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Global and local processing of musical sequences: an event-related brain potential study

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MUSICAL processing can be decomposed into the appreciation of global/holistic and local elements. Here, we investigated the pattern of neural activity associated with the processing of contour-violated (CV) and contour-preserved (CP) melodies. The CV and CP musical sequences were obtained by altering the pitch value of one note within the musical phrase, while keeping both the scale and the key constant. In the unadulterated melody, there was a sustained negativity that was larger over the right than left fronto-central regions. Participants were equally accurate in detecting CV and CP trials, but were slower in detecting CP than CV trials. Globally altered melodies (i.e. CV) generated an early, negative waveform (N2) and a P3b deflection, whereas the CP target only generated a P3b wave. This suggests that global precedence may occur at an early perceptual stage and argues in favor of fractionating musical processing into global and local components. *NeuroReport* **10:2467–2472 © 1999 Lippincott Williams & Wilkins.**

Key words: Auditory; Contour; Hemispheric asymmetry; Perception

Introduction

Musical perception depends on the listener's ability to process individual notes as well as to extract overall patterns or their global properties [1]. In part because of its emotional context, and because music appreciation requires integration of auditory stimuli, many believe that music is a capacity specific to the right hemisphere. However, evidence from behavioral [2,3], neuroimaging [4] and lesion studies [5–7] suggests that different elements within a musical sequence may be processed in a parallel, hierarchical manner in different brain regions. For example, rhythm, temporal and sequential components of music have been shown to be left hemisphere dominant [2,8] whereas melody discrimination, based on pitch contour, and appreciation of prosody are thought to be more right hemisphere dominant [8]. Together, these findings indicate that music perception is not solely dependent on the right hemisphere and that, in fact, it can be fractionated into components which may be subserved by different, interactive neural networks.

Peretz *et al*. [3,5,6,8] proposed that processing of musical sequences can be fractionated into at least two distinct components: global and local. In this model, a violation of pitch contour (i.e. the direction of the pitch transition between successive notes) is thought to disrupt the holistic (global) properties of the musical sequence. In contrast, a change in pitch, without violating the contour (e.g. increased pitch transition between successive notes without changing the direction), is defined as a local manipulation. The discrimination of local pitch information has been found to be impaired in patients with both right and left hemisphere damage. In contrast, the discrimination of contour-violated musical sequences has been found to be impaired only in patients with right hemisphere damage.

The present study aimed to investigate the neural events that mediate the processing of global or local elements of melodies in musically naive, neurologically intact individuals using event-related brain potentials (ERPs). Participants were presented with musical sequences that were either contour-violated (CV) or contour-preserved (CP). According to the global/local distinction of musical processing we expected to find a distinct ERP signature for each manipulation.

Materials and Methods

Twelve right-handed participants (age 21–38 years; six men), with normal hearing, volunteered their time or participated for pay. Participants were musically naive, i.e., they had less than 5 years experience playing a musical instrument, were not currently playing a musical instrument, could not read music and had no experience or formal training in music theory. Partici-

pants were also screened for neurological and psychiatric illness. All participants were provided with an information sheet and gave full, informed consent according to the Baycrest Centre for Geriatric Care and University of Toronto guidelines.

Participants were presented with a standard musical phrase and two deviant musical sequences. Each musical phrase was composed of 15 notes and lasted for 3890 ms with an interstimulus interval of 25 ms between the melodies. The deviant musical sequences were altered by modifying the frequency of the sixth note in the melody, which occurred at 1008 ms. In the CV condition, the contour of the musical sequence was altered by decreasing the frequency of the sixth note so that it changed the frequency direction of the surrounding intervals while keeping the original key (see Fig. 1, top). In the CP condition, the same critical note was increased in frequency so that it was out of scale to the same extent in terms of semi-tone distance, but it still remained within the original contour and scale (see Fig. 1, top). In keeping with Peretz [8], these manipulations represent globally altered and locally altered melodies, respectively.

