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ORIGINAL ARTICLE

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 the 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. in J Neurosci Methods 306:77–87, https://doi.org/10.1016/j.jneumeth.2018.05.011, 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.

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, Brooks, Howard, Downes, & Roberts, 2007; Talamini, Altoè, Carretti, & Grassi, 2017) and older adults (Román-Caballero, Arnedo, Triviño, & Lupiáñez, 2018).

In particular, attention is one of the cognitive aspects in which musicians exhibit advantages compared to non-musicians. Playing an instrument (often in 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 of time (Rodrigues, Loureiro, & Caramelli, 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, Kim, Herring, Schumaker, Macpherson, & Weber-Fox, 2013). Similarly, several studies have indicated better executive control in musicians than their

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counterparts (Bialystok & DePape, 2009; Jentzsch, Mkrtchian, & Kansal, 2014; Travis, Harung, & Lagrosen, 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, Swaminathan, Yazdanbakhsh, Zuk, Patel, & Kidd, 2016; Roden, Könen, Bongard, Frankenberg, Friedrich, & Kreutz 2014), vigilance (Carey et al., 2015; Roden et al., 2014; Wang, Ossher, & Reuter-Lorenz, 2015), or executive control (Clayton et al., 2016; Yeşil & Ünal, 2017; D'Souza, Moradzadeh, &Wiseheart, 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 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 Petersen and Posner (2012) and Posner and 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 environment with the aim of adapting 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 to the necessary level for readiness to imminent events (*phasic alertness*), and also involves the capacity to sustain attention for extended periods of time (*tonic alertness* or *vigilance*).

Several tasks have been developed to simultaneously measure these three components, such as the classic *Attentional Network Test* (ANT; Fan, McCandliss, Sommer, Raz, & Posner, 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 laboratory (the *ANT for Interactions* or ANTI task; Callejas, Lupiáñez, & Tudela, 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 have been shown to be 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 videogames, Dye & Bavelier, 2009, bilingualism, Costa, Hernández, & Sebastián-Gallés, 2008, or aging, Mahoney, Verghese, Goldin, Lipton, & Holtzer, 2010; with the ANTI: trait and state anxiety, Pacheco-Unguetti, Acosta, Callejas, & Lupiáñez, 2010, acute sport and caffeine intake, Huertas, Blasco, Moratal, & Lupiáñez, 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, 2018). 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 of time (Langner & Eickhoff, 2013; Lezak, Howieson, Bigler, & Tranel, 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 of time (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, Manly, Andrade, Baddeley, & Yiend, 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, Givens, & Bruno, 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, Stuss, Alexander, Picton, & Derkzen, 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, Castro, López-Ramón, & Lupiáñez, 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), a 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 0.70 in all cases; Luna, Roca, Martín-Arévalo, & Lupiáñez, 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 the right frontal and parietal cortices (reduced EV decrement on discriminability, but not in AV decrement; Luna, Román-Caballero, Barttfeld, Lupiáñez, & Martín-Arévalo, under review), fatigue across 8 h of testing (increased AV decrement, but no effect on EV; Feltmate, Hurst, Kopf, Gagnon, & Klein, 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, Blasco, Luna, & Lupiáñez, 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 (1) 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); (2) improvements in both alerting and executive control, but not in orienting (Lim & Sinnett, 2011; Medina & Barraza, 2019; Strait et al., 2010); and (3) benefits in the sustained aspects of attention (Rodrigues et al., 2013; especially in EV because of the implication of more executive components). Additionally, (4) 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.

Methods

Participants

To determine the sample size, we performed a power analysis with G*Power 3.1 (Faul, Erdfelder, Buchner, & Lang, Georg, 2009) with an alpha of 0.05 and a power of 0.80. 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 online 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 10 years or longer, at least 5 years of formal musical training, and an age of musical training onset prior to 14 years old. The non-musicians 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 10 years of practice or 5 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., 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 0.73 (two-tailed) for detecting a medium correlation coefficient of 0.3 ($\alpha = 0.05$). 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 ($> F_{k+1, n-k-1;\, \alpha = 0.50}$; Aguinis, Gottfredson, & Joo, 2013). A total sample of 140 participants remained (52 musicians, 65 non-musicians, and 23 intermediate musicians). The 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, in accordance with 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).

