

A Comparison of Contour and Interval Processing in Musicians and Nonmusicians Using Event-related Potentials

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Musicians and nonmusicians detected infrequent changes to the last note of five-note melodies that either altered the contour (up/down pattern) or the intervals (pitch distance between notes). Robust frontal P3as, reflecting automatic capture of attention, as well as P3bs, reflecting analytic stimulus evaluation, were generated in both contour and interval tasks. These components did not differ across groups for contour, but were smaller and delayed in nonmusicians compared to musicians for interval. However, the topologies were similar for P3a (frontal midline focus) and P3b (parietal midline focus) across groups and tasks. The amplitude of the P3b in musicians was negatively correlated with the age of onset of music lessons. Taken together these findings suggest that (a) contour processing is more basic, (b) interval processing may be more affected than contour by experience, and (c) similar brain networks are involved in generating the P3a and P3b in musicians and nonmusicians.

Processing melodic pitch structure is fundamental to understanding music. Although much remains to be learned about its neural basis, it is clear that melodic processing relies on a number of brain regions, including areas of both the left and right frontal and temporal regions (e.g., Beisteiner, Altenmüller, Lang, Lindinger, & Deecke, 1994; Johannes, Jöbges, Dengler, & Münte, 1998; Messerli, Pegna, & Sordet, 1995; Patel et al., 1997; Peretz & Babai, 1992; Samson & Zatorre, 1992; Tramo, Bharucha, & Musiek, 1990; Zatorre, Evans, & Meyer, 1994; Zatorre, Halpern, Perry, Meyer, & Evans, 1996). Melodic pitch structure is thought to be encoded in the brain in two different forms, *contour* and *interval*, each of which is processed in different brain regions (e.g., Bever & Chiarello, 1974; Dowling, 1978, 1982; Edworthy, 1985; Peretz, 1990; Peretz & Babai, 1992; Peretz & Morais, 1987; Peretz, Morais, & Bertelson, 1987). The contour representation consists of information about the up/down pattern of pitch changes, without regard to the exact size of the pitch changes, and is common to both speech and music. The interval representation encodes the more analytic structure of the exact pitch distances between successive tones; it is specific to music and allows the emergence of scale and harmonic structure. In this article, we use event-related potentials (ERPs) to examine contour and interval processing in musicians and nonmusicians. Commonalities between the groups should reflect more basic musical processes, whereas differences should give insight into the effect of extensive musical experience on brain function.

Behavioural studies suggest that contour processing is the more fundamental process. Both infants and musically untrained adults readily encode the contour but have more difficulty encoding the intervals of unfamiliar melodies (e.g., Bartlett & Dowling, 1980; Dowling, 1978; Cuddy & Cohen, 1976; Trehub & Trainor, 1993). The coding of contour is relatively independent of tonality (the key of a melody), whereas interval coding is highly dependent on tonality (Edworthy, 1985). When children begin to sing, they reproduce the contour accurately before they are able to reproduce the intervals accurately (Dowling, 1982). However, musically untrained adults and even infants are able to process interval information under certain circumstances, such as when the melodic structure is simple (e.g., Trainor & Trehub, 1993) or

the piece is very familiar (e.g., Attneave & Olson, 1971; Dowling, 1982). Thus, contour processing appears to be the more universal mode of processing, whereas interval processing depends to a much greater extent on experience and musical training (Dowling, 1978, 1982).

Most previous studies of contour versus interval processing confound the two types of processing in their tasks. It is relatively easy to get a pure measure of melodic interval discrimination because an interval can be altered without changing the contour (i.e., the up/down pitch pattern). However, because it is not possible to change the contour without also changing the interval, most of the so-called contour tasks used to date could be performed on the basis of interval analysis (McKinnon & Schellenberg, 1997). To get around this problem, in our contour task we presented melodies from two sets. All melodies in the standard set had an exclusively upward contour, and all melodies in the deviant set rose until the final note, which fell. The task on each trial was to detect whether a melody from the standard or the deviant set was played. Because the *size* of the intervals varied across the set of standard melodies, in order to use interval information to perform this task, all of the melodies and their matching oddballs would have to be memorised. Thus it is assumed that subjects would rely primarily on the readily available contour information.

Because ERPs give millisecond by millisecond information about neural processing, they are useful in studying various stages of processing (e.g., Näätänen, 1992; Rugg & Coles, 1995). ERPs are the electrical potentials measured at the scalp that reflect the processing of a particular stimulus or event. To obtain ERP waveforms, the continuous EEG signal is segmented into epochs that begin with the onset of the stimulus or event (the last tone in the melody in this case, that being the earliest point at which the melody class can be determined). Our analysis focused on the P3 complex of the ERP, so named because it is the third positive-going cortical peak that occurs in response to an infrequent stimulus occurring in a sequence of frequent stimuli (e.g., see Donchin & Coles, 1988; Johnson, 1988; Picton, 1992). Experimentally, we used an oddball paradigm whereby occasional deviant stimuli are randomly interspersed in a series of standard stimuli.

