Psychophysiology, 41 (2004), 341–349. Blackwell Publishing Inc. Printed in the USA.

DOI: 10.1111/1469-8986.00172.x

The music of speech: Music training facilitates pitch processing in both music and language

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Abstract

The main aim of the present experiment was to determine whether extensive musical training facilitates pitch contour processing not only in music but also in language. We used a parametric manipulation of final notes' or words' fundamental frequency (F0), and we recorded behavioral and electrophysiological data to examine the precise time course of pitch processing. We compared professional musicians and nonmusicians. Results revealed that within both domains, musicians detected weak F0 manipulations better than nonmusicians. Moreover, F0 manipulations within both music and language elicited similar variations in brain electrical potentials, with overall shorter onset latency for musicians than for nonmusicians. Finally, the scalp distribution of an early negativity in the linguistic task varied with musical expertise, being largest over temporal sites bilaterally for musicians and largest centrally and over left temporal sites for nonmusicians. These results are taken as evidence that extensive musical training influences the perception of pitch contour in spoken language.

Descriptors: Electroencephalogram, Event-related potentials, Prosody, Music, Pitch contour, Plasticity

The idea that exposure to music and intensive musical practice benefit in nonmusical domains is as old as the myth of Orpheus that illustrates the magical power of music. More recently, this idea has been submitted to experimental investigation. Results of several behavioral studies have indeed shown improvement of spatial and/or mathematical abilities due to music training in children. However, these findings are not always conclusive, mainly because of methodological problems (for a review, see Schellenberg, 2001). For example, although it has been found that 6-year-old children who were taught music for 7 months by means of the Kodály method showed improvements in mathematical and reading abilities compared to control children (Gardiner, Fox, Knowles, & Jeffrey, 1996), this method also includes some nonmusical training aspects that confound the interpretation of the results. To study the influence of music training on linguistic abilities in adults, Chan, Ho, and Cheung (1998) compared musicians that started playing music at an early age with nonmusicians without musical training. They found that musicians were better than nonmusicians at verbal-memory tasks. However, these findings were again somewhat difficult to interpret because the group with music training had a higher level of education, thus confounding the interpretation of the verbal advantage (Schellenberg, 2001). Finally, although some authors have also emphasized short-term effects of musical exposure on spatial reasoning (Rauscher, Shaw, & Ky, 1993), others have argued that these effects may be epiphenomenona of mood or arousal (Nantais & Schellenberg, 1999; Thompson, Schellenberg, & Husain, 2001).

The recent development of brain-imaging techniques offers new possibilities to test the hypothesis that intensive musical training influences performance in other cognitive domains. Previous studies using magnetic resonance imaging have shown structural differences in brain organization between musicians and nonmusicians, with larger corpus callosum (Schlaug, Jancke, Huang, & Steinmetz, 1995) and planum temporale in musicians (Schlaug, Jancke, Huang, Staiger, & Steinmetz, 1995), especially if musical practice started at an early age. At the functional level, increased representations for musicians have been described for somatosensory and auditory stimuli in both the motor (Elbert, Pantev, Wienbruch, Rockstroh, & Taub, 1995) and auditory cortex (Pantev et al., 1998). Using the event-related brain potentials (ERPs) method, previous studies have demonstrated that the amplitude of late positive components, elicited by pitch contour violations in music, is longer, and their onset latency shorter, for musicians than for nonmusicians (Besson, Faita, & Requin, 1994). Moreover, electrophysiological differences due to the subjects' expertise have also been found at an earlier level of

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This research was supported by a grant from the International Foundation for Music Research to Mireille Besson (IFRM: RA #194). Daniele Schön was supported by the IFMR to conduct this research (2001–2002). The authors thank Julien Bensa, Sophie Bretignière, Monique Chiambretto, Martien Schrooten, and Thierry Voinier for their methodological assistance, and Kara Federmeier, Michel Sémériva, and Andras Semjen for critical comments on a previous version of the manuscript.

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Figure 1. Examples of stimuli used in the experiment. Top panel: The speech signal is illustrated for a sentence: "*Un loup solitaire se faufile entre les troncs de la grande* ***forêt***" (Literal translation: "A lonely wolf worked his way through the trees of the large forest"). Bottom: The musical notation is illustrated for the song "Happy Birthday."

music processing (Koelsch, Schroger, & Tervaniemi, 1999; Regnault, Bigand, & Besson, 2001; Tervaniemi, 2001). However, although these studies, together with many behavioral experiments (e.g., Kishon-Rabin, Amir, Vexler, & Zaltz, 2001), have clearly demonstrated an effect of musical expertise in auditory and musical tasks, they did not tackle the question of the influence of musical training on other cognitive skills. To directly address this issue, we used both behavioral and ERPs measures in the present experiment to compare musicians and nonmusicians while they performed the same task (detection of pitch contour violations) in music and in another cognitive domain that presents interesting similarities with music: language. Our first aim was therefore to determine whether musical training influences pitch processing in language.