Materials

The information about inclusion criteria, confounds (see "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"). 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 Angular JS. 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

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

	Years of practice	Age of onset	Years of lessons	Professionals	N. of instruments	Main instrument	Main style	Other musical activities
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%	Teaching: 27 Composing: 11 Conducting: 7
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%	Composing: 3 Teaching: 1

each). Each arrow is separated horizontally by ~ 13 px from adjacent arrows. In EV trials, the central arrow is vertically 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) to increase the difficulty in detecting 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).

Procedure

Participants followed a link to participate in the study. Prior to the experimental task, participants completed the online questionnaire about inclusion criteria, confounds and musical variables. After completing the questionnaire, the link brought them to perform the online 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 Fig. 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 the warning signal and the visual cue, and participants had to stop the down counter by pressing any key as fast as possible.

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.

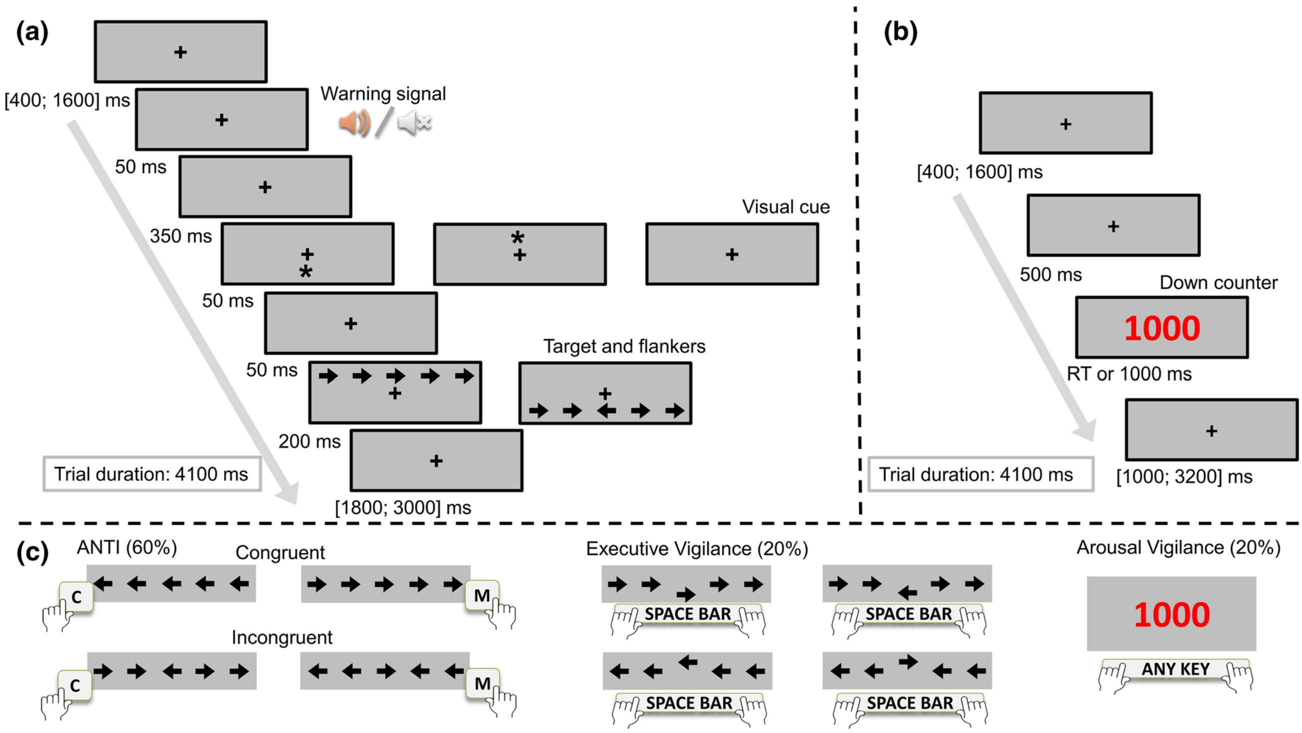

Fig. 1 ANTI-Vea procedure. Temporal sequence in ANTI and EV trials (**a**) and AV trials (**b**). **c** Arrow displacements (the five arrows are randomly displaced ± 2 px to generate noise in ANTI trials and the target is displaced 8 px in EV trials)

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, Imai, King & Stuart, 2011) 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 (Fig. 2). The results indicated no significant difference between matched groups in any of the confounding variables, as shown in Table 2.