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The P3 complex is of particular interest because it has two main components, the P3a and the P3b, each involving distinct brain networks (e.g., Courchesne, Hillyard, & Galambos, 1975; Ebmeier et al., 1995; Halgren, Marinkovic, & Chauvel, 1998; Johnson, 1989; Knight, 1997; Verleger, Heide, Butt, & Kömpf, 1994). The P3a is related to the inadvertent capture of attention by salient events and automatic attention switching (e.g., Comerchero & Polich, 1998; Holdstock & Rugg, 1993; Katayama & Polich, 1998; Schröger & Wolff, 1998; Squires, Squires, & Hillyard, 1975) and takes the output of the automatic auditory stimulus-change detection mechanism (reflected at the scalp by a component called mismatch negativity) as input (Escera, Alho, Winkler, & Näätänen, 1998). The P3b, on the other hand, is related to stimulus evaluation and the updating of working memory, such as occurs when subjects are required to respond to particular stimulus features (e.g., see Donchin & Coles, 1988; Katayama & Polich, 1998; Picton, 1992; Verleger, 1997). On the scalp, the P3a is largest at frontal sites and occurs around 300 ms after the onset of the rare stimulus, whereas the P3b is largest at parietal sites and occurs between 300 and 800 ms, depending on stimulus evaluation time. The P3b is very robust whereas the P3a is not always observed in individuals (Polich, 1988; Squires et al., 1975) and appears to be most reliable in response to rare and to-be-ignored stimuli in the attended channel which are very different from both the standard and target stimuli (e.g., Comerchero & Polich, 1998; Katayama & Polich, 1998; Holdstock & Rugg, 1995; Schröger & Wolff, 1998).

With respect to music, a number of studies have confirmed that P3bs are readily obtained with the oddball paradigm when subjects are asked to detect various changes in musical phrases (e.g., Besson, 1998; Besson & Faïta, 1995; Besson & Macar, 1987; Cohen, Granot, Pratt, & Barneah, 1993; Janata, 1995; Levett & Martin, 1992; Paller, McCarthy, & Wood, 1992). To our knowledge, the P3a has only been directly examined in one study of musical processing. Janata (1995) presented chord sequences, and participants were to indicate how well the final chord completed the sequence. Janata obtained robust, early frontal P3as in addition to fairly small P3bs. In another study where melodies occasionally ended in an incongruous note, the waveforms at frontal sites clearly show an earlier P3 component, although only the latency of the parietal P3b was analysed (Besson & Faïta, 1995). These two studies suggest that incongruities in musical sequences might be particularly attention-getting, as relatively large P3a components were generated in a simple standard-oddball paradigm, with stimuli that were not outside the focus of attention.

Our goal in the present study, then, was to examine melodic contour and interval processing with respect to the automatic attention switching mechanism (indexed by P3a) as well as the stimulus evaluation mechanism (indexed by P3b). We sought to test (a) whether musical incongruities were particularly good at triggering automatic attentional processes in general, (b) whether contour and interval triggered automatic attentional processes differently, and (c) whether musicians and nonmusicians differed in either their automatic attentional system or their stimulus evaluation system when processing contour and/or interval information.

METHOD

Participants

Ten non-musically trained (age range = 19 to 29 years, 6 female and 4 male) and 11 musically trained adults (age range = 21 to 33 years; 6 female and 5 male) participated. None had perfect pitch. Of these, ERP data from 1 nonmusician in the contour task was not useable because of technical problems. In addition, ERP data from 3 other nonmusicians in the interval

task was not used because they scored less than 70% correct. The musically trained had between 7 and 17 years of training (mean = 12.3, $SD = 3.4$) and most were currently playing. The nonmusicians had less than 4 years of training and were currently not playing.

Stimuli

Each participant completed two tasks, a contour task (210 trials) and an interval task (240 trials). In both cases, the melody on 80% of trials was from a standard melody set and on the remaining 20% from an oddball melody set. The order of trials was random with the constraint that at least two standard trials occurred between each oddball trial. Each melody consisted of five notes, with note onset-to-onsets of



Figure 1

The stimuli for the contour (upper panel) and interval (lower panel) tasks, showing the four common notes for each sequence, followed by the standard terminal and oddball terminal notes. In the contour task, one of the seven different common sequences was randomly chosen on each trial; on 80% of trials the standard terminal was played, and on 20% the oddball terminal was played. In the interval task, there was one common four-note sequence that was transposed to different keys on different trials; on 80% of trials the standard terminal was played and on 20% one of the oddball terminals (randomly chosen) was played.