The exploration of the similarities and differences between language and music, two of the most complex, uniquely human abilities, is a research topic that has recently received increased interest in the field of neuroscience (Besson & Schön, 2001; Maess, Koelsch, Gunter, & Friederici, 2001; Patel & Balaban, 2001; Zatorre, Belin, & Penhune, 2002). Interestingly, previous research has highlighted strong similarities between language and music processing. Because both language and music are rule-based systems, with syntax governing sentence structure and harmony favoring the expectancy of specific sequences of notes and chords within a musical piece, experiments have been designed to directly compare the effects of syntactic and harmonic violations. Patel, Gibson, Ratner, Besson, and Holcomb (1998) were able to demonstrate that both types of violations elicit similar positive variations in brain electrical activity (in ERPs), with maximum amplitude 600 ms after violations onset, that they interpreted as reflecting structural integration processes using a common pool of resources. Moreover, they also found that a negative component was elicited 350 ms after the onset of harmonically incongruous chords, with maximum amplitude over right anterior frontal regions. These findings were subsequently replicated (Koelsch, Gunter, Friederici, & Schroger, 2000), and, recently, Maess et al. (2001), using magnetoencephalography, showed that the magnetic equivalent of the electric negativity was generated in Broca's area and its right-hemisphere homologue, areas that are known to be involved in syntactic speech analysis. They, therefore, concluded that Broca's area is less language specific than previously thought.

By contrast, differences between language and music have also been demonstrated. For instance, Besson and Macar (1987) have shown that melodic incongruities (i.e., notes that violate the pitch contour of a musical phrase) elicit a different pattern of brain waves than semantic incongruous words in sentences (Kutas & Hillyard, 1980), thus indicating that semantic analysis requires different computations than melodic or harmonic processing.

It is striking to note that although the studies reviewed above have compared levels of processing in language and music that seem a priori quite different, such as syntax and harmony or semantics and melody, no study has yet used brain imaging methods to compare prosody (i.e., intonation contours of the voice, stress patterns, and rhythm) and melody (i.e., the succession of notes in a musical phrase), two aspects that are objectively more similar, because they both rely on the same acoustic parameters: fundamental frequency (pitch contour), spectral characteristics, amplitude, and duration. Therefore, the second aim of the present experiment was to directly compare pitch perception in language and music by recording the variations in the ERPs associated with different degrees of fundamental frequency (F0) expectancy violations (i.e., unattended increases in pitch contour, see Figure 1). Aside from the differences between musicians and nonmusicians mentioned above, results of ERP experiments have also shown that the stronger the pitch contour violations in music, the larger the amplitude and the shorter the latency of the late positive components (e.g., Besson & Faïta, 1995). By contrast, few ERP studies have directly examined prosodic processing (Steinhauer, Alter, & Friederici, 1999), and no such parametric study as the one presented here has yet been conducted on prosody. If prosodic and melodic pitch perception rely on common neural systems, different degrees of pitch violations should elicit similar effects for both language and music. Moreover, based on the hypothesis that frequency (Liegeois-Chauvel, Peretz, Babai, Laguitton, & Chauvel, 1998; Zatorre et al., 2002) and pitch contour (Johnsrude, Penhune, & Zatorre, 2000) analyses mainly involve the right auditory cortex, we expected these effects to be larger over the right than left temporal regions for both language and music.

Methods

Participants

Eighteen participants (mean age: 31 years), including nine musicians (15 years of musical training on average), were paid to participate in the experiment that lasted for about 2 h. All were right-handed, had normal hearing, and were native speakers of French.

Materials

The stimuli were comprised of 120 French spoken declarative sentences and 120 melodies, with an equal number of sentences/melodies (40) presented in each of three experimental conditions: the final word or note being prosodically or melodically congruous, weakly incongruous, or strongly incongruous (see Figure 1). Sentences were recorded in a soundproof room using a digital audiotape, sampling at 44.1 kHz. The choices of F0 modifications followed a general criterion of equating levels of difficulty. Based upon results of pretests with a preliminary version of this material, the F0 of the last word was increased using the software WinPitch (Martin, 1996) by 35% for the weak incongruity, and by 120% for the strong incongruity. For the percentage of correct responses with the music materials to be similar to the language ones, the F0 of the last note was increased by one fifth of a tone for the weak incongruity, and by a halftone for the strong incongruities (see Figure 1).

