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Long lasting musical training modifies language processing: a Dichotic Fused Word Test study

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ABSTRACT

Musical training modifies neural areas associated with both music and language and enhances speech perception and discrimination by engaging the right hemisphere regions classically associated with music processing. On these bases we hypothesized that participants with extended musical training could have reduced left-hemisphere dominance for speech. In order to verify this hypothesis, two groups of right-handed individuals, one with long-term musical training and one with no musical training, participated to a Dichotic Fused Word Test consisting in the simultaneous presentation of different pairs of rhyming words and pseudo-words, one to the left ear and one to the right one. Participants typically show a greater number of reports of the right ear input than of the left one. This effect, called right ear advantage (REA), reflects left-hemisphere dominance for speech processing. In our study, we expected that musicians had a reduced dichotic listening REA for linguistic stimuli. The main result of this study was the attenuation, and in some cases the complete suppression, of the dichotic effect in musicians, since most of them perceived both words, simultaneously. This finding suggests that both hemispheres may have similar verbal competence and contribute to speech processing in parallel. This contrasts with the normal brain organization in which hemispheres cooperate but are engaged in different analysis of speech. The "two words" perception also extended to pseudo-words. Thus, musical training, by shaping the language circuits, could produce the enhancement of bilateral processing of stimuli with linguistic characteristics (i.e. phonetics) independently of semantics.

Key words

Musicians • Speech processing • Hemisphere lateralization • Dichotic listening

Introduction

Mastering musical abilities requires a complex coordination of multiple sensory-motor circuits (Elbert et al., 1995; Lotze et al., 2003), and, in fact, skilled musicians typically show high degrees of motor coordination and temporal accuracy.

Beyond shaping the brain network specifically involved in musical capabilities, long-term musical training has been demonstrated to influence various cognitive functions (i.e. visuospatial abilities, general IQ) (Brochard, Dufour, & Despres, 2004; Schellenberg, 2013). Interestingly, spatial attention is represented more bilaterally in musicians than in non-musicians, likely due to the bimanual coordination required to play most of the instruments (Patston et al., 2007). This effect is particularly marked when musical training started at early age, thereby suggesting a significant modulation exerted by musical practice on brain plasticity during development (Amunts et al., 1997; Bengtsson et al., 2005; Elbert et al., 1995; Schlaug et al., 1995).

Actually, efficient transfer of sensory and motor information between hemispheres can be considered

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as one of the cerebral processes necessary for high quality musical performance. Neuroimaging studies, indeed, demonstrated that musicians have more bilateral connections, namely the anterior region of their corpus callosum is larger than in non-musicians (Schlaug et al., 1995), and research on interhemispheric communication, studied by calculating the interhemispheric transmission times, showed that musicians have a remarkably reduced hemispheres asymmetry for auditory stimuli (Woelfle & Grahn, 2013).

Research concerning the neural mechanisms involved in music and language processing demonstrated the overlap of neural networks involved in the processing of acoustic features of music and speech (Rogalsky et al., 2011). Also, musical training modifies neural areas associated with both music and language (Bever & Chiarello, 2009; Zatorre et al., 2002), and enhances speech perception and discrimination (Besson et al., 2007; Schon et al., 2004; Shain, 2011) by engaging the right hemisphere regions classically associated with music processing (Jantzen et al, 2014).

Based on these assumptions we hypothesized that participants with extended musical training have reduced left-hemisphere dominance for speech.

In order to verify this hypothesis, two groups of individuals with, respectively, long-term musical training and no musical training at all, participated to a Dichotic listening test. Dichotic listening is a useful non-invasive technique (Kimura, 1967) to study functional cerebral lateralization. It consists of the simultaneous presentation of two different acoustic stimuli, one to the left and one to the right ear. Using verbal stimuli participants typically show a greater number of reports of the right ear input than of the left one. This effect, called right ear advantage (REA), reflects left-hemisphere dominance for speech processing, and according to the two most influential models of dichotic listening (Kimura, 1967; Kinsbourne, 1970a,b; Sparks & Geschwind, 1968) is related to the integrity of the corpus callosum (Bamiou et al., 2007; Bryden & Bulman-Fleming, 1994; Hugdahl, 2003a). In particular, a negative correlation exists between the magnitude of corpus callosum and REA that is a larger corpus callosum, by either increasing the transfer of the left ear input or improving the equilibration between the hemispheres (Liederman, 2003), is associated to a reduced left-hemisphere dominance.