The standard musical sequence was presented in 60% of the trials. Each altered melody, CV or CP sequence, was presented in 20% of the trials. There were 105 trials per block, and six blocks per participant, for a total of 630 trials. All sequences were presented at 70 dB SPL. The first five sequences were a repetition of the standard melody. Thereafter, the sequences were quasi-randomly presented with the restriction that no more than two consecutive altered melodies were presented in a row.

Electrical brain activity was amplified and filtered (bandpass 0.5–50 Hz; 250 Hz sampling rate) via NeuroScan SynAmps from an array of 47 channels that included electrodes on the face and neck. Eye movements were monitored using bilateral electrodes placed at the lower orbital ridge for vertical measurements and at the outer canthi of the eyes for horizontal measurements. All electrodes were referenced to Cz during the recording and converted to an average reference off-line.

Participants were presented with the musical sequences in a sound and light-attenuated room. They were told that the first three melodies were a repetition of the standard. In reality, the first five trials were standard melodies, but participants were required to be vigilant for change after the third trial. Thereafter, they were asked to press the response key as soon as they detected any change in the standard melody. They were asked to keep their gaze on the central crosshair on the computer monitor to minimize eye and muscle artifact. There were short breaks between each block of trials. Behavioral data were collected in a second experiment held on a different day without EEG recording.

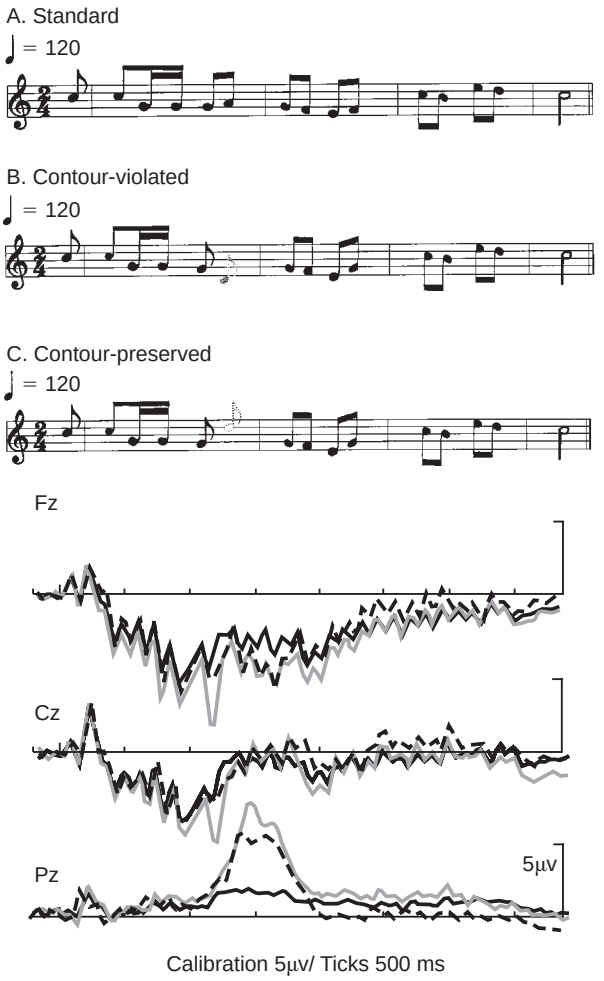

FIG. 1. Top: (**a**) Example of entire unadulterated melody and its (**b**) contour-violated and (**c**) contour-preserved alterations. Bottom: Group mean ERP waveforms elicited by each melody type at frontal (Fz), central (Cz) and posterior (Pz) sites. Solid lines denote the standard condition, grey lines denote the contour-violated condition and dashed lines denote the contour-preserved condition. Tick marks denote 500 ms intervals. Positivity plotted upward.

ERPs were averaged separately for each stimulus-type and electrode site. The epoch analysis included 200 ms pre-stimulus activity and 3900 ms post-stimulus activity. Trials contaminated by excessive peak-to-peak deflection (±120 μV) were excluded from the analysis. In each individual average, ocular artifacts not removed by the artifact-rejection criteria were corrected by source ocular components using brain electrical source analysis software [9]. This involved a sampling reduction from the original 250 data points to 180 points.