300 ms, for a total duration of 1500 ms. Trials were separated by 2000 ms. The notes were played from digitally recorded files created with the Korg MIDI Tonefile 01R/W using piano timbre. They were presented at 80 dB (C) with inhouse software running on a 486 computer with a ProAudio Spectrum 16 sound card through a Denon PMA 480R amplifier and a Grason Stadler speaker.

The contour task was constructed so that interval information was irrelevant. All seven melodies of the standard set were ascending in pitch, that is, each successive note was higher than the previous note (Figure 1). For each standard melody, a corresponding oddball melody was created where the first four notes were identical, but the final note descended rather than ascended in pitch. The sequences were constructed so that each terminal interval size was equally likely to occur in a standard or an oddball melody. Therefore, by far the easiest approach to this task was to attend to pitch contour and ignore pitch interval.

In the interval task, contour information was irrelevant. The standard set consisted of only one five-note melody, where the last two notes formed a perfect fourth interval (i.e., five semitones; Figure 1). However, on successive trials, it was transposed to start on a higher or lower pitch so that absolute pitch cues could not be used. Specifically, it could start on any one of the 12 notes used in Western musical structure, with the constraint that successive trials were transposed by perfect fifths (seven semitones) or perfect fourths (five semitones). There were four oddball melodies (also presented in the 12 transpositions), which differed from the standard melody only in the size of the last interval. Thus, the contour of the standard and oddball stimuli were identical. For two of the oddball melodies, the terminal note remained in the key of the melody (final intervals of four and seven semitones) and for the other two, the terminal note was not in the key of the melody (final intervals of three and six semitones).

Procedure

Approximately half of the participants received the contour and half the interval task first. They were instructed to blink between melodies. In the contour task, they were instructed to press one button on a button box if the last note of the sequence ascended and to press another button if the last note descended. They were then given a few practice trials to make sure that they understood the task. In the interval task, participants were informed that they would hear a five-note melody repeating at different pitch levels. They were instructed to press one button if the standard melody was played and another button if the last note of the melody changed. Again, participants were initially given a few practice trials so that they could learn the standard melody.

Recordings

Recordings were made from the following 27 sites: FPz, Fz, Cz, Pz, Oz, FP1, FP2, F3, F4, F7, F8, FC1, FC2, FC3, FC4, T3, T4, C3, C4, PTC5, PTC6, P3, P4, T5, T6, O1, O2. Electro-caps, NeuroScan software, 32-channel Synamps, and a 486 computer were used. The sampling rate was 500 Hz, and the bandpass was set between 1 and 40 Hz. Cz was used as the reference during recording, but a common average reference was calculated offline and used for the analyses.

ERP Data Analysis

Epochs were defined as beginning at the onset of the final melody note, and baseline was defined as the mean amplitude for the 50 ms preceding the onset of the final melody note. Waveforms were filtered between 1 and 18 Hz, and those

exceeding ± 80 μ V at FP1 or F8 were rejected as contaminated by eye movement artefact.

Standards and oddballs were averaged separately in each condition for each participant. The latency of the P3a for each participant was defined as the latency of the positive oddball peak at Fz that followed P2 and N2. The amplitude of the oddball waveform at each site was taken at that latency point, and measured relative to baseline. The latency and amplitude of the P3b were defined similarly for each participant, but using Pz instead of Fz to obtain the latency.

