animales y plantas que habitaban la zona eran tipos de comunicación que excedían con creces la capacidad de un sistema de sonidos guturales. Innovaciones como el léxico, la gramática y la sintaxis fueron apareciendo para dar lugar al lenguaje. Sin embargo, un segundo tipo de comunicación surgió, uno que era capaz de transmitir la riqueza de las emociones con una inmediatez mayor que la de las palabras. Del musicolenguaje surgió también la música, un lenguaje en el que el todo el grupo participaba a coro en el canto y se fundía en la misma emoción. Describir con el lenguaje los detalles de sentimientos tan complejos como la nostalgia o el dolor causado por la traición requeriría más de tres y cuatro oraciones, mientras que en la música esas sensaciones nos inundan con solo un par de acordes. La música no servía para transmitir referencias precisas como hacían las palabras, que orientaban rápidamente la imaginación hacia la clase de objeto del que se hablaba, por ejemplo, de un perro. Pero era un lenguaje capaz de inyectar emociones y de resetear el ánimo de la persona, no importa lo que estuviera sintiendo antes. Quizá nunca lo hayáis notado. Como os digo, la semántica de la música es cuanto menos ambigua. Pero Vivaldi compuso sobre perros en el segundo movimiento de su *Primavera*. "*Il cane che grida*" ("el perro que ladra") les encomendó a las violas en su partitura. Lo que Vivaldi quería no era un sonido de perro realista, para eso hubiera pedido que trajeran perros al mismo escenario. ¿*Per favore, viola, porta un cane e fallo gridare* ("por favor, viola, trae un perro y hazlo ladrar")? El compositor buscaba más una onomatopeya musical, "musical" en el sentido de "emocional". Lo que Vivaldi quería plasmar para siempre eran los sentimientos que los ladridos de aquel perro despertaron en él.

El don de comunicar y contagiar emociones es, en última instancia, el don de manipular los sentimientos. "Manipular" es un verbo con muchas connotaciones negativas, pero en el caso de la música el resultado fue beneficioso. Por ejemplo, las nanas, de las que ya hemos hablado antes, son una herramienta esencial que las madres utilizan para tranquilizar o activar a sus bebés para que comiencen a jugar con ellas. En el ambiente mucho más hostil del Paleolítico, imaginad el peligro que podía ser cargar con un bebé llorando a pleno pulmón y sin capacidad para controlarlo. En menos de un minuto el refugio de toda la comunidad, su cueva, podría llenarse de depredadores y echar a perder todos sus bienes preciados, si no vidas. O planteándolo a la inversa, imaginad la ventaja de poder calmar el llanto con tan solo susurrarle una melodía al oído. Lo que en nuestras sociedades puede no ser más que una forma muy dulce de hacer sentir al recién nacido que estamos allí con él o de conducirlo hacia un sueño profundo, en aquella época era una cuestión de vida o muerte para todo el grupo.

Después crecemos y tomamos las riendas de nuestro comportamiento, reprimimos o liberamos el llanto, la risa o la ira según las circunstancias. Pero los circuitos cerebrales con los que la música lograba "manipular" nuestras emociones siguen ahí. Solo hace falta que empiece a sonar un tema de reggaetón o una bachata para demostrar que sigue ahí intacto. Todo nuestro cuerpo se viene arriba y nos entran ganas de hacer lo que hace un rato no hubiéramos imaginado. "¡Qué subidón!, ¿no?". Luego estamos de fiesta y a veces se cuela en la lista del local alguna canción de indie lento o alguna balada, y la gente deja de bailar. "¡Me voy a dormir como la siguiente sea igual!", "yo aprovecho y voy al baño". Nos hemos acostumbrado a estas situaciones, pero lo que subyace a los cambios drásticos en nuestras ganas de hacer una cosa u otra es la música. Por supuesto, luego hay más cosas: qué nos ha pasado últimamente, con quién hemos quedado ese día, cuáles son los objetivos de la noche, ligar o pasarlo bien bailando, etc. Pero lo que enciende la mecha de nuestros sentimientos, lo que nos hace explotar de ganas, es la música. No quedamos para tomar algo y ver murales o escuchar poemas. O para contemplar flores y la belleza de los edificios. El plan normalmente implica música. Porque nos encanta (como las formas de arte anteriores, ¡es verdad!) y a la vez accede de una forma privilegiada a los centros emocionales de nuestro cerebro. Como hacían nuestras madres con las canciones de cuna, los centros comerciales utilizan la música para jaquear nuestro estado y llenarnos de energía "capitalista", mientras que las canciones en la iglesia sosiegan nuestras inquietudes. Una vez que somos conscientes de todo esto, comprenderemos de otra forma qué es lo que está pasando cuando escuchamos a solas uno de nuestros discos en casa. Tumbados o en el sofá, no estamos buscando bailar o ganar fuerzas para un atracón de tiendas. Estamos manipulando inocentemente lo que sentimos, y esa montaña rusa emocional nos va sentar muy bien. Si estamos tristes, alguien detrás del altavoz nos va a animar o, si Chavela Vargas canta con tristeza, vamos a vivir la tristeza con mayor profundidad, pero esta vez en compañía. "Menos por menos es más", dicen. ¿Queréis sabes qué más dicen sobre las funciones que tuvo la música?

En busca de una función III: ¿no te sabes la letra?

> *Aserejé-ja-dejé*
>
> *De jebe tu de jebere seibiunouva*
>
> *majavi an de bugui an de güididípi*

Esta letra no significa nada en español, ni en ningún otro idioma. Pero para quienes vivimos la década de los 2000 en España, esta letra rebosa significado. Habla de fiesta, del ritmo "ragatanga" que tanto le encanta a un tal Diego y que el *Aserejé* es su himno de las doce. La extravagancia de esta canción y de todos los detalles que la rodearon sirvió para catapultarla a la fama. Apareció en 2002 de la mano de tres cantantes cordobesas que se hicieron llamar Las Keptchup en honor a su padre, José Muñoz "El Tomate". De la noche a la mañana, un grupo que antes nadie conocía, de repente coronaba todas las listas de éxitos. Y tan rápido como llegó a la cima, se desvaneció. Un *one-hit wonder* ("un grupo de un solo éxito") en toda regla, quizá el caso más famoso de España. El ritmo del *Aserejé* es muy pegadizo, tiene una coreografía fácil que aprendieron hasta los más pequeños, y la letra, a la vez que sencilla, está repleta de pasajes con gran margen para la interpretación. Neologismos sonoros (como el del "ritmo ragatanga"), expresiones retóricas con bastantes toques de ambigüedad ("viene Diego rumbeando con la luna en las pupilas", "van restos de contrabando") y, por supuesto, su estribillo. Todo él es una parodia de la primera canción del hiphop, *Rapper's Delight*, de *The Sugarhill Gang*:

I said —a hip, hop, the hippie, the hippie

To the hip, hip hop— and you don't stop the rock it

To the bang bang boogie, say, up jump the boogie,

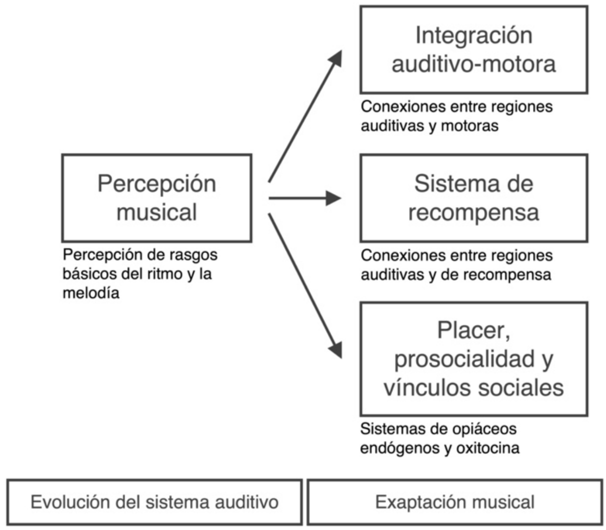
To the rhythm of the boogie, the beat

Esta letra de hiphop era un trabalenguas, por mucho significado que tuvieran estos sonidos en inglés, esa secuencia de fonemas era ideal para el ritmo, pero intrincada para recitarla; ingeniosa para el oído y una auténtica proeza lingüística. Pero el estribillo del *Aserejé* era un garabato de esa letra, una transcripción sonora de un idioma mal comprendido. La forma en la que los españoles aprendieron tal galimatías en el verano de 2002 fue escucharlo cientos de veces a la semana. Escucharlo y bailarlo, escucharlo y bailarlo, en las bodas, en las fiestas del pueblo, en los bailes del colegio, en la radio, etc., por todos lados sonó esta canción y pronto un país entero era capaz de seguir cada sílaba del estribillo.