Results

Participants were equally accurate in detecting CV and CP trials (79% *vs* 84% accuracy respectively,

$F(1,11) = 2.96$), but were slower in CP than CV trials (498 *vs* 446 ms, $F(1,11) = 4.89$, $p < 0.05$).

Figure 1 illustrates the musical sequences and the corresponding group mean ERPs at the midline electrodes. In all cases, the onset of the musical sequence generated a large positive deflection that peaked at about 200 ms and was maximal at midline electrodes. The ERPs elicited by the unaltered, CP- or CV-altered melodies were similar in amplitude until the presentation of the target note. In addition, all sequences generated a large sustained negativity that was more pronounced over the midline frontal electrode.

Figure 2 shows the brain responses elicited by the standard musical sequence. The onset of the standard melody generated an N1 and P2 wave that was maximal in amplitude over the central and frontal sites and reversed in polarity at inferior and posterior temporal sites (e.g. TP9). The N1–P2 wave was followed by a sustained negativity over the frontal and central regions that reversed in polarity at the mastoid sites. The sustained negativity lasted for almost the entire duration of the musical sequence and was larger over the right than the left central regions during the 500–3000 ms interval (F3 *vs* F4 ($t(11) = 2.606$, $p < 0.05$).

Compared with the standard melody, the CV and CP sequences generated similar ERP amplitudes until the onset of the deviant note ($F(2,22) = 0.860$, ns). Both deviant stimuli generated a negative potential at frontal and central sites that peaked at about 200 ms following deviant onset (N2) and reversed in polarity at the mastoid sites. This is best visualized by computing the difference wave between the ERPs elicited by the standard melody and those elicited by either the CV or CP melodies (Fig. 3). An analysis of variance on the N2 mean amplitude (150–180 ms) with stimulus type (standard, CV and CP) and electrode (Fz, Cz, Pz) as factors yielded a main effect of stimulus type ($F(2,24) = 3.96$, $p < 0.05$, $\varepsilon = 0.980$), a main effect of electrode ($F(2,24) = 25.91$, $p < 0.001$, $\varepsilon = 0.566$) and a significant stimulus type × electrode interaction ($F(4,48) = 12.21$, $p < 0.001$, $\varepsilon = 0.525$). The N2 was larger at Fz and Cz than Pz ($p < 0.01$ in both cases). Pairwise comparisons showed a larger N2 in the CV manipulation