In our experiment, we used the Dichotic Fused Word Test consisting in the simultaneous presentation of different pairs of rhyming words (Ws) and pseudo-words (PWs), one to the left ear and one to the right one. We expected that, since musicians have a larger corpus callosum and more bilateral connections than non-musicians, and musical training activates the right hemisphere components of language network, participants with extended musical training had a reduced dichotic listening REA for linguistic stimuli (words), but not for PWs.

Methods

Participants

Twenty undergraduate native Italian students (age range: 18-25) participated for course completion credit in a Psychophysiology laboratory at the Pisa University. All participants were right handed as established by the Edinburgh Handedness Inventory (Oldfield, 1971) and reported normal hearing and no history of speech or language disorders. Ten were musicians (N= 10, 5 F), and 10 were non-musicians (N= 10, 6 F).

Nine out of 10 musicians had received at least 5 years of musical training and could read music. The remaining one had played music for more than 5 years but played at ear. Of the 10 musicians, 2 played more than one instrument. Six played the piano, one the violin, four the guitar, and two the bass.

The non-musicians had no formal music training and could not read music.

All participants provided written informed consent prior to testing.

Procedure

The Dichotic Fused Word Test consists of different pairs of rhyming words (Ws) and pseudo-words (PWs) carefully timed so that, when dichotically presented, they are perceived as a single term. Ws consisted of naturally spoken medium frequency bi-syllabic words, according to the Frequency Dictionary of written and spoken Italian language (De Mauro et al., 1993) differing only in the first consonant. PWs were very similar to the Ws but totally non-sense. They all began with voiceless or voiced stop consonants, and were coupled to form 3 lists of fused Ws-Ws (i.e. *dalia-balia*), PWs-PWs (i.e. *cota-bota*) and Ws-PWs pairs (i.e. *casa-pasa*). Each list consisted of 24 pairs. Though the test was not intended to study the acoustic variables of dichotic listening, the possible relation between stimulus-dominance and phonetic couplings was taken into account in the preparation of paired-stimuli. The dichotic material included all the different combinations of stop consonant beginning the paired stimuli (i.e., /pa/-/ba/; /pa/-/ca/; /pa/-/da/, etc.) such that each phonetic pair is represented at least twice by different words.

All Ws/PWs were recorded, edited and synchronized for intensity and onset in a recording studio and stored in the computer memory. All the Ws/PWs were pronounced by an actor with the instruction to use an emotionally neutral tone and a normal intensity.

By appropriate software three sequence of dichotic stimuli were prepared, each containing 24 Ws-Ws, 24 Ws-PWs, 24 PWs-PWs pairs. Each member of the pairs was presented once to the right ear and once to the left ear (Fig. 1), in two sessions performed on different days.

Participants were not informed that a dichotic test was to be given. They were simply asked to repeat exactly what they perceived, immediately on each trial. In order to verify the hearing capability of each subject and to exclude possible differences between ears, after the dichotic sessions participants were monaurally tested for identification of a sample of 28 Ws and PWs of the dichotic pairs, 14 through the left and 14 through the right ear.

At the end of the test participants were interviewed in order to verify the easiness of the test (could you hear the words clearly?), the number of perceived words (how many words did you hear?) and, in the case of perception of more than one word, whether perception was better on the right or left ear (on which side did you have a better perception?).

Data analysis

In each subject we scored (a) the number of perceived stimuli; b) the number of errors, that includes both mistaken and missed stimuli; c) the rate of stimulus-independent responses (sIR), that is the number of dichotic listenings on which the subject reports each member of the pair through the same ear, either the right or the left (i.e., the response is *gaio* when this word is listened through the *right* ear, and is the paired-word *baio* when the earphone are switched and *baio* is presented to the *right* ear); d) the rate of stimulus-dominated responses (sDR), that is the number of dichotic listenings on which the subject reports the same member of the pair through the left as through the right ear.

Two indices of laterality were measured: (a) the lambda coefficient, that is the natural logarithm of the ratio between the right and the left ear responses (Bryden & Sprott, 1981). Following Zatorre (1989), the lambda was computed on the sIR. Positive lambda indicates the right ear prevalence and negative lambda the left ear prevalence; lambda is 0 when the same number of words is identified through the left as through the right ear; (b) the right ear advantage, that is the percent difference in favour the right ear (REA); it is conventionally computed on the total number of responses of each ear.

For statistical analyses the percent scores were arcsin transformed.