La anécdota del *Aserejé* es un ejemplo perfecto del poder que tiene la música para unir a grandes grupos de personas en una experiencia común y, a la vez, distinguirlos de otras culturas. El fenómeno del *Aserejé* trascendió nuestras fronteras, pero muy pocas personas extranjeras serían capaces hoy de cantar el estribillo completo. ¡Aquí tenéis un detector eficaz de forasteros! Reforzar la cohesión y la identidad del grupo son las dos funciones por las que muchos investigadores creen que nació la música. Si rescatamos algunos de los rasgos universales de la música que mencionábamos en el primer capítulo, nos daremos cuenta que tienen su razón de ser en la interpretación colectiva: el baile al son de la música, un pulso constante y marcado con instrumentos de percusión, la repetición de motivos, el uso de estribillos, las escalas con pocas notas, etc. Vivir en grupo tiene muchas ventajas, como disuadir a los depredadores y aumentar la eficacia de la caza y la defensa del territorio. Pero, como contrapartida, incrementa las necesidades de alimento y coordinación de la manada. Nuestros parientes los primates, también grandes vividores en grupo, mantienen sus comunidades cohesionadas a través de conductas como el acicalamiento, es decir la limpieza y retirada de parásitos, enredos o cualquier material que se haya depositado en el pelaje del vecino. Veremos una hilera de monos, uno detrás de otro, moviendo los brazos de la espalda del mono de enfrente a su boca, de la espalda a su boca, a menudo todos en sincronía. En cierto sentido, se parece a los masajes con crema solar de las parejas en la playa, todo sea por la salud de nuestra piel. Del mismo modo, el acicalamiento es una conducta de higiene que mantiene la salud del grupo, puesto que lleva la limpieza a rincones en los que el animal sería incapaz de llegar por sí solo (¡como ese trozo de la espalda que tanto nos cuesta untar en crema!), pero por otro lado consigue estrechar los vínculos de la comunidad. Y si se aburren del acicalamiento, los primates pueden estrechar sus vínculos personales a través del juego, la risa, el sexo recreativo, etc. ¡Desde luego, la variedad no es un obstáculo! El problema de todos estos comportamientos es que solo pueden realizarse de dos en dos o, en el caso de la risa, en grupos reducidos. Cada pequeño incremento en el tamaño del grupo, pongamos diez o veinte nuevos miembros, supone un enorme coste adicional de tiempo y energía si se desea que los lazos de grupo sigan siendo fuertes. Para comunidades de miles (quizá millones) de personas, el precio de mantener la cohesión social con el acicalamiento se vuelve inasumible. Es aquí donde irrumpen las canciones. La música pudo ayudar a superar esta limitación de las conductas ancestrales de cohesión, llegando a comunidades enormes al mismo tiempo. ¿Sabéis para cuántas personas tocaron los Beatles en su legendario concierto de 1965 en el *Shea Stadium*, el primer concierto de rock de la historia en un estadio? ¡55.000 personas! Todas unidas en la música que marcaría una generación.

Siguiendo la idea de Laurel Trainor de la exaptación, la música pudo aparecer como una invención cultural que, por sus virtudes para el grupo, allanaría el terreno para una evolución biológica. Al igual que el uso del fuego supuso un cambio en nuestra biología para adaptarnos mejor a una dieta de alimentos cocinados, o la invención de la ganadería lechera en muchas culturas europeas y africanas desembocó en la capacidad para poder digerir la lactosa en la adultez (con una producción persistente de la enzima lactasa), la creación cultural de una *protomúsica* pudo haber sentado las bases para un proceso de refinamiento de las habilidades musicales del *Homo sapiens*. Aprender una de las *protocanciones*, y sobre todo si era de una extensión considerable, sería un comportamiento muy difícil de realizar a la primera. Como sucede con el *Aserejé*, solo podrían cantar la *protocanción* del grupo aquellas personas que vivieran en la misma cultura y hubieran escuchado cientos de veces el mismo tema. Tuvo que ser muy sencillo, ¿conoces la canción? Eres de los nuestros. Seguro que alguna vez os ha pasado, estáis con vuestras amigas y suena uno de esos *hits* que hacen que todo el mundo se venga arriba. Habéis escuchado esa canción en muchísimas ocasiones, pero nunca le habéis prestado atención a la letra o, como en mi caso, simplemente entre vuestros dones no se encuentra el de memorizar la letra de cualquier canción con la que os cruzáis. El grupo empieza ahora a cantar las estrofas que no son del estribillo y tienes que disimular, pero alguien te delata: ¿no te sabes la letra? ¡No me lo puedo creer! Algo así como si te dijeran: ¿dónde has estado viviendo estos años? ¡Porque te conozco, si no pensaría que eres extranjera! Como podéis ver, existe una cierta paradoja en la unidad de grupo. Un grupo más cohesionado también es un grupo fácilmente diferenciable del resto y, a veces, eso facilita la exclusión o el enfrentamiento con el extraño. "Unidad" significa que podemos confiar en que los miembros van a cooperar entre ellos para que todos alcancen sus propios objetivos. Pero "unidad" también puede utilizarse como arma. Por eso, la música también aparece en la guerra o en los enfrentamientos entre bandos deportivos. El famoso *haka* "*Ka Mate*" que el equipo neozelandés de rugby canta al inicio de sus partidos es una expresión de este doble efecto de la música mostrando unidad "entre los míos" e intentando intimidar a "los otros". Quizá la hazaña bíblica de las trompetas de Jericó no es más que un símbolo de la unidad con la que el pueblo hebreo asedió la ciudad al son de aquella música. Quizá no fue el sonido lo que derrumbó las murallas, sino la fiereza que despertó en el ejército de Josué.

La música sería la actividad en la que el grupo fraguaba su identidad y compartiría horas y horas de unión. Lo que por un lado era una actividad muy trabajosa, por el otro era el modo de encontrarse y conocerse. Los humanos habían inventado un sucedáneo masivo para el acicalamiento de los primates. Así, cualquiera que por fortuna naciera con mejores habilidades musicales tendría una considerable ventaja aprendiendo *protocanciones* y detectando con rapidez quién pertenecía a la tribu (y quién no). La creación cultural se transformó en un elemento esencial de la vida en las comunidades. En este contexto, nuestro cerebro se volvió más musical: (a) se fortaleció la conexión auditivo-motora, (b) nos volvimos más propensos a escuchar y producir música, que comenzó a ser un estímulo muy reforzante con su forma predecible, y, como colofón, (c) nos volvimos más prosociales y se reforzaron nuestros vínculos cuando formábamos parte de una actividad musical.



Aumentó la comunicación entre las áreas auditivas del cerebro, encargadas de la percepción de las melodías y del ritmo, y las áreas implicadas en el movimiento, como vocalizar y bailar. Este cambio sentó los pilares de nuestra capacidad para sincronizar el cuerpo con la música y el grupo. Por eso, cuando escuchamos música, nuestro cerebro motor (la corteza premotora y los ganglios de la base) se activa. Y cuando la canción es muy bailable (*groovy* la llaman en inglés), ese tipo de música que es rítmicamente irresistible, modifica la excitabilidad de nuestra corteza motora.

La percepción de la música (el ritmo, el pulso, las melodías, etc.) y las sensaciones de los movimientos de nuestro cuerpo conforman un ciclo sin fin de predicciones, expectativas rotas y resoluciones. Por un lado, que la música sea predecible permite que todo el grupo pueda participar en sincronía de la actuación, ya sea cantando al unísono o aportando voces que generan el contrapunto a la melodía principal, bailando en bloque o con una aparente independencia. Las predicciones nos dan inercia: después de una introducción y un nudo, viene un desenlace; después de un acorde tenso, debe llegar la calma; ¡la canción no puede terminar así, está todo en el aire! Cumplir con nuestras expectativas es algo que disfrutamos y eso pone en marcha a las áreas del cerebro que recompensan la comida, el sexo y estímulos valiosos para la sociedad como el dinero. Regiones de este sistema de recompensa como el núcleo accumbens, que funcionan principalmente a través del neurotransmisor *dopamina*, se activan cuando escuchamos música que es predecible y, a la vez, placentera. Un estudio de la Universidad de Ámsterdam fue muy revelador. El señor B era un hombre de 59 años que desde la adolescencia había sufrido un trastorno obsesivo-compulsivo grave y, tras probar sin éxito muchos tipos de tratamiento, se sometió a *estimulación cerebral profunda*, la implantación de un electrodo intracraneal que genera pulsos eléctricos en una región específica del cerebro a la manera de un marcapasos. El área elegida en el caso del Sr. B fue el núcleo accumbens y afortunadamente el tratamiento para sus síntomas obsesivo-compulsivos fue todo un éxito. El Sr. B bromeaba que ahora tenían que llamarlo "Sr. B II", la versión nueva y mejorada del Sr. B. Lo interesante de este caso fue lo que pasó con su mundo musical. Él siempre había tenido gustos musicales limitados, en general solo escuchaba canciones holandesas, a los Rolling Stones y a los Beatles. Pero cuando la estimulación cerebral profunda acababa de comenzar, y su núcleo accumbens estaba siendo excitado artificialmente, un día escuchó la canción de country *Ring of fire* de Johnny Cash y se convirtió en un amante de la música de este músico. Más aún, aunque la música no fuera algo muy importante en la vida pretérita del Sr. B, con la estimulación del núcleo accumbens las canciones de Johny Cash se habían convertido en una de las experiencias más placenteras. Ya no escuchaba otra cosa, ni a los Rolling ni a los Beatles. Excepto cuando el estimulador se apagaba accidentalmente. En ese momento, las preferencias musicales del Sr. B volvían a ser las de siempre y Johny Cash quedaba en el olvido.

Al contrario que la *musicofilia* del Sr. B con la música de Johny Cash, algunas personas experimentan lo que se conoce como *anhedonia musical*, una falta de motivación y placer por todas las formas de música. Es una apatía que solo afecta a la música, pero que deja intacta el placer por el resto de cosas. En algunos casos la anhedonia musical es la consecuencia de un daño cerebral y es adquirida, pero en muchas personas esta condición es innata. El *Cuestionario de Recompensa Musical de Barcelona* que recordaréis del primer capítulo es una herramienta excelente para detectarla. Estas personas es muy raro que estén de acuerdo con la afirmación *Me emociono escuchando ciertas canciones* del cuestionario, y se identifican más con *En mi tiempo libre apenas escucho música*. En general, la anhedonia musical hace que la música se sienta como algo plano y sin emoción, como algo que carece de atractivo. Y se explica por una pobre conexión entre las partes auditivas del cerebro y las regiones asociadas a la recompensa y la emoción, como el núcleo accumbens y otras como la ínsula y la amígdala. Sean cuales sean esas regiones en el cerebro, la anhedonia musical muestra un estado de indiferencia hacia la música más similar al de nuestros parientes los primates. Con la alteración del cerebro humano, la anhedonia musical nos cuenta que el placer por la música es fruto de un cambio neurológico desde los primates. Resulta paradójico. Con sus *ausencias*, las del goce y la emoción, la anhedonia musical nos revela las *presencias* en el cerebro, lo que hoy tenemos y nos convierte en seres musicales.