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 fifth 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 min approx.) are enough to measure the three attentional networks.[1] For RT analyses of the ANTI measures, trials with

[1] Note that these 15 participants were not included in the analysis of vigilance decrements (both EV and AV) due to the fact that the analyses included time (6 blocks) as factor. Additionally, however, the same analyses were repeated with the whole sample but using only

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

	Unmatched						Matched					
	Musicians (n = 52)		Non-musicians (*n* = 65)		Statistic	*p*	Musicians (*n* = 49)		Non-musicians (*n* = 49)		Statistic	*p*
	M	SD	M	SD			M	SD	M	SD		
Age	**23.73**	**3.70**	**22.03**	**3.85**	***U* = *1188.5***	**.006***	23.25	3.19	22.59	4.05	*U* = 1010	.173
Sex (*n* males)	21		15		χ^2 (c.c.) = 3.291	.070†	18		13		χ^2 (c.c.) = 0.755	.385
Handedness (*n* left-handed; *n* ambidextrous)	3; 4		9; 1		χ^2 = 4.410	.110	2; 2		8; 1		χ^2 = 4.227	.121
Nationality (*n* Spanish)	46		57		χ^2 (c.c.) = 0	1	4		7		χ^2 (c.c.) = 0.410	.522
Education	**4.08**	**0.79**	**3.74**	**0.82**	***U* = *1297***	**.022***	4.06	0.80	3.90	0.82	*U* = 1057.5	.283
General tobacco	0.39	0.84	0.23	0.55	*U* = 1598	.473	0.22	0.55	0.22	0.47	*U* = 1177	.812
Actual tobacco	0.17	0.62	0.20	0.54	*U* = 1598	.387	0.1	0.47	0.18	0.44	*U* = 1081	.122
Physical exercise	62.20	35.15	50.19	32.51	*U* = 1348	.061†	61.70	35.93	51.63	33.61	*U* = 1008.5	.174
Bilingualism (*n* bilingual)	23		17		χ^2 (c.c.) = 3.431	.064†	20		16		χ^2 (c.c.) = 0.395	.530
L2 use	**2.87**	**1.63**	**1.95**	**1.63**	***U* = *1159***	**.003***	2.76	1.61	2.27	1.71	*U* = 995.5	.140
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	.229
Cognitive activities	6.87	3.62	5.57	3.07	*U* = 1339.5	.053†	6.78	3.68	6.06	3.15	*U* = 1073	.364
Video games	0.73	1.09	1.14	1.49	*U* = 1451	.149	0.74	1.10	0.84	1.30	*U* = 1171	.815

L2 second language, *(c.c.)* continuity correction, *M* average, *SD* standard deviation

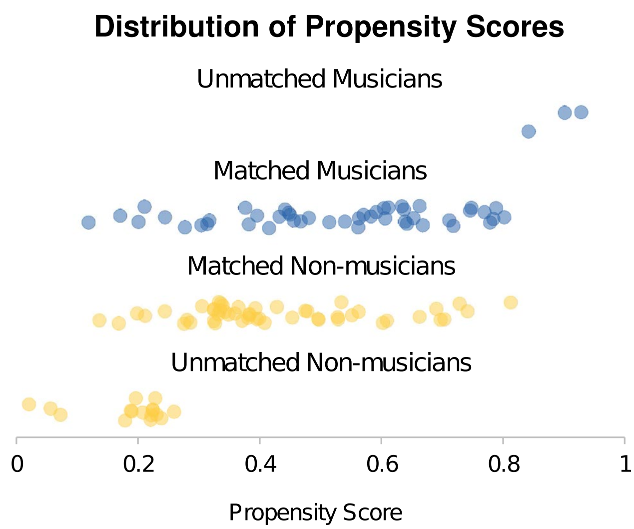

Fig. 2 Distribution of propensity scores. Groups were matched in nine variables: age, sex, education, lifelong tobacco consumption, physical exercise, bilingualism, second language use, involvement in cognitively stimulating activities, and video game playing

incorrect responses (4.71%), RTs smaller than 200 ms, or RTs higher than 1500 ms (0.53%) were excluded.

Footnote 1 (continued)

the first four blocks, to confirm the results without loss of statistical power. Note that we also observed in previous studies that four blocks are enough to observe the vigilance (EV and AV) decrement phenomenon.