Procedure

Participants were seated in a comfortable chair in an electrically shielded room. Each session began with a practice block to familiarize participants with the task and to train them to blink during the interstimuli interval, followed by two blocks of musical material and two blocks of prosodic material. In different blocks of trials, participants were required to listen attentively, through headphones, either to the melodies or to the sentences (presented in a pseudorandom order within each block), and to decide, as quickly and accurately as possible, by pressing one of two response keys, whether the pitch of the last word or note was correct or not. The hand of response and the order of presentation (musical or prosodic materials first) were counterbalanced across participants.

ERP Recordings

EEG was recorded for 2,200 ms starting 150 ms before the onset of the stimulus, from 28 scalp electrodes, mounted on an elastic cap, and located at standard left and right hemisphere positions over frontal, central, parietal, occipital, and temporal areas (International 10/20 system sites: Fz, Cz, Pz, Oz, Fp1, Fp2, F3, F4, C3, C4, P3, P4, O1, O2, F7, F8, T3, T4, T5, T6, Fc5, Fc1, Fc2, Fc6, Cp5, Cp1, Cp2, Cp6). These recording sites plus an electrode placed on the right mastoid were referenced to the left mastoid electrode. The data were then rereferenced off-line to the algebric average of the left and right mastoids. Impedances of the electrodes never exceeded 3 kΩ. To detect blinks and vertical eye movements, the horizontal electrooculogram (EOG) was recorded from electrodes placed 1 cm to the left and right of the external canthi, and the vertical EOG was recorded from an electrode beneath the right eye, referenced to the left mastoid. Trials containing ocular artefacts, movement artefacts, or amplifier saturation were excluded from the averaged ERP waveforms. The

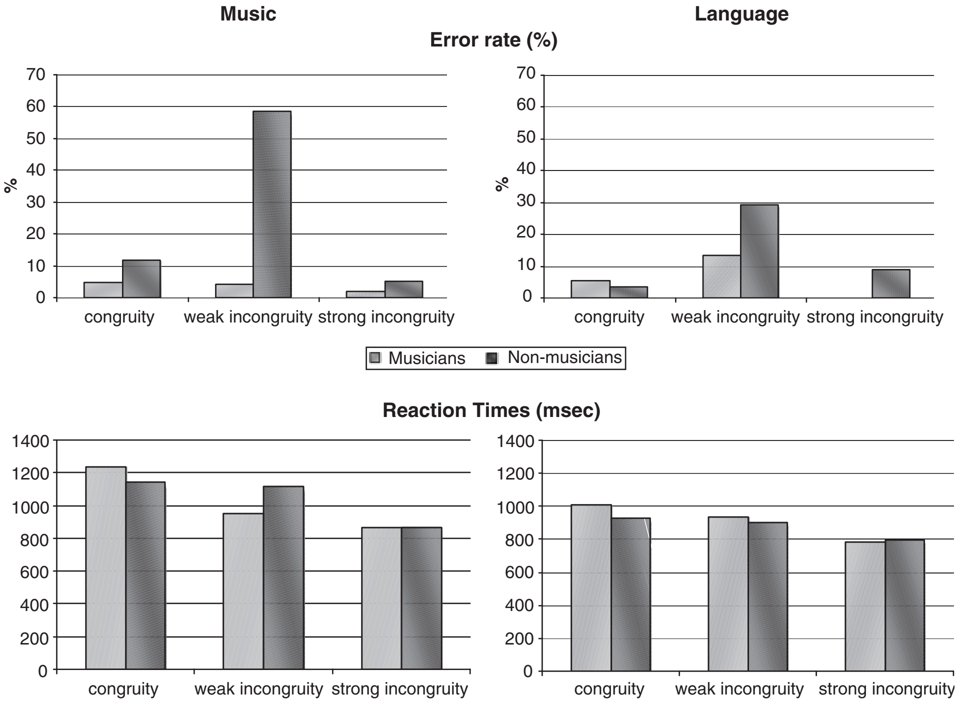

Figure 2. Percentage of error rates (top panel) and reaction times (RTs) in milliseconds (bottom panel) for congruous final notes or words and for weak and strong pitch violations in music and language are presented separately for musicians and for nonmusicians. Clearly, the percentage of errors was highest for nonmusicians in response to weak incongruities in both music and language. Moreover, whereas for musicians, the stronger the incongruity, the shorter the RTs, for nonmusicians, no differences between congruous items and weak incongruities were found in either language or music. Only RTs to strong incongruities were faster than in the other two conditions.