Pero la dopamina no solo se libera en el núcleo accumbens cuando las canciones que escuchamos son familiares y predecibles. También sucede cuando la música rompe con lo que esperábamos y, aun así, también nos gusta. Por ejemplo, cuando pensamos que la obra va a acabar y de repente sigue. Es por definición lo que sucede en las *codas* de las sinfonías de Mozart y Beethoven. Cuando todo ha terminado, una nueva sección se abre y nos sorprende con una última variación del material musical. Otro ejemplo de sorpresa aparece en el primer movimiento de la tercera sinfonía de

Beethoven, donde la trompa anticipa la reexposición del tema principal en toda la orquesta al completo. El discípulo de Beethoven, Ferdinand Ries, pensó que había sido un error del trompista:

> El primer ensayo de la sinfonía fue terrible, pero el trompista hizo bien lo que tenía que hacer. Yo estaba sentado cerca de Beethoven y, creyendo que había entrado mal, le dije: "¡Condenado trompista! ¿Acaso no sabéis contar? Esto suena espantosamente mal". Pensé que mis oídos se iban a desencajar. Beethoven no me lo perdonó durante mucho tiempo.

Estos sucesos inesperados son una señal para el cambio, para que actualicemos nuestra idea de lo "esperable" en música. Esta es la esencia de la buena música, predecible pero inesperada. Como decía Aristóteles sobre los buenos finales: "sorprendente pero inevitable".

La liberación de dopamina en el núcleo accumbens puede explicar por qué nos motiva escuchar música y es algo que nos gusta (o incluso exigimos) en nuestras celebraciones. Pero la dopamina no explica las experiencias de placer. Esas sensaciones provienen del funcionamiento de otro tipo de sustancias cerebrales, los *opiáceos*. Quizá los opiáceos más conocidos son las endorfinas, que sabemos que están estrechamente vinculadas con las sensaciones de placer cuando actúan sobre el núcleo accumbens. Drogas como el opio, la morfina o la heroína producen sus efectos suplantando a los opiáceos endógenos como las endorfinas. Pero no solo son señales químicas de nuestro cerebro para producir el goce. Los opiáceos también están detrás de la analgesia y las conductas prosociales. Una forma fácil de estudiarlo ha sido utilizando fármacos que reduzcan temporalmente la acción de estos neurotransmisores, como la naltrexona, que bloquea los receptores opiáceos. Obstaculizando el efecto de los opiáceos con este químico, se reducen nuestros sentimientos de conexión con el grupo. Escuchar música o, mejor aún, participar en crearla cantando o tocando un instrumento aumenta la actividad opiácea de nuestro cerebro, y como consecuencia nos volvemos más tolerantes al dolor y aumentan nuestros sentimientos de cercanía al grupo. Pero todos estos cambios se esfuman cuando la naltrexona impide los beneficios de los opiáceos que nuestro cerebro libera. La música se vuelve menos placentera y su efecto analgésico desaparece. Lo mismo sucede con otra sustancia, la *oxitocina*, que se segrega durante actos sociales tan intensos como la lactancia, los orgasmos y la interpretación musical. Cuando la oxitocina se une al núcleo accumbens también tiene el poder de generar sentimientos de unión, por eso en muchos sitios se la simplifica como la hormona de los abrazos o incluso del amor. La oxitocina, como los opiáceos, es capaz de fortalecer los vínculos de una madre con su hija, los de una pareja, o los de los miembros de una banda de jazz.

Cuando sincronizamos nuestras voces y nuestros cuerpos en la música, sentimos mayor confianza en el resto del grupo, nos identificamos más con esas personas, sentimos cercanía, atracción, semejanza, ganas de cooperar, pertenencia, etc. En pocas palabras, la música nos une. Cuanto mayor es la escala, mejor. Los cantantes de coros grandes, con más de ochenta personas, experimentan esta cohesión de una forma más intensa que los cantantes de coros pequeños. Pero hasta el momento en el que somos capaces de formar parte de este tipo de actividades musicales, pasan muchos años. Como mencionábamos, las primeras interacciones musicales que vivimos son las canciones que nos dedican nuestras madres. Al poder calmante de las nanas, hay que añadirle su poder para fortalecer el vínculo entre un hijo y su madre. Y desde ese momento se extiende al resto de relaciones personales que el pequeño va encontrando. Un estudio del grupo de Laurel Trainor demostraba el poder de la sincronía en un contexto controlado. Quizá los detalles del diseño experimental sean los que hacen tan peculiar a este estudio. En el laboratorio, dos investigadoras se balanceaban arriba y abajo una enfrente de la otra, una de ellas portando a un niño de catorce meses al que no conocían. De fondo sonaba el *Twist and Shout* de los Beatles. Pero lo importante es que los movimientos de las dos investigadoras con algunos de los niños estaban sincronizados, mientras que con otros los balanceos seguían un patrón diferente. Después de esta sesión de baile, comenzaba la acción. La investigadora que estaba justo enfrente del niño durante los balanceos, es decir aquella que habían visto o bien en sincronía con su cuerpo o siguiendo un ritmo desfasado, ahora comenzaba a realizar una serie de tareas en las que necesitaba ayuda. Recoger bolas de papel que no podía alcanzar, tirar sin querer unos rotuladores, o estar tendiendo la ropa y que se cayera una pinza. Lo que el equipo de Laurel Trainor observó fue que en todas estas situaciones los niños que habían vivido un baile sincronizado con esa persona, no importaba que fuera una extraña, eran más propensos a ayudarla. Además, la ayuda que ofrecían era sin recelo, en cuanto presenciaban la situación. Sin embargo, cuando aquella investigadora extraña se había balanceado sin sincronía, los niños no se mostraban tan cooperativos, con tanta tendencia a ayudarla. El resultado de este estudio es muy llamativo, pero la guinda de esta tarta (juro que he estado tentado de escribir "tarta de queso") la pondría un segundo estudio. El procedimiento fue muy similar al que os acabo de contar, solo que las tareas de ayuda en las que el niño podía cooperar las realizaba otra investigadora. Antes de nada, los niños veían como esa persona interactuaba con la investigadora que se balanceaba en sincronía o no. En algunos casos la conversación entre las dos era amistosa, dando señales de que eran parte del mismo grupo, utilizaban gestos similares, etc. En otras ocasiones, ambas investigadoras hablaban mostrando un escaso vínculo personal. La clave en el estudio es que los niños que habían estado en sincronía con una investigadora que aparentemente era amiga de una extraña "en apuros", se mostraban más cooperativos también con esta segunda extraña. Todos estos resultados lanzan un mensaje claro: dos de los componentes más esenciales de la música, el ritmo y la sincronía, tienen el poder de desdibujar lo "desconocido". Compartir ritmos y música nos hace sentir parte de la misma tripulación, y esa tripulación también puede implicar a las amigas de nuestras nuevas "camaradas". No importa que los niños de estos estudios nunca hubieran coincidido antes con aquellas investigadoras, la música tiene la capacidad de convertir lo "extraño" en "cercano".

Más allá de la función primigenia

Lo que acabamos de ver son las funciones que muchas investigadoras han considerado como las ventajas que originalmente nos convirtieron en seres musicales. Al igual que somos una especie que evolucionó para hablar (seres lingüísticos), para vivir en grupo (seres gregarios) y para razonar (seres racionales), nuestra naturaleza es musical y parece que las responsables de ello podrían ser la selección sexual, la regulación de las emociones y la cohesión de grupo que las canciones nos otorgaron. ¡No podíamos esperar un origen más simple para la música! Es una evolución compleja para un rasgo aún más complejo. Pero desde luego que estas no han sido las únicas ventajas, los únicos "regalos" que la música nos ha dejado. En nuestro día a día, las canciones también facilitan la coordinación de labores repetitivas en profesiones como los agricultores, marineros y militares, nos ayuda a memorizar textos y propagar información importante, nos entretiene y acaba con el aburrimiento. Todos estos usos de la música son creaciones posibles gracias a que somos animales con musicalidad. Al no ser causa, si no consecuencia, yo no esperaría que nuestras habilidades musicales hayan evolucionado mucho gracias a estas otras funciones. Pero eso no las hace menos valiosas.

Como presagiaba, muchas de las ideas que he recogido aquí son, en su mayoría, teorías sobre un pasado del que no hemos podido ser testigos. Resulta muy difícil saber cuántos matices de la evolución de la música aún no conocemos hoy. La verdadera certeza, la que de verdad afecta al presente, es que la música es una parte importante de nuestras vidas. No es solo ocio y arte, que son las etiquetas habituales que se le colocan. Quizá la música pudo llegar a nosotros por accidente, como un *regalo* de la naturaleza. Pero desde ese momento, es ella la que no ha parado de regalarnos.

Un leve telón de fondo

Sobre el rendimiento cuando escuchamos música

Un hombre es siempre más que un hombre y siempre menos que un hombre, más que un hombre porque encierra eso que el jazz alude y soslaya y hasta anticipa, y menos que un hombre porque de esa libertad ha hecho un juego estético o moral, un tablero de ajedrez donde se reserva ser el alfil o el caballo, una definición de libertad que se enseña en las escuelas, precisamente en las escuelas donde jamás se ha enseñado y jamás se enseñará a los niños el primer compás de un ragtime y la primera frase de un blues, etcétera, etcétera.

Julio Cortázar (Rayuela, 1963)

"Nadie cuestiona que escuchar música a una edad muy temprana afecta el razonamiento espacial y temporal que subyace a las matemáticas, la ingeniería e incluso el ajedrez". Con estas palabras el gobernador del estado de Georgia, Zell Miller, pedía en 1998 a la Asamblea destinar una partida de 105.000$ para discos de música clásica. Miller quería que todos los nuevos georgianos nacieran escuchando a Mozart y Beethoven, porque esa la forma de alimentar el intelecto de la sociedad desde muy temprano. El gobernador reprodujo en plena Asamblea la *Oda a la alegría* de la novena sinfonía de Beethoven y preguntó a los legisladores: "¿No se sienten ya más inteligentes? Espero que sean lo suficientemente inteligentes como para votar a favor de esta partida presupuestaria". Sin embargo, la partida no fue necesaria. Sony se ofreció para distribuir los discos de forma gratuita a los hospitales de todo el estado.