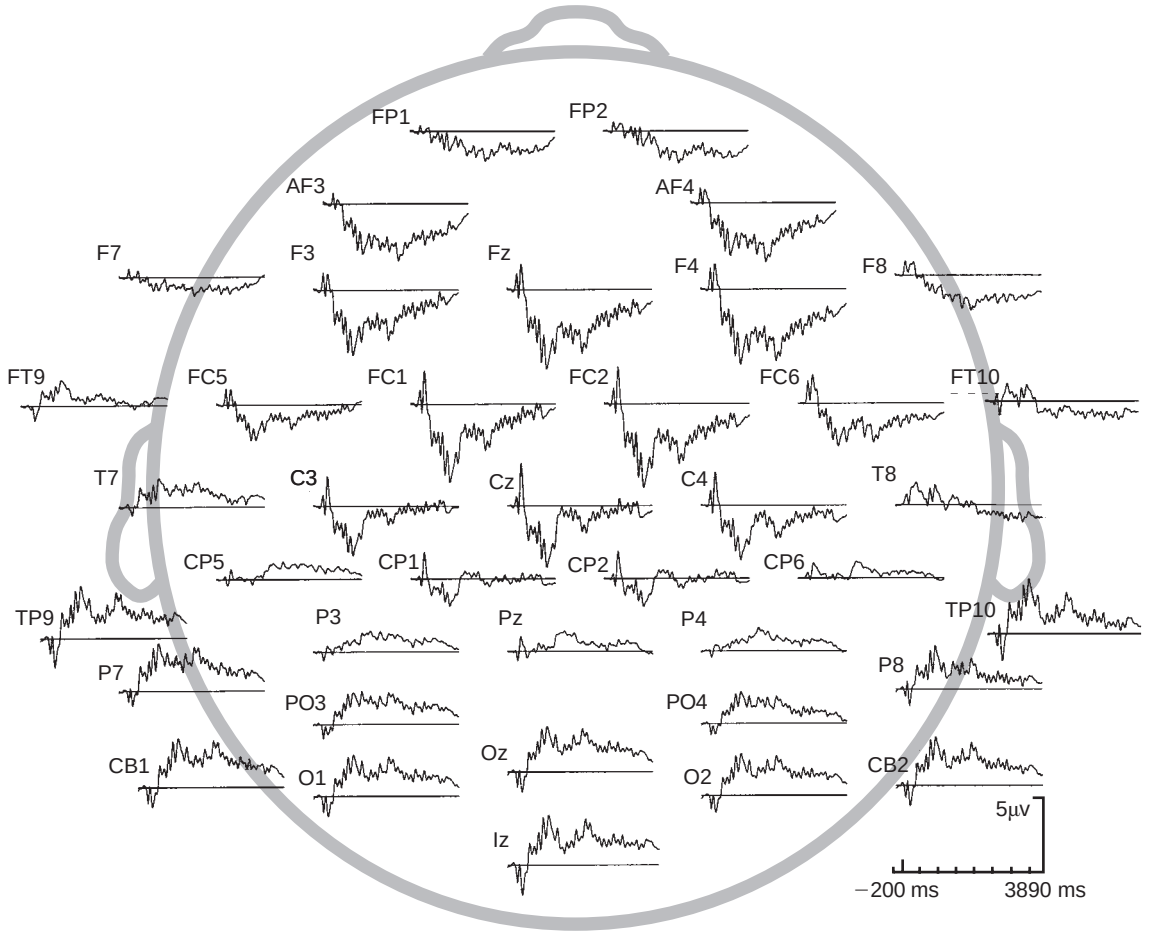

FIG. 2. Group mean ERPs elicited by the standard melody. Tick marks denote 500 ms intervals.