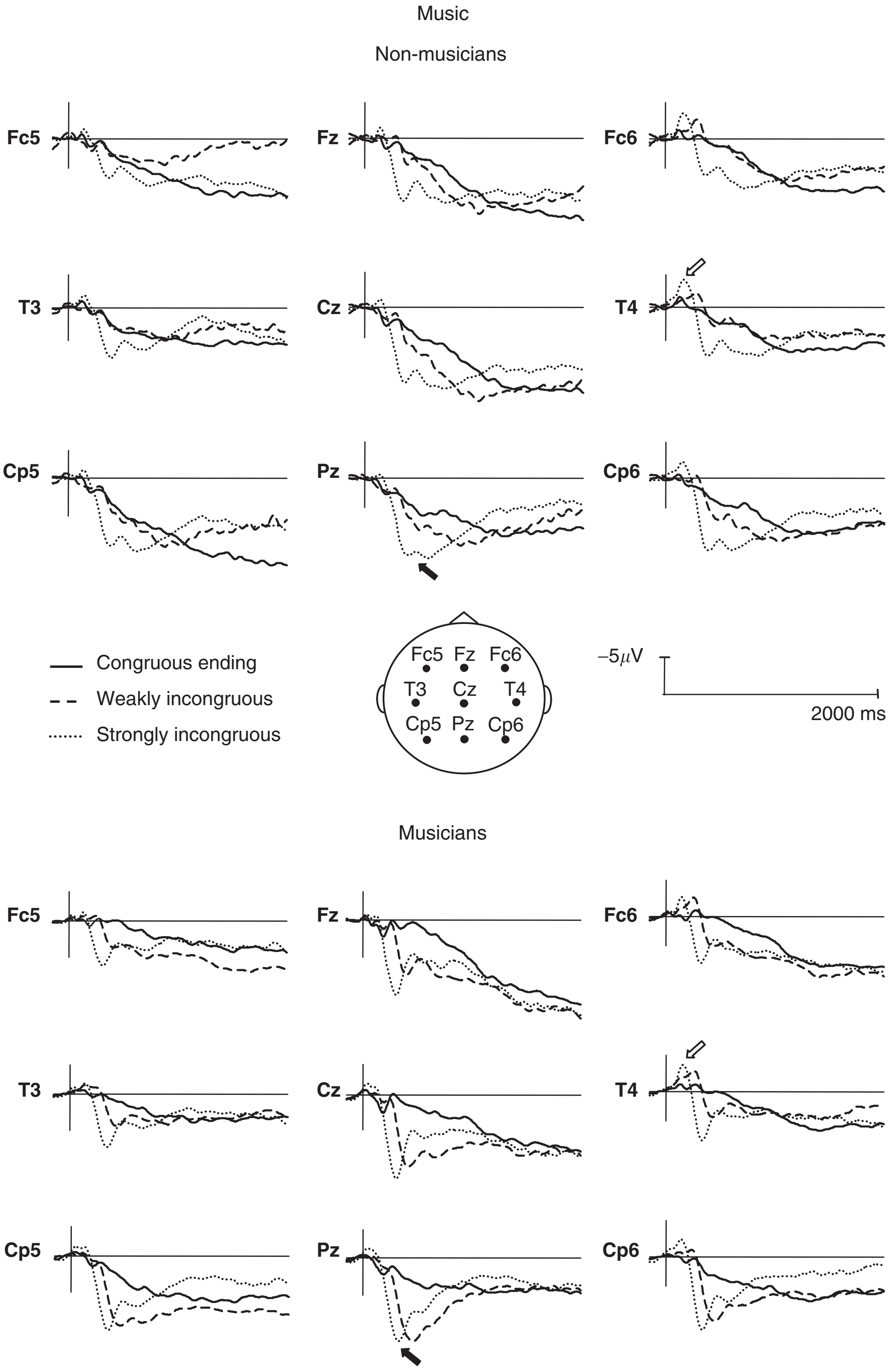

Figure 3. Illustration of the variations in brain electrical activity time-locked to final note onset and elicited by congruous, weak, or strong manipulations of pitch contour. Each trace represents an average of electrophysiological data recorded from 9 musicians and 9 nonmusicians. Although EEG was recorded from 28 electrodes, only the most representative clusters of electrodes (22 electrodes) were analyzed using ANOVAs, and selected traces from 9 electrodes are presented. In this figure, as in the following ones, the amplitude (in microvolts) is plotted on ordinate (negative up) and the time (in milliseconds) is on abscissa. Overall, two main effects emerged from the analyses: an early effect (white arrow) with largest negativity to strong incongruities, and a late effect (black arrow) with larger positive components to strong incongruities than to congruous endings.

electroencephalogram (EEG) and EOG were amplified by a SA Instrumentation amplifier with a bandpass of 0.01 to 30 Hz, and were digitized at 250 Hz by a PC-compatible microcomputer (Compaq Prosignia 486).