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

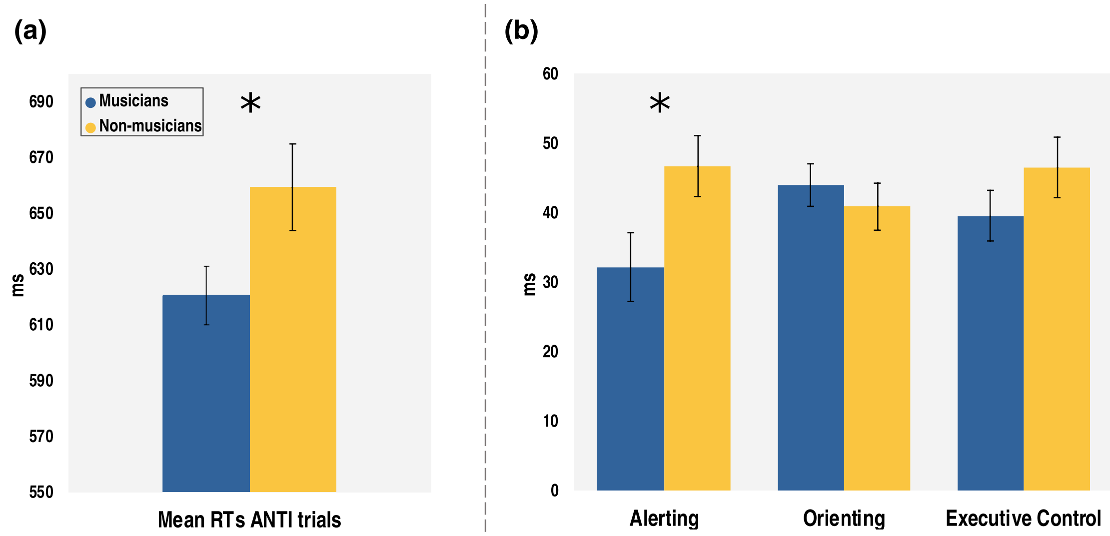

Fig. 3 **a** Mean RTs in ANTI trials and **b** attentional network indeces. Musicians showed lower overall RTs and a smaller alerting index than non-musicians. Significant differences ($p<.05$) are indicated by *. Error bars represent standard errors of the means

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).

Results

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, $F(1,96)=152.89$, $p<0.001$, $\eta^2_p=0.614$, in valid as compared to invalid trials, $F(2,192)=162.69$, $p<0.001$, $\eta^2_p=0.629$, and in congruent as compared to incongruent trials, $F(1,96)=222.11$, $p<0.001$, $\eta^2_p=0.698$. In addition, the usual two-way interactions were also observed: alerting × orienting, $F(2,192)=21.60$, $p<0.001$, $\eta^2_p=0.184$, alerting × congruency, $F(1,96)=19.50$, $p<0.001$, $\eta^2_p=0.169$, and orienting × congruency, $F(2,192)=9.03$, $p<0.001$, $\eta^2_p=0.086$. 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, $t(96)=2.07$, $p=0.021$, $d=0.418$ (see Fig. 3a and Table 3). Furthermore, the alerting × musicianship interaction was significant, $F(1,96)=6.29$, $p=0.014$, $\eta^2_p=0.061$, as musicians showed a smaller alerting effect as compared to non-musicians, $t(96)=2.20$, $p=0.030$, $d=0.445$. On the contrary, there were no between-groups differences in the rest of indices (all $ps>0.05$; Fig. 3b).

Executive vigilance trials

There was a main effect of musicianship for RTs, $F(1,80)=11.22$, $p=0.001$, $\eta^2_p=0.123$, as musicians were faster than non-musicians. However, neither the main effect of block nor the two-way interaction between musicianship and block were significant (Fs < 1).

Moreover, a significant decrement across blocks was observed on A′, F1-LD-F1 test: ATS = 2.89, $p=0.014$, and a significant block × musicianship interaction, ATS = 2.50, $p=0.031$. With no differences at baseline, $U=695$, $p=0.137$, $r_B=0.19$, the trends in discriminability were clearly different for the two groups, as shown in Fig. 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, $p=0.007$), with both groups of participants becoming more conservative across blocks. Note that these results did not substantially change using the whole