Estas fueron algunas de las consecuencias políticas del terremoto que originó un artículo publicado en la revista *Nature*. Además de aparecer en una de las revistas más prestigiosas del ámbito científico, el estudio (titulado "*Music and spatial task performance*"*) tenía el atractivo de esos procedimientos simples que con poco consiguen grandes resultados. Los autores, Frances Rauscher, Gordon Shaw y Katherine Ky, llevaron al laboratorio a una treintena de estudiantes universitarios para someterlos a tres condiciones experimentales: diez minutos de silencio, diez minutos de una grabación de voz invitando a la relajación y diez minutos escuchando el primer movimiento de la sonata para dos pianos de Mozart. Para quienes no la conozcáis, es una música rebosante de alegría. Un *Allegro con spirito*. Está escrito en el estilo *galante*, que en la Europa del siglo XVIII intentaba abandonar la complejidad de la polifonía barroca para ensalzar la simplicidad y adoptar formas parecidas a las de las canciones. El espíritu de esta obra es el de un Mozart justo al llegar a Viena, recién emancipado de su padre y del yugo de su anterior patrón, el arzobispo Colloredo, y lleno de ganas por deslumbrar a la aristocracia vienesa. El dato curioso de esta sonata es que el tema principal del movimiento es una copia literal del concierto de piano n.º 2 del hijo de Bach, Johann Christian Bach, por lo que alguien podría preguntarse cuánto de Mozart y cuánto Johann Christian Bach hay en esta música.

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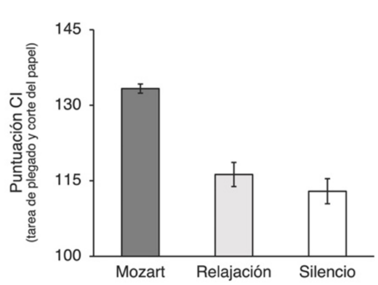
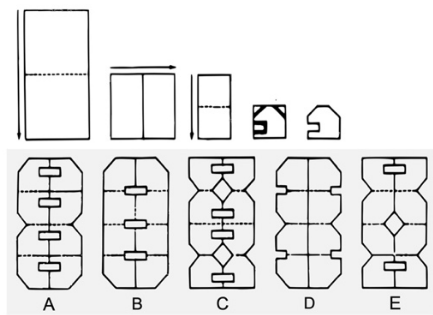
* Música y ejecución en una tarea espacial (trad.).

Los participantes del estudio, después de esas tres situaciones, realizaban tareas de razonamiento de la clásica escala de inteligencia Stanford-Binet. Mientras que nada cambió entre la condición de silencio y la grabación relajante, las puntuaciones en las pruebas de inteligencia fueron mayores tras escuchar la música de Mozart. De hecho, el efecto fue especialmente grande con una de las pruebas, la tarea de *plegado y corte de papel*, en la que una secuencia de dibujos describe cómo se ha ido doblando y recortado un folio para formar un patrón. Las personas tienen que adivinar entre un grupo de patrones cuál es el correcto, cuál es el resultado de todas esas rotaciones espaciales y cortes en el tiempo. El hallazgo de este estudio incendió la curiosidad de la comunidad científica y no tan científica. ¿Solo con escuchar a Mozart nos volveríamos más inteligentes? ¿Puede la música modificar nuestro cerebro y, sobre todo, nuestras capacidades mentales? ¿Qué tendrá que ver la música con el razonamiento espacial y temporal que utilizamos en el ajedrez y la ingeniería? Este fuego fue el origen de muchas preguntas, ideas y mitos que veremos en este capítulo. Acompañadme.





El efecto Mozart

Aunque el efecto de la sonata de Mozart era claro, no tenía una explicación intuitiva. Los autores del estudio de *Nature* plantearon una teoría intrincada que ha sido difícil de mantener con el tiempo sin estudios sucesivos que la demuestren. Fue un planteamiento que nació y permaneció como una mera especulación. Paras los investigadores, este efecto era consecuencia de una milagrosa casualidad de nuestro cerebro: escuchar algunos tipos de música como la de Mozart y el razonamiento espaciotemporal producirían el mismo patrón de respuestas neuronales en el hemisferio derecho. Daría igual hacer una cosa que la otra, el patrón de respuesta de nuestro cerebro sería el mismo. Así, la música podía actuar como una especie de "ejercicio" sin esfuerzo de aquella porción del cerebro que nos hace capaces de resolver problemas como los rompecabezas, una jugada maestra con el alfil y, como no, responder correctamente a la tarea de *plegado y corte de papel*. Entendida así, escuchar música sería como un gimnasio del razonamiento, en el que si la usamos antes de hacer alguna de estas actividades actuaría como una especie de calentamiento y por eso los participantes del estudio de *Nature* fueron mejores. Pero más allá, para Rauscher, Shaw y Ky, la segunda lectura de este "entrenamiento placentero" de nuestro intelecto es que si se realiza a diario podría convertir irreversiblemente a la persona en un ser más inteligente de lo que era. Este era el motivo por el que Zell Miller quería a toda costa que las nuevas madres de Georgia volvieran del hospital con un bebé en una mano y con un disco de Mozart en la otra. Por esta razón el disco que Sony creó en satisfacción de aquella idea se tituló *Build your baby's brain through the power of music**. Desde aquel momento, las embarazadas de todo el mundo debían

* Desarrolla el cerebro de su bebé a través del poder de la música (trad.).

de añadir a su lista de buenos hábitos la costumbre de escuchar música clásica. Estaréis siendo conscientes de que en ningún momento se hablaba del "efecto de la escucha" o de la música en general. Rauscher, Shaw y Ky solo mencionaban la sonata de Mozart, porque Mozart fue uno de los compositores más precoces, comenzando a la temprana edad de los cuatro años, y por eso, por su pureza pueril, habría descubierto la fórmula natural para explotar con música "el repertorio inherente de patrones de disparo espaciotemporales en la corteza". Otras músicas, más ligeras y simples, tendrían en todo caso el efecto contrario, el de interferir con el razonamiento humano. La idea que se lanzaba es que el milagro del efecto Mozart no sería obra solo de la sonata para dos pianos, que hoy sabemos que no es original de Mozart sino de Johann Christian Bach (¿el efecto Johann Christian Bach-Mozart?). El milagro sería monopolio del selecto repertorio de la música clásica, y la prueba fue que desde el artículo de *Nature* muchos otros laboratorios de psicología volvieron a documentar los beneficios temporales de escuchar la sonata para dos pianos, pero también con obras de compositores como Johann Sebastian Bach o Schubert (¿efecto Johann Sebastian Bach o efecto Schubert?). Curiosamente, el *Build your baby's brain* no contenía la sonata para dos pianos, pero era un disco repleto de los *hits* de la música clásica que siempre escuchamos en anuncios, bodas o cualquier ocasión en la que a alguien se le ocurre que lo que pega es "música clásica": la *Música acuática* de Handel, la *Primavera* de Vivaldi, el *Canon* de Pachelbel, el *Para Elisa* de Beethoven, etc. Aunque los argumentos de los autores del artículo no eran demasiado sólidos como para defender *a priori* que solo la música clásica era *la* elegida, en la Asamblea georgiana también se hicieron eco de este prejuicio. *The New York Times* recogía estas palabras del representante republicano Homer DeLoach tras el debate sobre la partida de 105.000$: "Pregunté sobre la posibilidad de [incluir en el disco] un Charlie Daniels o algo así, pero dijeron que pensaban que la música clásica tiene un mayor impacto positivo". *Sottovoce*, la idea que se asumía (sin muchas razones científicas) era que la música clásica era una categoría separada del resto, una tipología superior. En palabras de Alessando Baricco:

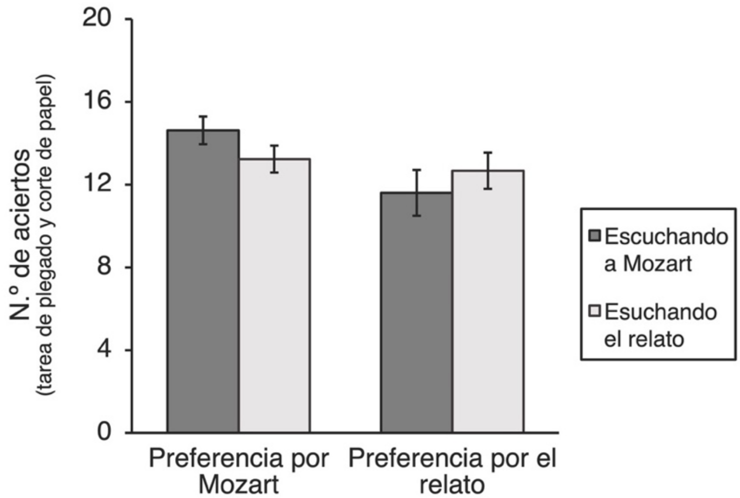
> “el mundo de la música culta sigue considerándose culturalmente y moralmente *distinto*. Y, calladamente, superior. […] La música culta acaba siendo vivida como lugar separado en el que categorías éticas y tótems culturales sobreviven en un áurea de inexpugnabilidad. La ilusión es que entrando en una sala de conciertos, automáticamente se accede a ese lugar separado”.

Lo que sucedió con el efecto Mozart era una expresión más de este prejuicio que define a la música clásica como el oasis de la civilización musical. En el capítulo anterior os contaba que Pinker recelaba de muchas de las funciones adaptativas que los científicos modernos estaban “inventando” porque, según él, existía un profundo deseo de dar a la música un estatus de “rasgo vital”, de ennoblecerla con teorías sobre su relevancia biológica. Probablemente, el efecto Mozart esté cargado de esa misma actitud hacia la música clásica. ¿La afirmación de que solo la música clásica era la que estimula el intelecto, la que desarrolla las capacidades nobles de nuestro cerebro, era un hecho científico o más bien un prejuicio? ¿Estos estudios estaban “forzando” confirmar la idea de que la música clásica es esencialmente distinta al resto?