Data Analysis

ERP data were analyzed by computing the mean amplitude in selected latency windows both based upon visual inspection of the waveforms and in the most commonly used latency bands, relative to a 150-ms baseline. Analysis of variance (ANOVA) was used for all statistical tests, and all p values reported below were adjusted with the Greenhouse–Geisser epsilon correction for nonsphericity. Reported are the uncorrected degrees of freedom and the probability level after correction. Separate ANOVAs were computed for midline and lateral sites. The factors included were expertise (2), congruity (3), and electrodes (4) for midline analyses, and hemisphere (2), anterior-posterior dimension (3 regions of interest (ROIs): fronto-central, temporal, and parieto-temporal), and electrodes (3 for each ROI) for lateral analyses. Tukey tests were used for all post hoc comparisons. Topographic maps were computed using ICA (Makeig, Westerfield, & Jung, 2002).

Results

Error Rates

Results of a three-way ANOVA (expertise [2], materials [2], and congruity [3]) on the transformed percentages of error showed main effects of expertise, $F(1,16) = 48$, $p < .001$, and congruity, $F(2,32) = 42$, $p < .001$. Clearly, nonmusicians made overall more errors than musicians (Figure 2). Moreover, the weak incongruity was the most difficult to detect. Most importantly, musicians detected the weak incongruity better than nonmusicians, not only in music, but in language as well (congruity by expertise interaction: $F(2,32) = 15$, $p < .001$).

Reaction Times (RTs)

Results of ANOVA including the same factors as above showed no main effect of expertise, $F < 1$, but significantly faster RTs with the linguistic than musical materials, $F(1,16) = 7.5$, $p = .01$, and for incongruous than for congruous trials, $F(2,32) = 66$, $p < .001$ (Figure 2). Interestingly, musicians detected weak incongruities faster than congruous endings in music as well as in language (Expertise × Congruity interaction: $F(2,32) = 6$, $p = .006$). By contrast, no significant differences were found for nonmusicians, either in music or language.

Electrophysiological Data

Music. The ERPs associated to the final note clearly differ as a function of congruity. Between 200 and 850 ms, both weak and strong incongruities elicited larger positivities than congruous endings (main effect of congruity: midline, $F(2,32) = 30.96$, $p < .0001$; lateral, $F(2,32) = 27.49$, $p < .0001$, see Figure 3) that were largest over parieto-temporal sites bilaterally (midline, $F(6,96) = 7.07$, $p = .005$; lateral, $F(4,64) = 11.69$, $p < .001$, Figure 4). Moreover, for musicians, the onset latency of the positivity was 100 ms shorter for the strong incongruity than for the weak incongruity (see Table 1). By contrast, no such relationship was found for nonmusicians, mainly because there were no significant differences between the weak incongruity and the congruous note in any of the latency bands considered for analysis. Only the strong incongruity elicited larger positivity than both the weak incongruity and the congruous note.

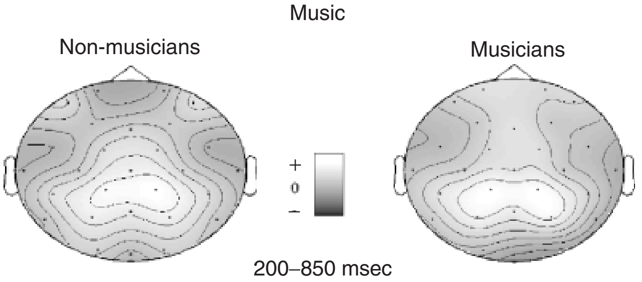

Figure 4. Topographic maps computed as an integration of mean amplitude values across time in the strong incongruity condition, in specific time windows. These maps illustrate the comparison between musicians and nonmusicians for the music materials. The positivity that develops in the later time window (200–850 ms) is temporo-parietally distributed for both musicians and nonmusicians.

Note also that for both musicians and nonmusicians, strong incongruities elicited larger negative components than congruous and weakly incongruous endings in the 50–200-ms range (main effect of congruity: midline, $F(2,32) = 5.99$, $p = .006$; lateral, $F(2,32) = 7.82$, $p = .002$). As can be best seen on Figure 3 at the T4 electrode, this negativity was clearly localized over right temporal sites (lateral, $F(4,64) = 3.13$, $p = .033$).

Language. The main effect of congruity was significant in the 200–850-ms range (midline, $F(2,32) = 27.8$, $p < .001$; lateral, $F(2,32) = 37.25$, $p < .001$, Figure 5), with larger positivities to strong and weak incongruities than to congruous endings over parieto-temporal sites bilaterally (midline, $F(6,96) = 3.45$, $p = .012$; lateral, $F(4,64) = 5.21$, $p = .003$, Figure 6). Moreover, for musicians, the onset latency of the positivity was 50 ms shorter for the strong than for the weak incongruities (see Table 1). Note that nonmusicians also showed larger positivities to strong and weak incongruities than to congruous words. Moreover, the onset latency of this positivity was 100 ms shorter for strong than for weak incongruities (see Table 1).