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

		Musicians ($n = 49$)		Non-musicians ($n = 49$)		Statistic	p	Effect size[a]
		M (SD)	Md	M (SD)	Md			
ANTI outcomes								
Mean RT		620.51 (73.58)	617.2	659.32 (108.66)	644.4	(one-tailed) $t = 2.07$	.021*	0.418
Alerting index	RT	32.17 (34.65)	30.08	46.71 (30.63)	50.39	$t = 2.20$	.030*	0.445
Orienting index	RT	43.98 (21.39)	41.51	40.87 (23.69)	45.49	$t = -0.68$	.496	− 0.138
Congruency index	RT	39.58 (25.53)	39.84	44.72 (30.50)	44.72	(one-tailed) $U = 1052$	.147	0.124
Gratton effect	RT	6.54 (35.05)	10.51	12.35 (39.85)	6.63	(one-tailed) $t = 0.77$	.223	0.155
Post-error slowing		47.85 (39.98)	40.49	39.17 (37.19)	27.36	$U = 953$	.079†	− 0.206
EV outcomes								
Mean RT		729.8 (82.33)	724	772.4 (92.15)	777.7	(one-tailed) $t = 2.41$	.009*	0.487
A′ slope		− 0.0004 (0.011)	− 0.003	− 0.004 (0.010)	− 0.006	(one-tailed) $t = -1.69$	.048*	− 0.426
B″		0.41 (0.48)	0.54	0.52 (0.38)	0.64	(one-tailed) $U = 1068$	.11	0.110
AV outcomes								
Mean RT		493.5 (53.67)	494.4	529.1 (65.53)	522.4	(one-tailed) $U = 831$	.004*	0.308
Standard deviation		81.99 (31.97)	74.84	92.25 (31.73)	87.63	(one-tailed) $U = 911$	.020*	0.241
% of lapsus		10.90 (13.60)	6.25	18.76 (18.55)	14.58	(one-tailed) $U = 811$	.003*	0.324

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

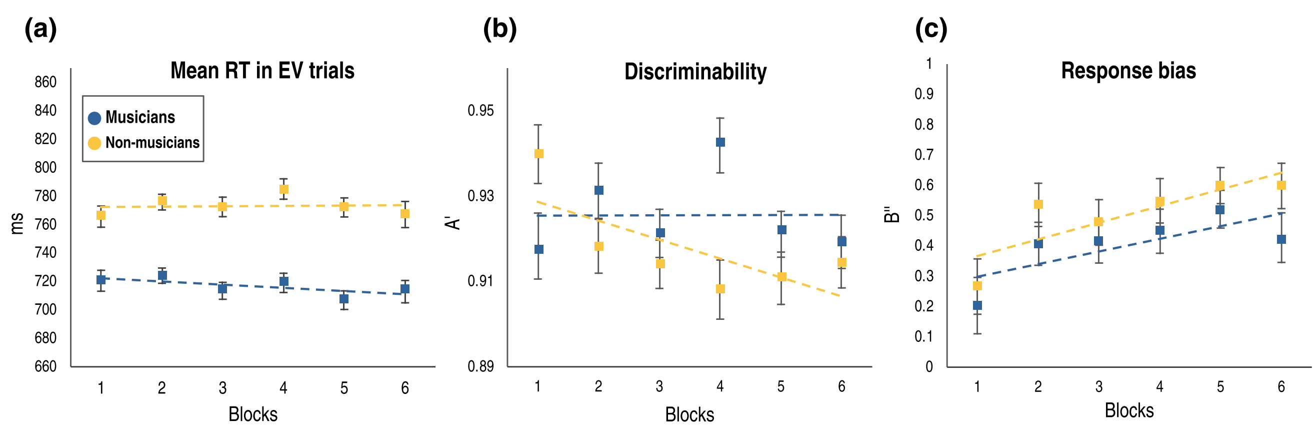

Fig. 4 Executive vigilance outcomes in both groups, musicians (in blue) and non-musicians (yellow). Musicians showed smaller overall mean RTs than non-musicians (**a**) and no decrement in discriminability across blocks (**b**). On the other hand, both groups showed a similar change in the response bias, 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)

sample, but considering only the first four blocks of trials (Appendix B).

Arousal vigilance trials

In AV trials, the main effects of musicianship, F1-LD-F1 test: ATS = 6.63, $p = 0.010$, and block, ATS = 6.84, $p < 0.001$, were significant for RTs, with musicians showing overall faster responses than non-musicians and RTs tending to become slower over time-on-task (Fig. 5a).