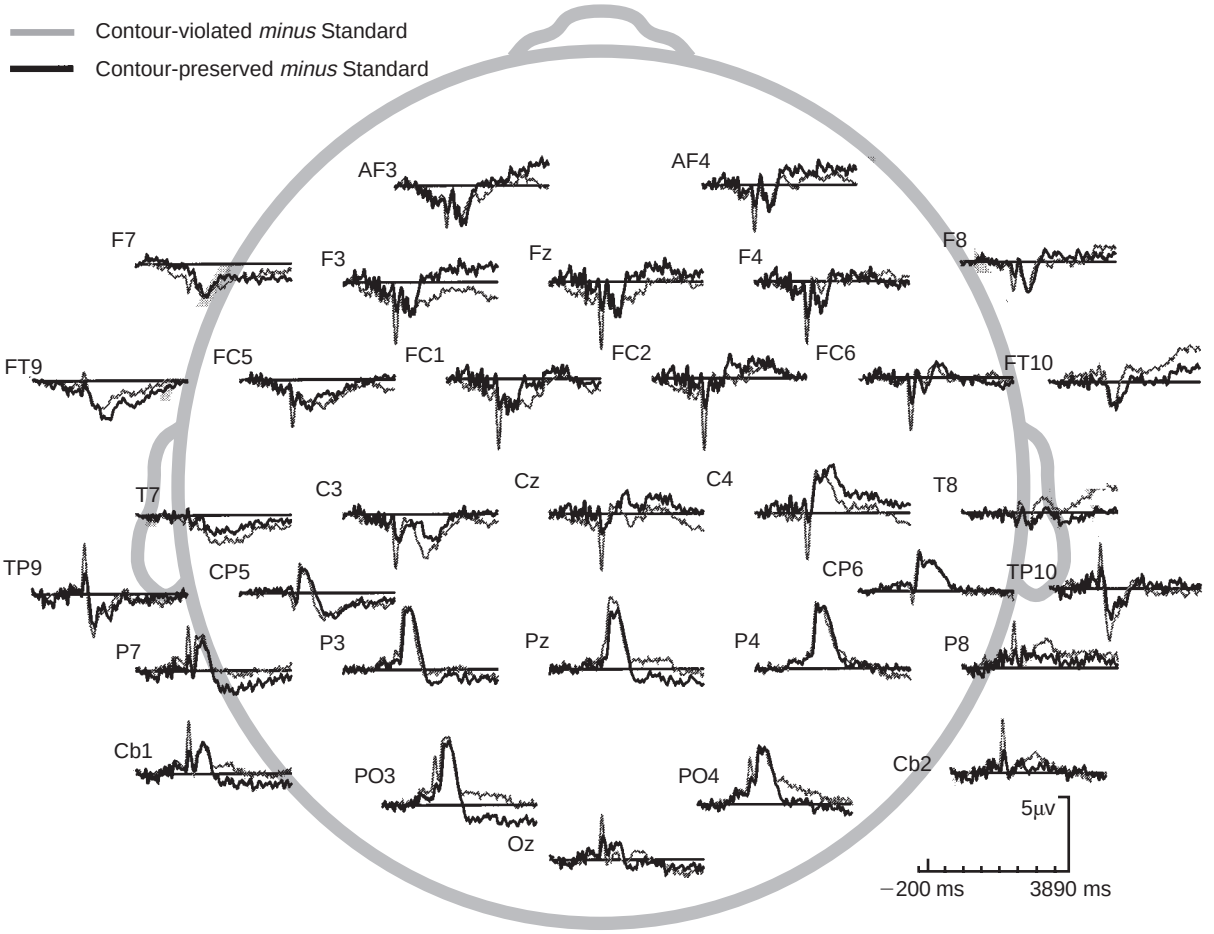

FIG. 3. Difference waves for the contour-violated minus the standard melody (grey lines) and the contour-preserved minus the standard melody (black solid lines). Note that the deviant note occurs 1008 ms after sequence onset. Tick marks denote 500 ms intervals.

than in the CP manipulation ($p < 0.01$) or from the standard melody ($p < 0.001$).

The N2 wave was followed by a parietally distributed P3b response and slow-wave, that was maximal over the central regions, peaking respectively at about 400 ms and 1000 ms following target onset. The P3b peak amplitude and latency were similar for both CV and CP melodies, and were symmetrically distributed over both hemispheres. However, visual inspection of the data showed that the CV manipulation generated a P3b with an earlier, sharper rise in amplitude than the one elicited by CP trials (see Fig. 1; Fig. 3). The difference in P3b onset was quantified by comparing the mean amplitude between 233 ms and 433 ms following target onset. At Pz the analysis yielded a significant difference in amplitude between the P3b elicited by CV and CP melodies ($t(11) = 2.419$, $p < 0.05$), and confirmed that, indeed, the rising phase of the P3b wave was earlier in the CV- than in the CP-altered melodies.

On visual inspection of the difference waveforms (Fig. 3) it appeared that the CV manipulation resulted in a greater negative shift at central sites than did the CP manipulation. This shift in negativity lasted throughout the remaining time interval. The difference in amplitude was quantified over the 900–1100 ms interval following target onset. An ANOVA with deviant type and electrode (C3 *vs* C4) as factors yielded a main effect of deviant type ($F(1,11) = 5.91$, $p < 0.05$). The negative shift was greater for the CP than the CV conditions. The interaction between hemisphere and condition was not significant.