El poder de estar alegre

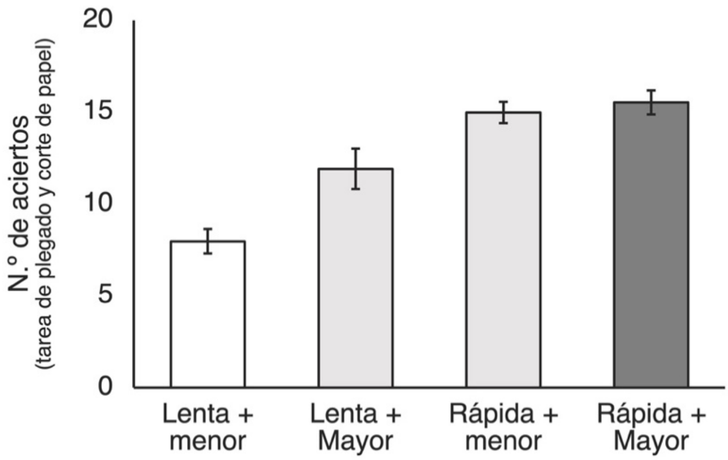
La tormenta estaba al caer. En muy poco tiempo, el mismo atrevimiento que llevó a los investigadores a utilizar músicas de otros compositores que no eran Mozart los llevó a indagar en el efecto de otras expresiones musicales. Los beneficios sobre la tarea de *plegado y corte de papel* se repitieron con la música minimalista de Philip Glass, quien, además de obras propias de la música clásica (sinfonías, cuartetos de cuerda, sontas, etc.), ha sido el autor de bandas sonoras populares como la de *Las horas* y *El show de Truman*. Y la separación del efecto Mozart de Mozart siguió creciendo cuando los efectos aparecieron también con la música de Yanni y música pop, como el *Return of the Mack* de Mark Morrison y el *(I'm Not Your) Steppin' Stone* de *The Monkees*. Pero el golpe definitivo lo asestarían los estudios del investigador canadiense Glenn Schellenberg. En primer lugar, porque dio el paso más alejado y, en vez de utilizar música de Mozart, música clásica o simplemente música, utilizó la narración grabada de uno de los relatos breves de Stephen King, *The Last Rung on the Ladder*. Os diréis: ¡eso no es música! ¿Qué beneficios tuvo? Sorprendentemente, los cerca de treinta participantes de estudio obtuvieron las mismas puntuaciones en la prueba de razonamiento tras haber escuchado diez minutos del relato que tras haber escuchado la sonata de Mozart. ¡Ni siquiera el efecto Mozart es un efecto de la música! ¿Ya cualquier cosa es capaz de hacernos más inteligentes? Lo que el grupo de investigación de Schellenberg sospechaba era que todos los beneficios que estaban apareciendo con la música eran la consecuencia de algo todavía más elemental: pasar un rato contentos y animados. No era un cambio en la arquitectura del cerebro, era la consecuencia de una emoción positiva. El mismo efecto que el subidón de recibir un regalo o ver un vídeo de tomas falsas justo antes de las pruebas de inteligencia.

Así, Schellenberg intentó aportar más evidencias que respaldaran esta otra interpretación del efecto Mozart. La primera de ellas la encontró en el mismo estudio del relato de Stephen King. Aunque, en general, el efecto de la música Mozart fue el mismo que el del relato de King, el equipo de investigación detectó que en estos datos había dos tipos de patrones: las personas que preferían la música de Mozart antes que escuchar la historia y las personas con el gusto opuesto. Resulta lógico que las personas que prefieren las sonatas de Mozart se sientan más contentas cuando escuchan a Mozart, mientras que sucedería lo contrario con las amantes de Stephen King y sus novelas. Siguiendo esta lógica, el grupo de Schellenberg descubrió que la sonata para dos pianos era más beneficiosa en las personas que preferían a Mozart y, a la inversa, las personas con predilección por Stephen King obtenían mejores puntuaciones en la prueba de razonamiento tras escuchar el relato.



El siguiente estudio de Schellenberg no tardó en llegar, comparando la clásica sonata de Mozart, que es una música radiante y enérgica, con el *Adagio en Sol menor* atribuido a Tomaso Albinoni, uno de esos *hits* de la música clásica que continuamente aparece en series y películas, y que destaca por su *tempo* lento y su emoción triste. Pero esta vez no querían suponer nada, tenían que medir también los cambios en el estado de ánimo para comprobar que la alegría y la activación inducidas por la música estaban detrás de todos los beneficios en las pruebas de razonamiento. Y así fue. La música vibrante de Mozart aumentó la alegría, la energía mental, el vigor, etc., mientras que el *Adagio* de Albinoni produjo tristeza, enlentecimiento, languidez, etc. Nada inesperado. Lo verdaderamente interesante fue que las puntuaciones de razonamiento solo mejoraron con la música de Mozart, y que la mejora fue proporcional al aumento en la alegría y la activación de los participantes.

Pero, por si aún quedaban dudas, el grupo de Schellenberg se embarcó en el estudio definitivo. Volver a los orígenes del efecto Mozart, es decir, utilizar solo la sonata para dos pianos y manipular su sonido para que sonara más o menos triste o alegre. Los investigadores eran conscientes de que el *tempo* y el modo de la tonalidad (mayor o menor) son ingredientes fundamentales de la emoción que percibimos en la música. Las canciones lentas y en tonalidades menores transmiten tristeza, mientras que los ritmos rápidos y las tonalidades mayores producen sensaciones de júbilo. La relación entre *tempo*/modo y emoción ha sido un recurso básico que los compositores llevan explotando siglos para dinamizar los sentimientos de sus obras. Que ahora pegan más sentimientos positivos, acordes en modo mayor. Que puede encajar mejor algún matiz de melancolía, rebajemos el *tempo* de la obra. Así, Schellenberg y sus colaboradores, cual compositores, construyeron versiones de la sonata para dos pianos en modo mayor (como estaba escrita) y en modo menor, rápidas (♩ = 165) y lentas (♩ = 60). En un proceso similar a la opción de *cambiar la velocidad de reproducción* de plataformas de *streaming* como YouTube o Netflix, la sonata sonaría a mil revoluciones o a paso lento. Al combinar los cambios de *tempo* y de modo dio lugar cuatro versiones de la sonata, una eminentemente alegre ("rápida + modo mayor") y otra profundamente triste ("lenta + modo menor"), dejando dos versiones en medio con una emoción más ambigua (una versión "rápida + modo menor" y otra "lenta + modo mayor"). El resultado de este estudio apoyó una vez más la teoría de que no era el estilo de la música de Mozart lo que beneficiaba el razonamiento, sino la alegría y la energía que producen algunas formas de música. La versión extremadamente triste de la sonata ("lenta + modo menor") produjo el menor de los beneficios y, a medida que la sonata adquiría más rasgos alegres, las puntuaciones en la prueba de razonamiento eran cada vez mejores.



Al comprobar que los efectos milagrosos de la sonata de Mozart dependían de si transmitía más o menos alegría y más o menos energía, Schellenberg demostraba que el poder "milagroso" en todos estos estudios era el de unas personas que afrontaban una actividad aburrida y costosa, una prueba de inteligencia, con motivación y con ánimo, sintiéndose contentas. Ese estado marcó la diferencia para que hicieran un buen trabajo. Más aún, los estudios de Schellenberg no discutían el estatus de la música como una herramienta excelente para producir placer, llenarnos de energía o cambiar nuestro estado de ánimo. Al contrario, aunque estos cambios también aparezcan con estímulos que no son musicales, como con el relato de Stephen King, lo que la evidencia científica sugiere es que la música, sea pop o de Mozart, tiene un poder privilegiado para llevarnos a ese estado óptimo que nos hace mejores hasta en los tests de inteligencia.

Lo que Schellenberg demostró es que estos beneficios vienen por una vía que no es la del cambio de la estructura del cerebro, escuchar música no es ningún *gimnasio sin esfuerzo de la mente*. El efecto Mozart nos llega a través de la vía de la emoción. No hay nada de malo en que millones de familias en el mundo hayan comenzado a escuchar música de Mozart después del artículo del efecto Mozart o que la música que estereotípicamente asociemos en nuestra cultura a la infancia y al desarrollo de los bebés sea la música clásica. No hay nada de malo mientras seamos conscientes de que esa música no va a "esculpir" nuestro cerebro y ni nos va a convertir permanentemente en mejores matemáticos, ingenieros o jugadores de ajedrez. Algunos tipos de música tienen un especial poder calmante en los recién nacidos, como sucede con las nanas, que son capaces de consolar el estrés con mucha más eficacia que incluso cuando se le habla al bebé. Si la industria discográfica ha sido capaz de encontrar un grupo de obras de música clásica con virtudes similares, eso es una buena noticia. Pero es importante que no se anuncien como una forma de "desarrollar el cerebro de nuestro bebé". Tal vez, *Cheer up your baby's brain**. Quizá no solo sea la emoción y la energía, quizá también influya el estereotipo detrás de la música clásica como un producto que debemos consumir en las "ocasiones intelectuales", en los momentos más nobles y grandilocuentes de nuestra existencia. Asociamos la música de un cuarteto de cuerda a restaurantes con manteles sedosos y lámparas de cristales, no a hamburgueserías. ¿Por qué no iba a transformar de la misma forma el ambiente neutro de un laboratorio? Escuchamos una sonata para dos pianos y nuestra actitud se vuelve más reposada, a esa música le pega que seamos cultos y meticulosos. Tenemos que completar la prueba de razonamiento en consecuencia a ese ambiente.

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* Alegra el cerebro de tu bebé (trad.).