SD analyses also revealed significant main effects of musicianship, F1-LD-F1 test: ATS = 19.38, $p < 0.001$, and block, ATS = 8.60, $p < 0.001$, with less variable RT for musicians than for no-musicians and a linear increase across blocks (Fig. 5b). The results were similar for the percentage of lapsus, which showed the effects of musicianship, F1-LD-F1 test: ATS = 7.54, $p = 0.006$, and block, ATS = 10.49, $p < 0.001$. Overall, musicians showed fewer lapsus than non-musicians and the proportion of lapsus increased progressively across blocks in both groups (Fig. 5c). A larger AV decrement for non-musicians than for musicians was apparent, as can be observed in Fig. 5, although with no

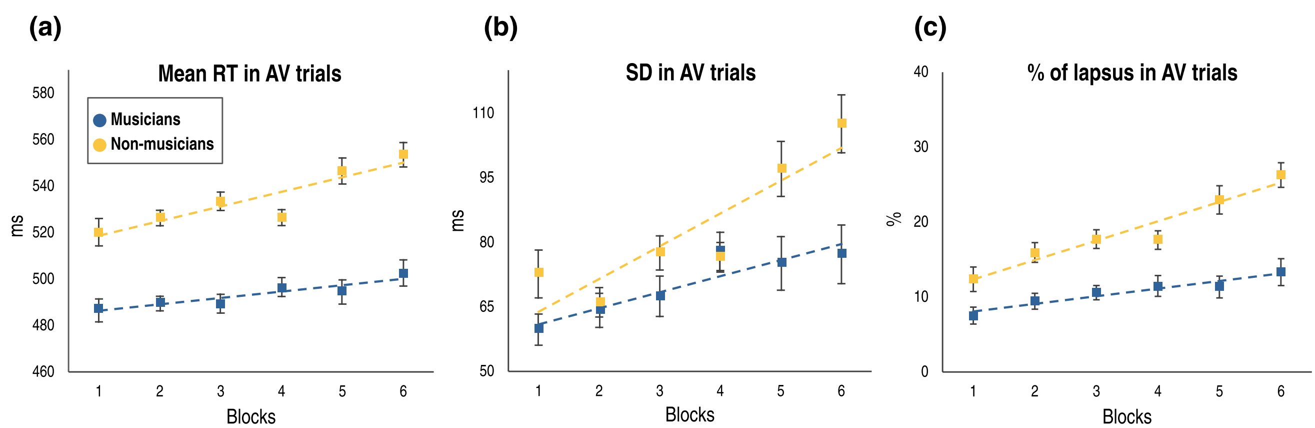

Fig. 5 Arousal vigilance outcomes in both groups, musicians (in blue) and non-musicians (yellow). Musicians showed overall faster responses (**a**), smaller SD in RTs (**b**), and higher proportion of lapsus than non-musicians (**c**). Error bars represent standard errors of the means, with between-participants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

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 fourth block (Appendix B).

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, $t(48) = 1.31$, $p = 0.198$, $d = 0.187$, but did so for non-musicians, $t(48) = 2.17$, $p = 0.035$, $d = 0.310$. On the other hand, we found a trend in post-error slowing, $U = 953$, $p = 0.079$, $r_B = -0.21$, with a higher effect for musicians than for non-musicians.

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 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 $\tau = -0.22$, $p_{\text{uncorrected}} = 0.008$; years of lessons – percentage of lapsus in AV trials, Kendall's $\tau = -0.22$, $p_{\text{uncorrected}} = 0.010$; and years of lessons – Alerting effect, Kendall's $\tau = -0.18$, $p_{\text{uncorrected}} = 0.042$. None of these correlations remained significant after Benjamini–Hochberg correction though. As we mentioned in "Methods",, 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.

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 0.80), and with an 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 that 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 that underpin vigilance. However, this type of explanations, 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 that 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, Lewycky, Kilgour, & Stoesz, 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, Schellenberg, & Misura, 2013), supporting pre-existing advantages. In fact, 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 in any individual who undertakes it, certain backgrounds could increase the probability of selecting it as a lifestyle. Other variables such as personality, socio-demographic 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 confounds, 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, Kaplan, Der Sarkissian, & Habibi, 2017).

Other cognitive results in relation 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, Shih, & Lin, 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 to 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, Loui, Rüber, & Schlaug, 2011; Steele, Bailey, Zatorre, & Penhune, 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 this 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 difference 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, it is possible that 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 have an influence in 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).

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 to 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 prior to carry 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

Conflict of interest The 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, in accordance with 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).

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

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