Errors, SIRs, SDRs and REA calculated for word-word, word/pseudo-word, pseudo-word/pseudo-word pairs were compared in musicians and non-musicians, by means of separate one-way ANOVAs. Since no significant differences were found between the 3 pairs, in the subsequent analysis data were pooled together. Also, we evaluated possible gender effects by comparing, within each group, errors, SIRs, SDRs and REA scores of males and females, by means of separate one-way ANOVAs. No differences between males and females were found, thus in the subsequent analysis the gender effect was not evaluated.

Results

All the participants reported they could hear the Ws/PWs easily but had problems in understanding the first letter. Seven out of 10 musicians heard 2 or 3 Ws/PWs without a specific side prevalence and during the test reported either the W/PW they have heard more clearly or the perceived stimuli in sequence, according to the order of perception. Nine out of ten non-musicians reported to have heard only one word. The remaining one reported to have heard two words only occasionally. In the case of multiple perception, we measured the various laterality indexes based on the W/PW of the pairs they better perceived, or, in case of similar perception quality, on the first one reported.

Errors, Stimulus Independent Responses (SIRs), Stimulus Dependent Responses (SDRs) and REA, calculated for W/W, W/PW, PW/PW pairs, were compared in musicians and non-musicians, separately, by means of one-way ANOVA. Since no significant differences were found between the 3 pairs, data were pooled together.

Table 1 shows the mean ± standard deviation (SD) of errors and lateralization indices of Non Musicians and Musicians.