Como era de esperar, el grupo de Schellenberg demostró con sus estudios que el "subidón" de la radiante sonata de Mozart no solo mejoraba el rendimiento en pruebas de razonamiento. Otras capacidades mentales también se beneficiaban, como la rapidez mental y la creatividad. La tormenta científica que desencadenó el efecto Mozart terminó por matizar todos los puntos de este llamativo efecto. Ni solo ocurre con la música de Mozart, ni se debe al fortalecimiento de nuestro hemisferio derecho, ni solo ocurre con nuestra capacidad de razonamiento. Pero aquella anécdota científica abrió puertas que nunca más se cerrarían. En primer lugar, la certeza de que, sea como sea, escuchar música nos ayuda a rendir y afrontar la vida de una mejor forma. En segundo, el efecto Mozart sembró en la mentalidad colectiva una serie de preguntas: ¿puede la música cambiar nuestro cerebro? ¿Puede una actividad tan placentera potenciar aquel órgano que nos hace ser quien somos? ¿Por tanto, la música transforma el modo en el que sentimos y comprendemos el mundo?

*Musique d'ameublement**

Los estudios del efecto Mozart, al final, describían una situación que pocas veces se da en nuestra rutina diaria. Por un segundo imaginaos en la piel de esas personas, sentadas en la silla de una habitación, sin moverse, con el móvil apagado o en modo avión y sin ninguna otra distracción. Solamente escuchando diez minutos de una sonata de Mozart. En esta situación la música estaría en el foco de nuestra atención, si me permitís el símil teatral, la acción principal sobre la *escena*. Pero pensad en

* Música de mobiliario (trad.).

la última vez que hicisteis algo similar. Probablemente fuera el último concierto al que asististeis. Aunque estamos rodeados de canciones, la mayor parte del tiempo que escuchamos música estamos realizando otras actividades. En el metro o en el bus de camino al trabajo, conduciendo, cocinando en casa o mientras nos duchamos. La música es nuestra fiel compañera, la que ahuyenta la monotonía, ese microcosmos en el que, como el olor a hogar o el tacto a pijama, nos hace sentir la seguridad de un placer previsible. *Musique d'ameublement* la llamaría el compositor francés Erik Satie en un tiempo en el que aún no existían los centros comerciales. "La música de mobiliario crea una vibración, no tiene otro objetivo; desempeña el mismo papel que la luz, el calor y la comodidad en todas sus formas", diría. La pregunta después de haber examinado la investigación sobre el efecto Mozart es ¿esas canciones de fondo, el hilo musical de nuestro día a día, también influyen en nuestras capacidades mentales? Es una pregunta legítima, porque qué más da si la música suena antes, como *escena principal*, o mientras hacemos otras actividades, como *telón de fondo*.

Antes incluso que apareciera el efecto Mozart, un grupo numeroso de estudios ya sugería que escuchar música de fondo favorecía el rendimiento en otras tareas cotidianas. Por ejemplo, un viaje largo en el coche es una actividad monótona en la que solo a veces necesitamos cambiar de acción, como cuando aparece un obstáculo en la carretera que exige que dejemos de acelerar, frenemos o cambiemos de carril. Escuchar música en esos trayectos largos, sobre todo cuando estamos cansados y las canciones son estimulantes como las de *heavy metal*, nos hace mantener la capacidad para reaccionar. Y lo mismo sucede con actividades académicas como aprender nuevos conceptos en clase, aprender nuevos idiomas, realizar cálculos matemáticos, leer y comprender textos, e incluso comprender el significado de las gráficas que acompañan a los textos. Esto es así porque la música de fondo es capaz de potenciar temporalmente nuestras capacidades mentales. Con música de fondo a veces somos más ágiles percibiendo nuestro entorno y tenemos un mejor desempeño en pruebas de inteligencia, manteniendo la atención durante largos periodos de tiempo, memorizando palabras o reteniendo secuencias arbitrarias de números como la de nuestro número de identidad.

Pero al igual que sucedía con el efecto Mozart, rendir mejor durante un tiempo no significa que la arquitectura de nuestro cerebro haya cambiado con unos cuantos minutos de canción. Seguro que alguna vez cuando os sentíais cansados en el coche habréis empezado a escuchar música, porque sabéis que eso os ayudará a mantener la concentración. Pero nunca tomasteis esa decisión pensando que la música de Shakira "esculpiría" vuestra materia neuronal. ¡Lo hicisteis porque queríais animaros! Como os decía con el efecto Mozart, la música nos alegra y nos estimula, sobre todo si escuchamos rock o nuestra lista de reproducción favorita, y eso nos mantiene ágiles al volante. Cuando la tarea es aburrida es muy probable que la monotonía acabe haciendo mella en nuestro ánimo. Las tareas que se usan en psicología para medir la capacidad de vigilancia pertenecen a esa categoría de actividades que no son especialmente divertidas, en las que las participantes pasan un periodo de tiempo largo en una habitación, a veces cerca de una hora, percibiendo continuamente estímulos distractores (por ejemplo, un *flash* de luz, un sonido agudo, etc.) y detectando lo más rápido posible cuándo aparece un evento raro (una luz de otro color, un sonido grave, etc.). En este tipo de tareas también es probable que desconectemos y empecemos a pensar en nuestras vidas: ¿qué tenía que comprar en el supermercado? ¿Qué planes había para este fin de semana? Es un vagar de nuestra mente (en inglés se lo conoce como *mind wandering*) en el que una vez dentro, somos menos conscientes de lo que está pasando fuera y cometemos más errores. Sin embargo, es más fácil de mantener la concentración cuando junto a esa tarea suena una música animada o el disco que tanto nos gusta. La situación en el laboratorio, que de otra forma sería muy tediosa, cobra un interés renovado con todas esas melodías. Nuestra atención, que antes tendía a evadirse porque lo que estaba pasando era insustancial, de repente se siente atraída por un contexto mucho más interesante.

Otra forma en la que la música de fondo puede favorecer el rendimiento es a través de la calma. En la escuela puede ser una herramienta excelente para sosegar las emociones de los niños y generar un ambiente más tranquilo en el aula. Cuando la clase tiene menos ruidos, menos interrupciones y menos niños deambulando por las mesas, es lógico que los niños realicen mejor sus ejercicios de matemáticas. Sea porque nos anima o porque nos calma, escuchar música de fondo puede tener beneficios interesantes sobre nuestros resultados en otra actividad. Lo que no debemos olvidar es que *hacer mejor* una prueba de aritmética no significa *ser mejor* en aritmética. Todo cuanto hace la música es sembrar en nosotros su emoción.

The dark side of the song*

Ojalá todo lo que tuviera que contaros sobre escuchar música fuera positivo. Ojalá todo fuera tan sencillo y tan directo: *escuchar música* = *beneficios*. Por desgracia no podemos estar a todas horas con los altavoces encendidos. Seguro que lo habréis vivido, estabais conduciendo con tranquilidad y la radio a todo volumen, y de repente sucede algo que lo tensa todo, un aparcamiento imposible, una calle en obras, coches realizando maniobras extrañes. No podéis evitarlo; ahora la música es demasiado molesta y necesitáis bajarla. O estabais haciendo algo repetitivo

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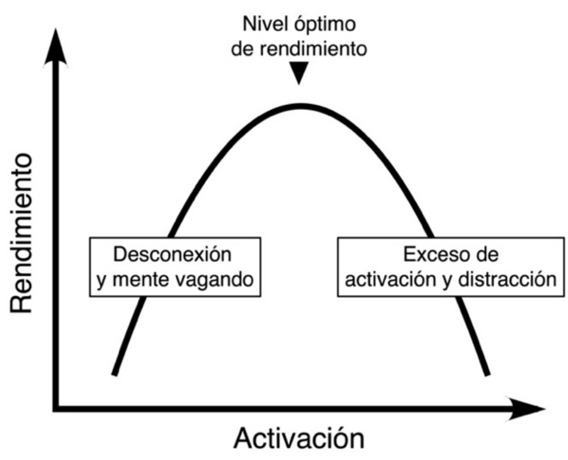
* El lado oscuro de la canción (trad.)

con el ordenador, quizá configurar la estética y los colores de una presentación, y una canción os estaba amenizando ese rato. Pero a continuación comenzamos a leer el texto de uno de los recuadros para comprobar que tampoco hay fallos en el lenguaje y aquí también tenemos que parar la música. El origen de esa interferencia está en la propia naturaleza de la música, es un estímulo auditivo que estamos obligados (¿*condenados* podríamos decir en esos casos?) a procesar. Nuestros oídos no son como nuestros ojos, que podemos cerrar a placer y cancelar la entrada de información visual. De hecho, es habitual ver a personas escuchando música con los ojos cerrados, evitando la distracción de lo visible, deseando que la única información sensorial que les llegue sea la del sonido. Por eso, desde el momento en el que comenzamos a escuchar música de fondo, aunque sea sin prestarle atención, ya no estamos haciendo solo una cosa, comenzamos a hacer dos.

Como seres limitados en el tiempo y en el espacio (¡nuestra vida y nuestra materia se extienden hasta donde se extienden!), también disponemos de una capacidad cognitiva limitada. Si la actividad principal que estamos realizando es muy exigente, eso significa que nuestras habilidades se encuentran al límite de sus posibilidades. Y de repente, con el vaso casi a rebosar, llega una canción que no podemos evitar que acapare parte de los recursos de nuestro cerebro. Parte de nuestra capacidad para percibir, atender, memorizar se destinan a ese hilo musical que es irrelevante pero que procesamos sin opción. Cuando dedicamos menos a una tarea exigente, os podréis imaginar que la música en lugar de facilitar las cosas, lo que hace es empeorarlas. Así, las canciones de fondo, al igual que el bullicio, el ruido de tráfico o el de oficina, pueden perjudicar nuestro rendimiento cuando leemos, memorizamos textos, prestamos atención a hojas llenas de símbolos y números, o realizamos cálculos. Del mismo modo, la música puede obstaculizar que los cirujanos aprendan técnicas de quirófano nuevas o el desempeño de los conductores en situaciones de carretera en las que no podemos perder ni un ápice de concentración. Por tanto, una variable esencial en el efecto de la música de fondo son las demandas de la tarea. Si la actividad es muy difícil para la persona, la música rebosará el vaso de su capacidad. En esos casos, más que una compañera, la música se convierte en una distracción, en un evento más cercano al ruido que al placer. Mientras que, si la tarea es enormemente sencilla, quizá ni siquiera haya margen de mejora, el único beneficio esperable en ese caso sería ayudar a la persona a no desengancharse de seguir repitiendo una acción tan banal durante mucho tiempo.