Table 1. *Time Course of the Congruity Effect*

	Strong incongruity				Weak incongruity			
	Music		Language		Music		Language	
	Musicians	Nonmusicians	Musicians	Nonmusicians	Musicians	Nonmusicians	Musicians	Nonmusicians
200–250 ms	**	—	**	—	—	—	—	—
250–300 ms	**	**	**	*	—	—	*	—
300–350 ms	**	**	**	**	*	—	**	—
350–400 ms	**	**	**	**	**	—	**	*

Differences between conditions were statistically significant at ** = .01 or at * = .05.

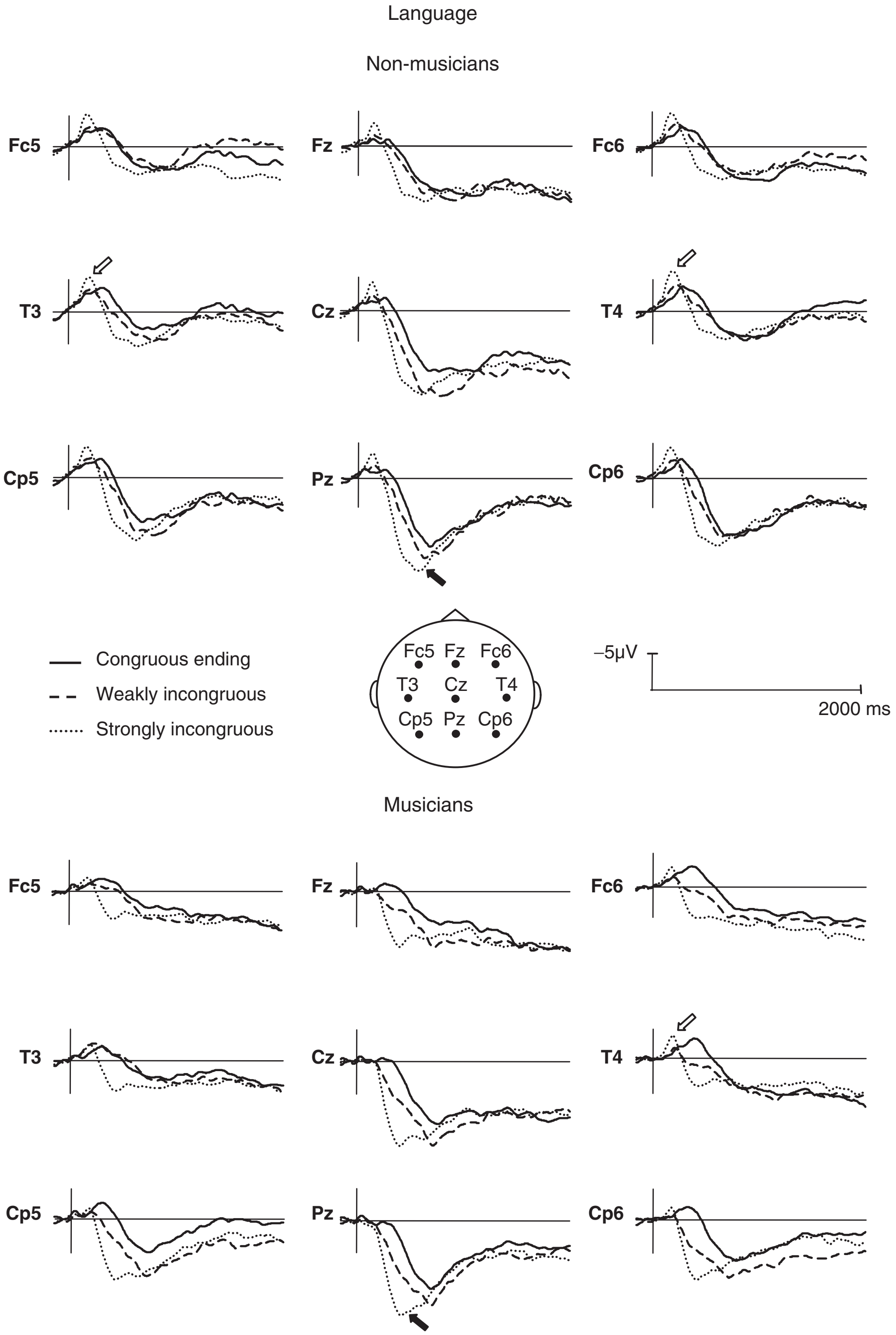

Figure 5. Illustration of the variations in brain electrical activity, time-locked to final word onset, and elicited by congruous, weak, or strong manipulations of pitch contour. Each trace represents an average of electrophysiological data recorded from 9 musicians and 9 nonmusicians. As for the music materials, two main effects emerged from the analyses: an early effect (white arrow) with largest negativity to strong incongruities, and a late effect (black arrow) with larger positive components to strong incongruities than to congruous endings.