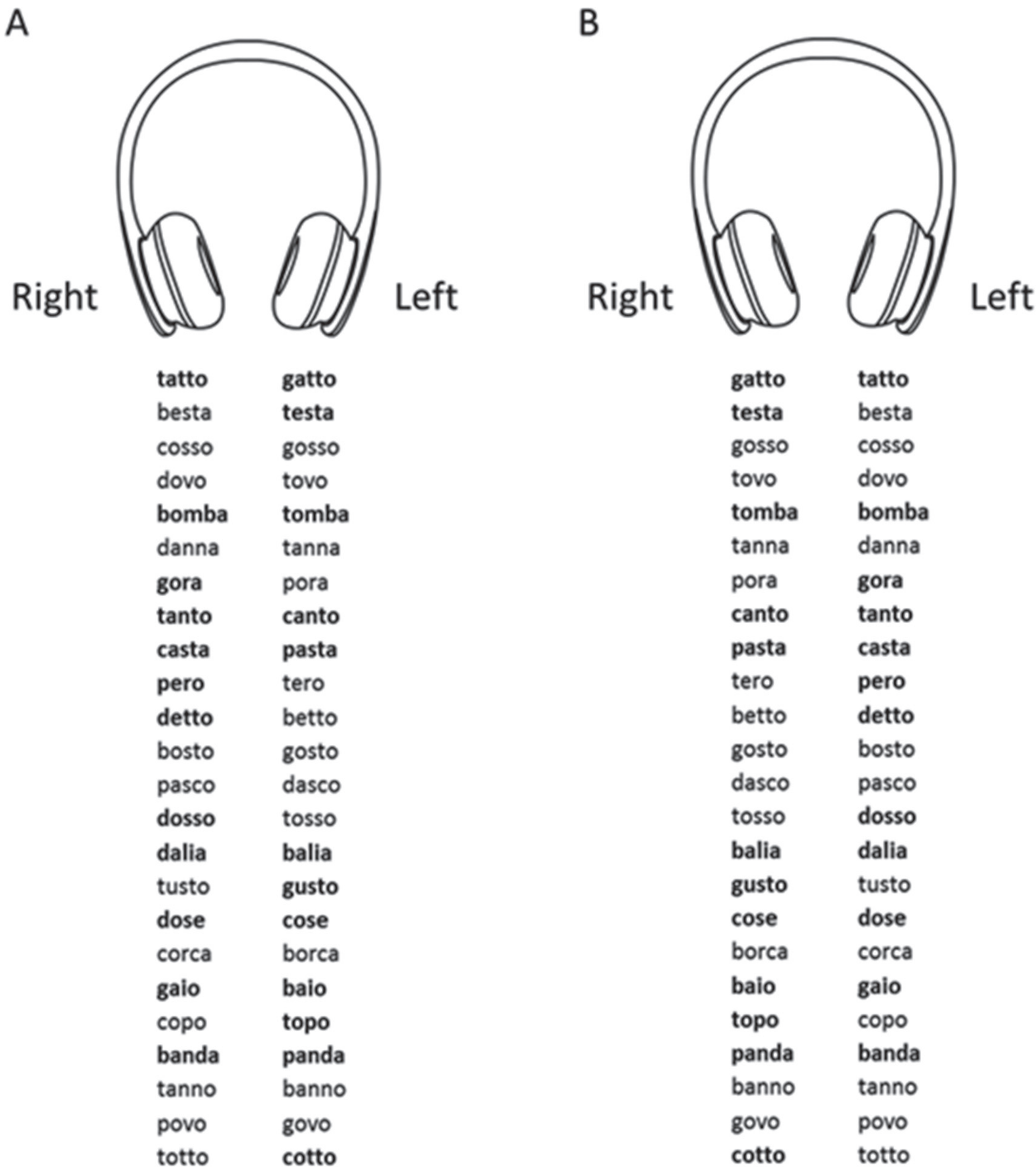

Fig. 1. - Dichotic Fused Word Test. The figure shows one of the 3 lists of dichotic pairs presented to each participant. Each member of the pair was presented once to the right/left ear (A) and once to the left/right ear (B). Each list contains 8 Ws-Ws, 8 Ws-PWs, 8 PWs-PWs pairs. Words are indicated in bold.

The mean percentage of errors was 6% in non-musicians and 11% in musicians.

In all subjects, the majority of the errors consisted of blend errors resulting from early acoustic blending (Repp, 1977; Studdert-Kennedy & Shankweiler, 1970): if the dichotic pair starts with the syllables /pa/ and /da/ the error was more likely to be a word starting with /ba/ or /ta/ than with other alternatives.

Table I. - Errors and Lateralization Indices				
	Non Musicians		Musicians	
	mean	SD	mean	SD
Errors	0,06	0,04	0,11	0,14
sIRs dx	0,28*	0,15	0,16	0,05
sIRs sn	0,02	0,02	0,023	0,01
sDRs	0,65	0,14	0,67	0,21
REA	0,26*	0,16	0,14	0,05
Lambda	3,13	1,46	2,23	0,72
Significant difference between groups are indicated (*p<.005)				

The mean percentage of SIRs through the right and the left ear for non-musicians were, respectively, 28% and 2%, while for musician 16% and 2%. Analysis performed on arcsin sqrt transformed data yielded a significant difference between non-musicians and musicians for SIRs through the right ear ($F(1,19)= 5.3$, $p=0.034$). The lambda coefficient computed on the SIRs yielded positive values for both groups thus indicating a right ear prevalence in both musicians (lambda 2.2) and non-musicians (lambda 3.1). Even though the mean lambda value of non-musicians was higher than that of musicians the difference was not significant.

Analysis of REA showed a quasi-significant ($F(1,19)= 3.8$, $p=0.06$) larger REA in non-musician (26 %) than in musicians (14 %). Also, despite both groups showed a positive association between lambda and REA (non-musician, $r=0,77$, musician $r=0.61$), the correlation was highly significant for non-musician ($p=0.009$) and quasi-significant for musicians ($p=0.06$) (Fig.2).

Non-musician and musician presented SDRs respectively on 65 % and 67 % of dichotic trials. Although there wasn't any significant difference between groups, in non-musician the number of SDRs decreases linearly with increasing lambda ($r= -0.66$, $p=0.038$). In contrast, in musicians SDRs tended to increase in parallel with lambda even if no significant correlation was found ($r=0.45$, $p=0.187$) (Fig.3).

Discussion

The main result of this study was the attenuation, and in some cases the complete suppression, of the dichotic effect in musicians since the two words simultaneously presented one to the left and one to the right ear were both perceived. The slight difference in the time of perception or in the intensity between the two words could be interpreted in terms of a residual ear advantage. However, the analysis of the lateralization indices (lambda and REA), performed in musicians on the better/earlier perceived words, showed a reduced lateralization, thus suggesting a general decrease of hemispheric dominance for linguistic stimuli in this group.

According to Kimura (1961), linguistic stimuli presented to the ear contralateral to the language hemisphere are favored because of their direct access to the language processing areas, while the ipsilateral stimuli are conveyed by interhemispheric connections.

The fact that musicians could easily perceive both words is quite surprising. In fact, it suggests that both hemispheres may have similar verbal competence and thus contribute to speech processing in parallel. This contrast with the normal brain organization in which hemispheres cooperate but are engaged in different analysis of speech (i.e. right hemisphere: prosody) (Berman, et al., 2003; Dobel et al., 2001).