Pero la música puede afectar negativamente a lo que hacemos también por el tipo de emoción que transmite. Hay canciones que en lugar de animar o calmar, resultan irritantes, desagradables. Y al inducir un estado de ánimo así de negativo, perjudican el aprendizaje. Por ejemplo, la obra del compositor Nikolái Rimsky-Kórsakov *El vuelo del abejorro* es una candidata ideal para este tipo de efectos. Es una música frenética, una secuencia cromática de semicorcheas que parece no tener fin, suben y bajan, tal y como el vuelo que dibujaría un abejorro en el aire. Solo hay que mirar su partitura para hacerse una idea de ello. Imaginad si manipulamos la velocidad de reproducción de esta breve obra y enlentecemos su *tempo* hasta la pesadez. Imaginad reproducir esa lluvia de semicorcheas en el diluvio torrencial de notas que es o transformarla en un goteo lento y grueso como el de una cornisa. Imaginad escuchar cualquiera de ambas opciones en bucle durante diez minutos. Las personas, como es lógico, se vuelven más impulsivas con ese hilo musical, tomando decisiones más rápido y cometiendo más errores. Ante una situación tan irritante como un diluvio o un goteo espeso en la cara, se desata la impaciencia, surge una tendencia para intentar acabar cuanto antes con aquello.

También, la activación que produce la música puede en muchos casos ser excesiva. Un disco de los *Scorpions* puede ser realmente útil para no decaer conduciendo en una autovía recta y kilométrica, pero a la vez las canciones de *heavy metal* pueden ser demasiado intensas cuando estás en una carretera angosta de montaña, mal asfaltada y con un desfiladero a un palmo. Quizá la activación en ese momento sea suficiente para que cualquier otro estímulo añadido nos excite en exceso y nos desborde. Desde que pusimos las ruedas en ese valle los *Scorpions* dejaron de ser algo placentero e, irremediablemente, necesitamos parar la música.



Por último, la música puede cautivar. Puede ser tan sorprendentemente satisfactoria y recorrer con aterciopelados roces nuestra nuca que en ocasiones puede convertirse en una distracción. Tener el altavoz encendido crea una oportunidad para que las mentes que desean desconectar se enganchen a las canciones que reproduce, es disponer las condiciones para el velcro, un deseo y una oportunidad. Cuentan que en el estreno de una de sus series de *Musique d'ameublement* Erik Satie había dispuesto toda la sala para que la audiencia se divirtiera charlando y bebiendo mientras sonaba aquella música que solo debía servir para "crear una vibración" y "desempeñar el mismo papel que la luz, el calor y la comodidad en todas sus formas". Pero el público no hablaba, permanecía en silencio cautivado por aquella música y Satie enfureció: "¡Hablad! ¡Hablad!".

¿Telón de boca o telón de gasa?

Actuar es abrazar el presente con la expresión del pasado. Los conocimientos que forjamos con las experiencias de ayer guían nuestras acciones hoy. Y a la inversa, nuestros esquemas del pasado se actualizan y transforman con el presente. "Quien controla el presente controla el pasado y quien controla el pasado controlará el futuro", diría George Orwell. Sin ahondar en reflexiones sociales y políticas como las del escritor, nuestra capacidad para realizar cualquier actividad y aprender de ella depende de los eventos que vivimos en cada momento. Pero, como os imaginaréis, la información que nuestro cerebro puede mantener activa, lo que en psicología se conoce coma *memoria a corto plazo*, es también limitada. Cuando queremos retener algo, sobre todo si es de una exigencia considerable como un número de teléfono o conocimientos nuevos, es recomendable que nos centremos y no hagamos en paralelo otras actividades. Vivimos en un momento de la humanidad en el que el tiempo es más valioso que nunca y el *multitasking* abunda, presentándose como una buena forma de ahorrar minutos. Pero debemos de ser conscientes que esta estrategia no siempre sale bien. Uno de los condicionantes de nuestro rendimiento en las diversas tareas de nuestro *multitasking* es el contenido de esas actividades. La neurociencia actual muestra que la información auditiva y verbal se representa en nuestro cerebro separada de la información visual y espacial. En uno de los modelos de memoria a corto plazo más influyentes, el modelo de *memoria de trabajo* de Alan Baddeley, denomina a estos dos sistemas cerebrales de memoria a corto plazo *bucle fonológico* y *agenda visoespacial*. Lo importante de esta escisión es que la capacidad de cada uno es independiente del otro, lo que implica que escuchar un *podcast* mientras organizamos la ropa en el armario no interfiera lo mismo que cuando leemos un libro. Es cierto que las palabras, cuando están escritas, son estímulos visuales, pero para poder trabajar con ellas necesitamos recodificarlas fonológicamente. En nuestro interior, más que algo que "se ve" es algo que "se escucha". Así, cuando las dos tareas del *multitasking* son verbales la capacidad del bucle fonológico se satura rápido y al final acabamos sin entender lo que acabamos de leer (probablemente se inicie o una espiral de repeticiones de la última frase hasta que al final la comprendemos o nos hartemos y decidamos pasar al *monotasking*).

Os preguntaréis: ¿qué sucede cuando la tarea secundaria es de un tipo diferente a la principal? En el laboratorio, el grupo de investigación de Baddeley reprodujo situaciones de *monotasking* y *multitasking*, eligiendo como tareas centrales una actividad visoespacial, identificar en un patrón de cuadrados blancos y negros uno que de repente cambia, y una tarea verbal, memorizar una serie de números presentados en la pantalla de un ordenador (T, L, B…). Para la condición de *multitasking* también hubo una tarea secundaria verbal, sumar a la cantidad anterior un número escuchado (5 + 7, + 4, + 9…), y otra visoespacial, imaginar una matriz de 3×5 con cuadrados rellenos o no según una secuencia escuchada.

Las tareas del estudio de Baddeley tenían una cierta exigencia y por tanto no les sorprendió observar que el rendimiento en las condiciones de *multitasking* fue en general peor que en el *monotasking*. El dato importante era que el *multitasking* tenía todavía peores resultados con tareas que trabajaban con el mismo tipo información, visoespacial-vioespacial y verbal-verbal, mientras que la interferencia no era drástica en las condiciones de *multitasking* mixto (una tarea visoespacial y otra verbal).

A veces este tipo de interferencia ocurre aunque no busquemos realizar un *multitasking*. Estamos leyendo, quizá estudiando en una biblioteca, y de repente una conversación se cuela por la ventana. A pesar de que lo único importante en ese momento es el texto de nuestro libro, sus palabras se mezclan en nuestra cabeza con las de otras personas extrañas. Este fenómeno se explica porque, como con la música, no podemos impedir que nuestro cerebro procese el lenguaje una vez lo tenemos delante y porque para memorizar el texto de nuestro libro necesitamos repasar internamente las palabras. Sin embargo, las palabras de aquella conversación son verdaderos obstáculos, un palo en la rueda de nuestra capacidad para repasar. Esto sucede incluso cuando el diálogo es en otro idioma que no conocemos.