Again, for both musicians and nonmusicians the main effect of congruity was significant in the 50–200-ms range (midline, $F(2,32) = 4.01$, $p = .028$; lateral, $F(2,32) = 6.84$, $p = .003$), with the largest negative components to strong incongruities (Figure 5). However, the scalp distribution of this effect differed as a function of expertise (Figure 7): whereas for musicians, the negativity was largest over temporal sites bilaterally (hemisphere, $F(1,8) = 2.3$, $p > .1$, main effect of anterior-posterior dimension, $F(2,16) = 9.6$, $p = .002$), for nonmusicians, it was largest over left temporal sites (main effect of hemisphere, $F(1,8) = 7.26$, $p = .027$; main effect of anterior-posterior dimension, $F(2,16) = 7.92$, $p = .016$).

Comparison between musicians and nonmusicians. Both musicians and nonmusicians showed larger positivities to strong

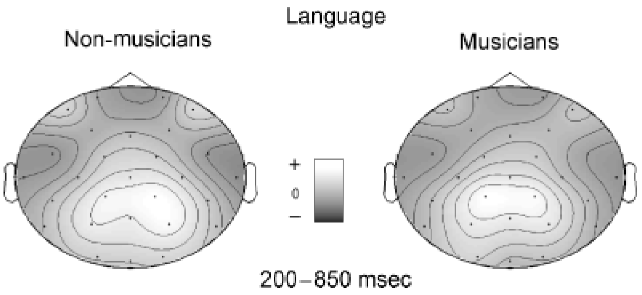

Figure 6. Topographic maps computed as an integration of mean amplitude values across time in the strong incongruity condition, in specific time windows. These maps illustrate the comparison between musicians and nonmusicians for the linguistic materials. As for the music material, the positivity that develops in the later time window (200–850 ms) is temporo-parietally distributed for both musicians and nonmusicians.

incongruities than to congruous endings in both music and language. Most importantly, this positivity has its onset 50 ms earlier for musicians than for nonmusicians, not only in music but in language as well. Weak incongruities also elicited larger positivities than congruous endings in language for both musicians and nonmusicians. Most notably, the onset latency of this positivity was 100 ms shorter for musicians than for nonmusicians (Expertise × Congruity interaction in the 200–350-ms range: always $p < .05$; see Table 1). As noted above, for nonmusicians, no clear differences were found between weak incongruities and congruous notes in music.

Discussion

Musicians and nonmusicians performed the same task, detection of pitch contour violations, in both music and language to determine whether extensive musical training influences behavior and ERPs not only in music but also in language. Moreover, the same parameter, F0, was manipulated in both music and language to determine whether domain-specific or general cognitive principles, relying on specialized or common neural systems, are involved in pitch processing in these two domains. ERP results clearly showed that for both language and music, F0 violations elicited large positive components with similar parieto-temporal scalp distribution. Most importantly, the onset latency of these positivities varied as a function of expertise and congruity. Finally, early negative components, with maximum amplitude around 150 ms, were elicited by strong incongruities in both language and music, although with a different scalp distribution. The functional significance of these findings is considered in the following discussion.

Influence of Intensive Musical Training

First and most importantly, behavioral measures in both language and music revealed that musicians were not only more accurate in detecting pitch violations in music, which was expected on the basis of previous reports (Besson & Faïta, 1995), but they were also more accurate in detecting pitch violations in language (see Figure 2). Moreover, analysis of RTs showed a clear-cut pattern of results for musicians: The stronger the incongruity, the fastest the RTs. For nonmusicians, in contrast, no difference was found between the weak incongruities and the congruous items.

Note also that ERP data are in line with behavioral data. Although both musicians and nonmusicians generated a similar pattern of effects, precise analyses of their time course reveal clear differences between groups. Analysis of the ERP elicited by the language materials showed that for musicians, and as early as 200 ms, the stronger the incongruity, the shorter the onset latency of the positive components. For nonmusicians, such differences developed around 100 ms later. Taken together, both ERP and RT data clearly show that musical expertise influences pitch processing. Thus, musical training, by refining the frequency-processing network, facilitates the detection of pitch changes not only in music, but in language as well. Further studies will be conducted to track the generality of these findings with children who did or did not have an early exposure to music and with language-impaired patients to test the hypothesis that specific musical training may improve some aspects of language rehabilitation.