In the general population, the difference between the ears is quite variable among subjects (Morton, 2001; Speaks & Niccum, 1977). For instance, the bilateral control of language (Zatorre, 1989) is more frequent in left-handed people then in right handed ones (Milner et al., 1966), and the size of corpus callosum has been positively associated to the reduction of language lateralization (Hellige et al., 1998). Indeed, a larger corpus callosum has been reported in left- than in the right-handed individuals (Habib et al., 1991; Witelson, 1985). Our results cannot be ascribed to difference in handedness since our participants were all right-handed. However, similarly to left-

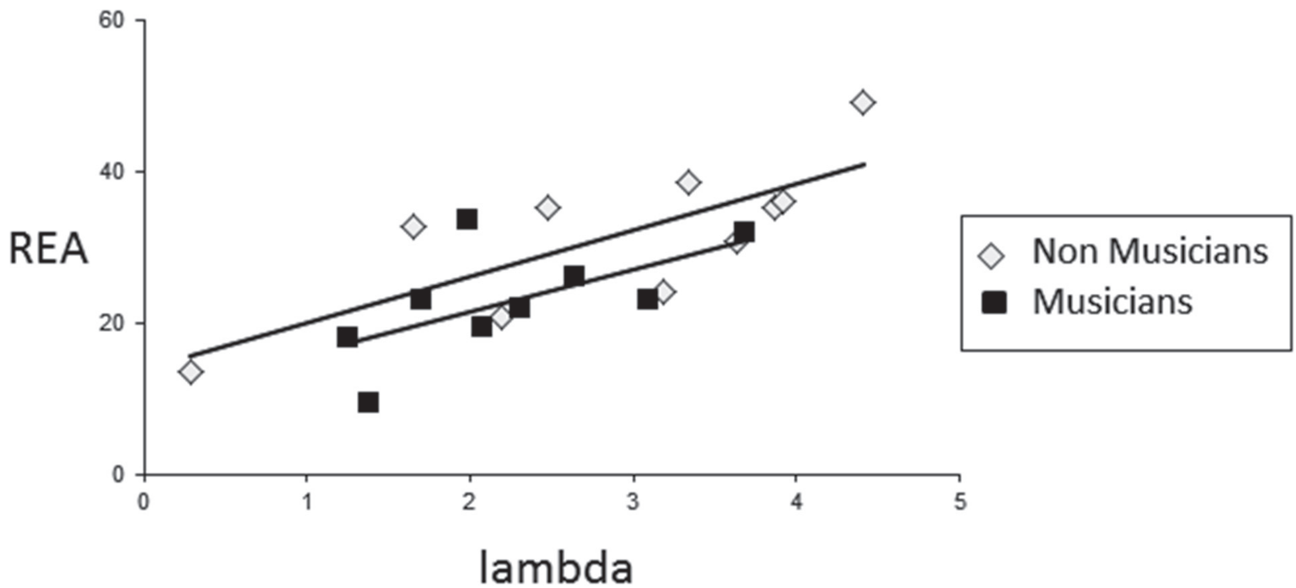

Fig. 2. - Lambda-REA correlation. The figure shows the positive correlation between lambda and Right Ear Advantage (REA) in Non-Musician (light grey diamonds) and Musician (black rectangle). For each series of values trends lines are shown (black lines).