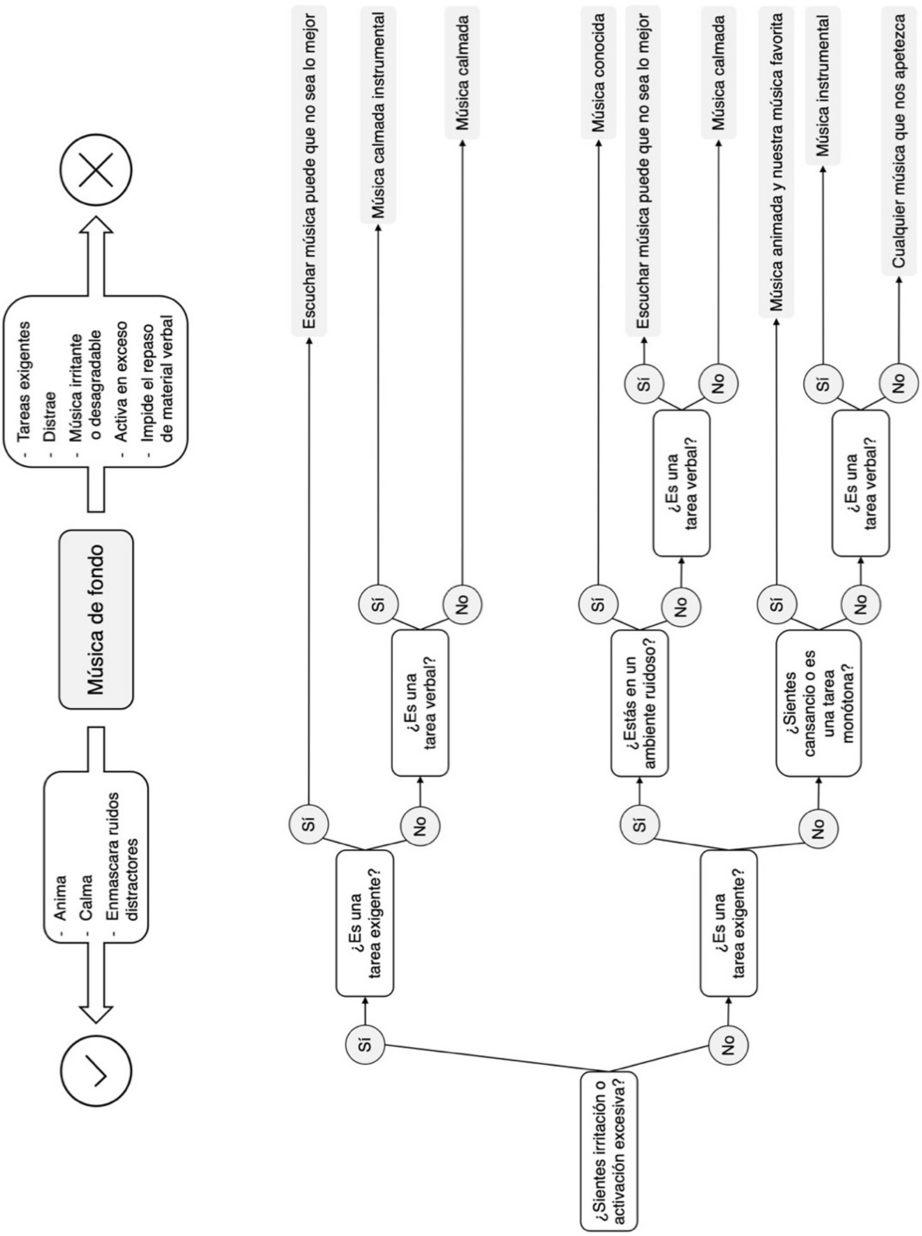
Para lo bueno y para lo malo, el lenguaje y la música comparten muchos aspectos, también esta capacidad para lastrar el repaso interno de los textos. En primer lugar, porque muchos tipos de música contienen letras y, como os podréis imaginar, este es la clase de música que más interferencia produce. Pero la música más pura, la que existe al margen de las palabras como las notas de un violín o los acordes de una guitarra, accede igualmente a nuestra memoria auditiva y compite con la representación fonológica de las palabras que acabamos de leer. En ese caso la música es un obstáculo, un *telón de boca* que nos impide presenciar la escena principal. Por eso, escuchar canciones de fondo, vocal e instrumental, puede ser un impedimento en actividades verbales como estudiar, realizar cálculos mentales, memorizar, etc., y no suponer ningún problema para otras tareas más visuales, como cocinar o conducir. Incluso cuando las canciones se transcriben a instrumentos, quedándose sin letra, como sucede con las versiones de los karaokes o las *covers* de piano, si la canción es lo suficientemente popular puede que continúe evocando su letra. Hay melodías que están tan estrechamente asociadas a una letra, pensemos en la melodía del *Cumpleaños feliz*, en la que escuchar sus notas es casi como escuchar las sílabas de sus palabras.

Sin embargo, el poder enmascarador de la música puede ser una bendición cuando estamos en contextos ruidosos, como cuando estudiamos en una biblioteca bulliciosa. En esas ocasiones, lo mejor es que nos coloquemos los cascos, reproduzcamos las canciones que conocemos bien y disfrutamos, e intentemos concentrarnos lo máximo posible. Ya sabemos que con la música aprovecharemos menos el tiempo que en silencio, pero mucho mejor que escuchando conversaciones imprevisibles, sin capacidad para anticiparnos a las risas, a las subidas de volumen, a las apariciones de voces nuevas, etc. Y en nuestras canciones favoritas conocemos hasta la duración de los silencios. Esta es la versatilidad de la música de fondo. A veces funciona como *telón de boca*, ocultando lo que es importante, y otras es *telón de gasa*, cubriendo el revuelo de las acciones secundarias y resaltando la escena principal.

Depende. ¿De qué depende?

La investigación sobre el efecto Mozart y la música de fondo demuestra que la relación entre música y rendimiento no es nada simple. En ocasiones, *escuchar música = beneficios*, en otras, las melodías son una desventaja, y en otras, nada. Los efectos de la música son complejos porque es algo que nos remueve, algo que nos afecta a nivel emocional. Esto es así por la diversidad de efectos que tiene la música, sobre nivel de activación, sobre nuestros sentimientos, cubriendo sensorialmente a otros estímulos, etc. Teniéndolo en cuenta, podemos hacernos una idea de lo que pasará si colocamos la aguja sobre el vinilo en un contexto determinado. En el siguiente diagrama he intentado sintetizar la generalidad de las conclusiones de la investigación sobre este tema. Sin embargo, la norma no representa a todos los casos y es ahí, en la empresa de conocer las singularidades de cada persona, donde están las fronteras de nuestro conocimiento y desde donde la ciencia se está expandiendo en el laboratorio. Por ejemplo, hoy sabemos que las canciones, cuando actúan como una distracción, perjudica más a las personas introvertidas que a las extrovertidas, y que las personas que habitualmente estudian con música son o acaban convirtiéndose en personas que resisten mejor los efectos negativos de la música. Seguro que en los próximos años descubriremos más sobre la música de fondo y optimizaremos mejor nuestros hilos musicales para cada ambiente. Por ahora, nos queda disfrutar de estas pinceladas a brocha gorda de conocimiento.

Han pasado treinta años desde que apareciera el efecto Mozart y la ciencia, tan perpleja como el resto de la sociedad ante un efecto con promesas revolucionarias, solo ha podido confirmar fuerza emocional de la música. Eso, y que estar animados es sinónimo de un buen desempeño. Atrás han quedado las ideas de que la música podía ser el *gimnasio mental* para los perezosos. Tristemente, los niños de Georgia y de todas las familias del mundo que pasaron años escuchando música clásica no se hicieron más inteligentes. Las sinfonías de una hora no transformaron su memoria o su razonamiento. Al menos no de la forma tan sencilla que proponía el efecto Mozart. Ahora viven con recuerdos musicales, reconocen la música de muchos anuncios y han crecido rodeados de la materia cultural que formó los cimientos de la música en occidente. Pero no hay rastro de aquella hipertrofia cerebral. En consecuencia, ¿deberíamos desechar la idea de que la música cambiar nuestro cerebro? ¿La introducimos en el cajón de los *neuromitos* así sin más? Si la música fuera un mundo pasivo, en el que solo recibimos o, incluso, recibimos sin atención como con los hilos musicales, probablemente la respuesta sería más rotunda. Pero las canciones nacen de la acción, de cantar, tocar y sincronizarse con un grupo. La música surge de interpretar los temas clásicos y crear otros nuevos. Esto es algo muy diferente a revisar sentados nuestras listas de Spotify y ver las novedades qué nos ofrece esta semana la plataforma de *streaming*. En lo primero no hay ni un segundo sin decisiones, implica a la persona como un agente que recuerda, improvisa, se mueve, respira, etc. Lo segundo es, en comparación, solo un momento plácido. No hay oportunidad de cambiar el curso de la música que está grabada, solo podemos elegir el instante y el ambiente en el que vamos a escucharla. Dejadme que os hable de lo que hoy sabemos de los beneficios cerebrales de tocar un instrumento. Hablemos de la música como creación.



Música de fondo
- Anima
- Calma
- Enmascara ruidos distractores
- Tareas exigentes
- Distrae
- Música irritante o desagradable
- Activa en exceso
- Impide el repaso de material verbal
¿Sientes irritación o activación excesiva?
Sí
No
¿Es una tarea exigente?
Sí
No
Escuchar música puede que no sea lo mejor
¿Es una tarea verbal?
Sí
No
Música calmada instrumental
Música calmada
¿Es una tarea exigente?
Sí
No
¿Estás en un ambiente ruidoso?
Sí
No
Música conocida
¿Es una tarea verbal?
Sí
No
Escuchar música puede que no sea lo mejor
Música calmada
¿Sientes cansancio o es una tarea monótona?
Sí
No
Música animada y nuestra música favorita
¿Es una tarea verbal?
Sí
No
Música instrumental
Cualquier música que nos apetezca

Appendix B2

Román-Caballero, R., & Lupiáñez, J. (2019). El impacto cognitivo de la práctica musical: Explorando las ventajas de un mundo musicalmente activo. *Ciencia Cognitiva, 13*(1), 21–23.

https://www.cienciacognitiva.org/?p=1808

(English version:

Román-Caballero, R., & Lupiáñez, J. (2019). The cognitive impact of musical practice: Exploring the advantages of a musically active world. *Ciencia Cognitiva, 13*(1), 24–26.

https://www.cienciacognitiva.org/?p=1813)

Appendix B3

Román-Caballero, R. (2021, June 24). ¿Cuáles son los beneficios cerebrales de tocar un instrumento?. *The Conversation: Spanish Edition*.

https://theconversation.com/cuales-son-los-beneficios-cerebrales-de-tocar-un-instrumento-163225

Appendix B4

Román-Caballero, R. (2021, September 8). ¿Por qué los monos no cantan flamenco?. *The Conversation: Spanish Edition*.

https://theconversation.com/por-que-los-monos-no-cantan-flamenco-166983

Appendix B5

Román-Caballero, R., & Lupiáñez, J. (2022, June 21). ¿Cómo cambia nuestro cerebro la práctica musical?. *The Conversation: Spanish Edition*.

https://theconversation.com/como-cambia-nuestro-cerebro-la-practica-musical-181031

Appendix B6

Román-Caballero, R., & Lupiáñez, J. (2020). "Rockin'in rhythm": la atención en contextos rítmicos. *Ciencia Cognitiva, 14*(2), 37–39. https://www.cienciacognitiva.org/?p=1958

(English version:

Román-Caballero, R., & Lupiáñez, J. (2020). Rockin' in rhythm: Attention in rhythmic contexts. *Ciencia Cognitiva, 14*(2), 37–39. https://www.cienciacognitiva.org/?p=1960)

Appendix B7

Dissemination on radio, television, and talks for non-specialized audiences:

https://www.youtube.com/watch?v=v9Jme-T8mO4&t=833s

https://www.canalsur.es/multimedia.html?id=1783499&jwsource=cl

https://www.canalsurmas.es/videos/detail/48763-tesis-22052022

https://www.youtube.com/watch?v=FTRhxJTijgk&t=212s

https://www.canalsurmas.es/videos/detail/66373-tesis-11022023