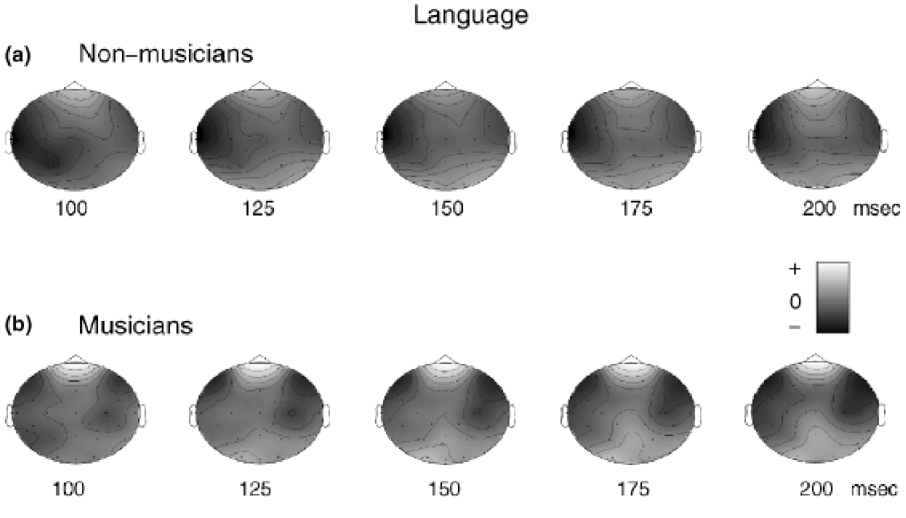

Figure 7. Topographic maps computed as an integration of mean amplitude values at specific points in time in the congruous prosodic condition. These maps illustrate the time course of the negativity for musicians and for nonmusicians. Whereas for musicians the negativity develops bilaterally over the two hemispheres, its distribution is left lateralized for nonmusicians.

Early Effect of Strong F0 Violations in Both Language and Music

For both musicians and nonmusicians, early negativities, largest to strong incongruities, developed around 150 ms in both language and music, although with a different scalp distribution. For music, and independently of expertise, the amplitude was largest over the right temporal cluster of electrodes. Such a scalp distribution is in line with Zatorre's et al. (2002) hypothesis that right auditory cortical areas are specialized in frequency analysis. By contrast, the scalp distribution of the negative components in language varied with musical expertise, being largest over temporal sites bilaterally for musicians and largest centrally and over left temporal sites for nonmusicians.

Although such a left temporal distribution for nonmusicians may fit with the general idea of left lateralization for language processing, based on the hypothesis mentioned above (Zatorre et al., 2002), one may have expected a similar distribution of the early negativity for language and music because participants were paying attention to pitch changes in both cases. It may be that the analysis of the temporal aspects of language, described by Zatorre et al. as mainly involving the left auditory cortex, overrides the frequency analysis required by the task. Most importantly, the finding of differences between musicians and nonmusicians in the scalp distribution of the early negativity is in line with results demonstrating functional and structural experience-dependent plasticity in the auditory system in animals (Kilgard & Merzenich, 1998; Tian, Reser, Durham, Kustov, & Rauschecker, 2001) and in different aspects of music processing in musicians (Bever & Chiarello, 1974; Elbert et al., 1995; Schlaug, Jancke, Huang, & Steinmetz, 1995; Schlaug, Jancke, Huang, Staiger, et al., 1995). Thus, the intriguing possibility that musical expertise influences the anatomo-functional architecture of prosodic processing in language is an issue that needs to be pursued in further experiments.

Similar Processing of F0 in Language and in Music

Using a parametric F0 manipulation, results show that for both language and music, the stronger the incongruity, the larger the amplitude of centro-parietally distributed late positive components. The similarity of the effects found in both cases, together with their similar scalp distribution, suggests that similar cognitive processes are called into play by the processing of pitch violations in both language and music. This interpretation is in line with the results reported by Patel, Peretz, Tramo, and Labreque (1998) from two amusic patients showing similar levels of performance in prosodic and musical discrimination tasks, thus suggesting shared neural resources across domains. However, other cases have been reported of patients with impaired melodic but not prosodic pitch processing abilities (Ayotte, Peretz, & Hyde, 2002; Peretz et al., 2002; Schön, Lorber, Spacal, & Semenza, in press). These contradictory results can be explained by differences in task difficulty because a small change in F0 (i.e., a quarter tone), is readily noticeable by musicians, whereas the rise in intonation to produce a question, for instance, is much larger, around one octave. In the present experiment, however, the material was pretested in an attempt to equate task difficulty. This was useful insofar as error rates showed no significant differences on the main effect between language and music, and the finding that RTs were overall faster for language than for music mainly reflects differences for congruous items.

Although the present results favor the view that similar cognitive computations and neural systems are involved in the integration of pitch processing in both language and music, further experiments using brain imaging methods with better spatial resolution, such as those conducted by Kotz et al. (2003), are needed to precisely localize the brain areas active in prosody and melody pitch contour processing.

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(RECEIVED August 21, 2002; ACCEPTED February 21, 2003)