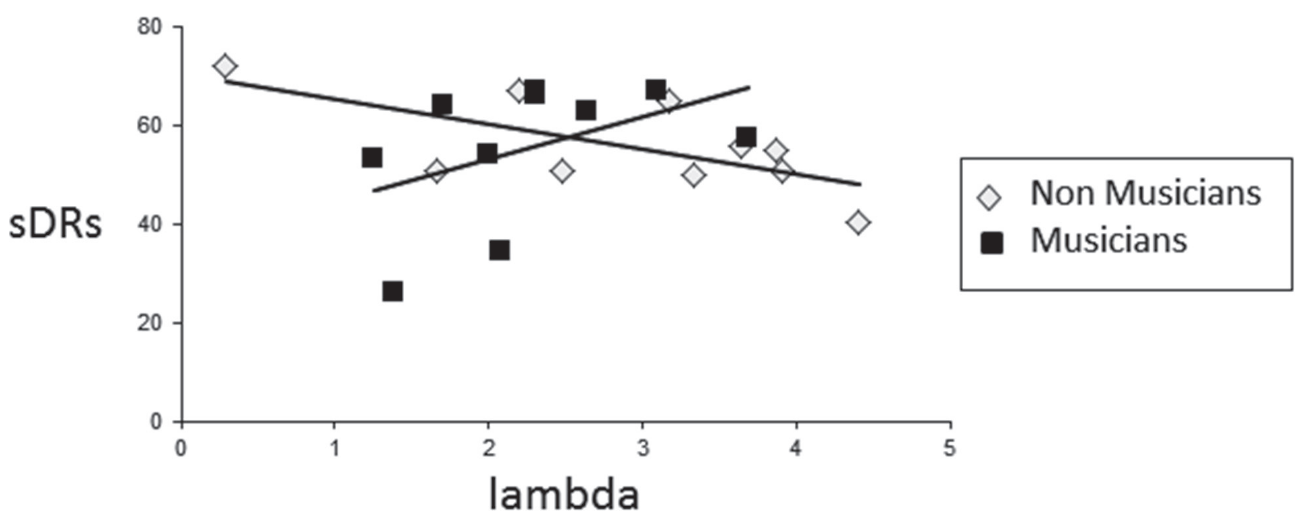

Fig. 3. - Lambda-SDRs correlation. The figure shows the correlation between lambda and Stimulus-Dependent Responses (SDRs) in Non-Musician (light grey diamonds) and Musician (black rectangle). For each series of values trends lines are shown (black lines).

handed individuals, trained musicians have a larger corpus callosum than non-musicians (Schlaug et al., 1995) that could allow a better interhemispheric communication (Woelfle & Grahn, 2013) and the bilateral control of language.

Another important result concerns the stimulus-dominance effect: namely in about 60% of the cases, the same member of the word pair was reported through the left as through the right ear. The stimulus-dominance effect is more prevalent among humans with intact hemispheres and with a low degree of hemispheric lateralization (Di Stefano et al., 2004), and indicates a possible contribution of phonetic and/or semantic features of the words in determining an interhemispheric interference. Even though no differences were found in the percentage of stimulus-dominance effects between the two groups, in non-musicians, as expected on the bases of previous findings (Di Stefano et al., 2004), the number of SDRs decreased linearly with increasing lambda. In contrast, in musicians there was a positive correlation between lambda and SDRs, thus contrasting with the previous finding of a greater stimulus-dominance effect in individuals with less hemispheric lateralization.

The "two words" perception effect was not limited to words, that is the real linguistic stimuli, but extended to pronounceable, though unfamiliar letter strings (pseudo-words). Previous studies showed a segregation of the brain areas involved in pseudo-words (inferior and anterior part of the left supramarginal gyrus) and words processing (left superior temporal gyrus) (Roux et al., 2012). However, on the bases of data from patients with brain damage, some authors challenged the hypothesis of a complete segregation pointing out that pseudo-words and real-words activate the same neural areas, yet with different spatio-temporal dynamics (Xu et al., 2001). Thus, musical training, by shaping the language circuits, could have produced a more general effect, namely, the enhancement of bilateral processing of stimuli with linguistic characteristics (i.e. phonology) independently of semantics.

In a previous dichotic listening study, musicians and not musicians showed a left ear advantage for nonverbal stimuli, while male musicians exhibited a right ear advantage for consonant-vowel syllables, in comparison to non-musicians. Thus a specific sex-dependent effect of musical experience on lateralization of phonological auditory processing was suggested (Spajdel et al., 2007). Our data contrast with these findings since we did not find any gender effect.

One limitation of the study related to the use of pesudowords, with no semantics, but with meaningful phonetic content, is the impossibility of unraveling whether the linguistic plasticity in musicians is guided by phonology or is due to a mere acoustic effect. We can assume that the use of "non-words", completely meaningless but with a linguistic acoustic pitch (Specht et al., 2003), could help to clarify this issue and maybe to enhance the differences between musicians and non-musicians.

Another limitation of the study is the fact that, despite the apparent different mean scores of the two groups – that is the mean value of REA in musicians is about 50% lower than the mean REA of non-musicians, and the mean lambda of musicians is one point (in a logarithmic scale) lower than lambda of non-musicians – no clear significant differences between the lateralization indices of the two groups were found. This is likely to be ascribed to the small sample size. Hence, increasing our sample could allow to increase the statistical power and, thus, to detect differences.

In conclusion, this study demonstrated that long lasting musical training promoted the widening of the language network by recruiting the right hemisphere areas, homologous of the left language ones. This broadening would allow the bilateral, parallel processing of words conveyed by the two ears.

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