Discussion

There has been much discussion about the role of the right hemisphere in musical processing. Our findings lend some support to this hypothesis. Indeed, there was a sustained negativity that was larger over the right than left frontal sites that lasted throughout the duration of the unadulterated musical sequence. This finding appears to be consistent with those reported in the neurometabolic literature [4] and lesion studies [10,11], suggesting a right-

hemisphere dominance for musical processing. The lateralization of the slow, negative wave obtained during the processing of the unaltered melodies is also consistent with the findings of Patel *et al.* [12], who compared music and language incongruencies and their effect on ERPs. They found a music-specific component that was lateralized to the right hemisphere, most prominent in the antero-temporal region. EEG results from studies of passive listening of musical stimuli [13,14] and comparing passive to psychoacoustic discrimination (active listening) [15] have also suggested a predominant contribution of the right hemisphere. Auzou *et al.* [15] proposed that processing of pitch information relies on a network composed of the right Heschl gyrus, which is necessary to extract fundamental frequency in a sound in which fundamental frequency is absent, and the right frontal lobe, which is necessary for tonal memory or auditory working memory [4,16].

The globally altered melodies generated a large negative potential over the fronto-central regions, peaking at about 200 ms following deviant onset. This component appeared to be specific to detecting global changes in the musical sequence, since it did not appear in the locally altered melodies. In the oddball paradigm, the N2 deflection has been associated with mismatch processing and stimulus categorization [17]. In the current study, the N2 may index a mismatch process between the incoming deviant sounds and the corresponding standard note. The fact that the N2 was larger for the CV than CP manipulations, despite the fact that the deviant note differed from the expected one by the same amount of semitone distance, suggests that the mismatch process did not occur between the incoming deviant and a memory trace of the corresponding standard note. Instead, it implies that the mismatch process involved a comparison between the incoming sounds and a representation that included the frequency transitions between the successive notes, rather than the actual representation of the note [18,19].

Globally altered melodies were also associated with earlier P3b onset and faster RT than locally altered melodies. This may reflect some difference in the discriminability between global and local changes in the musical phrase. This is consistent with the phenomenological experience reported by participants that the CV manipulation seemed easier to detect than the CP targets. These findings also concur with those observed in the visual modality. For example, Han and Chen [20] found that discrimination of local stimuli elicited longer reaction times, lower accuracy, a decreased N1 component, and a longer latency of the N2 and P3 components. Together with our findings on the N2, this suggests that global precedence may occur at an early perceptual stage.

As has been demonstrated in previous visual hierarchical tasks, we observed faster reaction times in the global than local condition, although there were no significant accuracy differences. Previous studies [21] have shown that when non-musicians were instructed to respond as fast as possible in a melody discrimination task, contrary to participants who had not received such instruction, they exhibited a right-ear advantage in accuracy for 'different' responses. Thus, time pressure was instrumental in inducing participants to rely mainly on left hemisphere processing using a self-terminating search process. Peretz *et al*. [21] suggested that the features sought for were local. In the current study, the instructions were also to respond as quickly as possible. However, participants were faster in detecting globally altered than locally altered melodies, as has been repeatedly shown in the visual hierarchical literature [22]. Although our paradigm required detection rather than a same–different judgment, which did not necessitate a search strategy, there is no reason to postulate a different attentional set to account for our data, as has been previously shown in vision [23,24].

Conclusion

Processing musical sequences was associated with right hemisphere dominance in brain activity. Moreover, the processing of globally and locally altered melodies generated distinct patterns of neural activity. The N2 wave may index a neural mismatch and reflect the automatic detection of musical incongruity. The topography and time course of the N2 is suggestive of a source in auditory cortices along the supratemporal plane. Evidence from lesion studies has shown that the superior temporal gyrus plays a critical role in melody processing [25]. Our results are also compatible with apparently incongruous PET data, where pitch has been shown to elicit right temporal [4] and left temporal [26] activations. Together, these findings underscore the relevance of fragmenting the processing of musical phrases, and suggest that complimentary neural networks mediate the processing of global and local elements within a musical sequence.

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