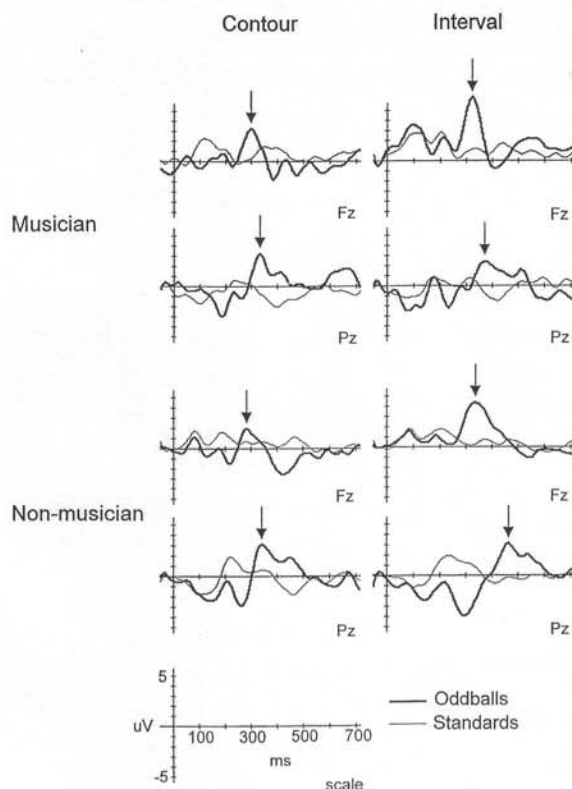
Because different but overlapping groups of nonmusicians were tested in the contour and interval tasks, separate ANOVAs were performed on the contour and interval data. The amplitude data was examined with analyses of variance (ANOVAs) with group (musicians, nonmusicians), component (P3a, P3b), and site (FPz, Fz, Cz, Pz, Oz, FP1, FP2, F3, F4, F7, F8, FC1, FC2, FC3, FC4, T3, T4, C3, C4, PTC5, PTC6, P3, P4, T5, T6, O1, O2) as factors. Latency differences (based on the P3a and P3b latencies measured at Fz and Pz, respectively) were examined in ANOVAs with group (musicians, nonmusicians) and component (P3a, P3b) as factors. Contour and interval data were directly compared in musicians, since all 11 participants completed both tasks. To correct for nonadditive effects, the interaction terms in all amplitude ANOVAs were tested using normalised data as recommended by McCarthy and Wood (1985). In addition, the Greenhouse-Geisser correction for repeated measures was used where appropriate. The uncorrected degrees of freedom and corrected probabilities are reported.

RESULTS

Performance

The mean proportion correct for the musicians was 1.00 ($SD = .00$) on standard and .98 ($SD = .023$) on oddball trials in the contour task, and .99 ($SD = .01$) on standard and .97 ($SD = .02$) on oddball trials in the interval task. Before excluding the poor-performing nonmusicians (see *Participants*), the nonmusicians achieved .96 ($SD = .06$) on standard trials and .95 ($SD = .07$) on oddball trials in the contour task, and .96 ($SD = .04$) on standard trials and .85 ($SD = .18$) on oddball trials in the interval task. The relatively poor performance and the large standard deviation in the nonmusician group on the interval task was due to 3 participants who each scored less than .70 correct. After excluding these nonmusicians from the interval task, the remaining 7 nonmusicians achieved a mean percentage correct of .95 ($SD = .05$) on standard and .95 ($SD = 0.05$) on oddball trials in the interval task. With the 3 poor-performing nonmusicians excluded from the interval task, there were no significant differences between the performance of musicians and nonmusicians or between the interval and contour tasks.

The mean reaction times for the musicians were 551 ms ($SD = 83$) on standard and 633 ms ($SD = 54$) on oddball trials for the contour task, and 557 ms ($SD = 79$) on standard and 660 ms ($SD = 98$) on oddball trials for the interval task. For the selected group of nonmusicians, these numbers were 593 ms ($SD = 121$) on standard and 696 ms ($SD = 165$) on oddball trials in the contour task, and 679 ms ($SD = 209$) on standard and 672 ms ($SD = 117$) on oddball trials in the interval task. Given the large variability in latency, there were no significant differences in reaction time on either standard or oddball trials between musicians and nonmusicians or between the contour and interval tasks. Thus, while the interval task was more difficult for a few of the nonmusicians, once these participants were excluded there were no significant behavioural differences between the musicians and nonmusicians in the final sample used for the ERP analyses.

**Figure 2**

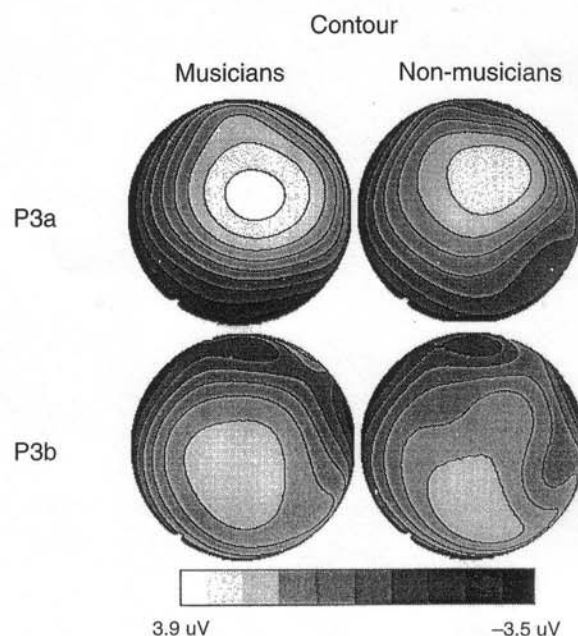
Averaged standard and oddball waveforms for one musician and one nonmusician at Fz (arrows show the P3a) and at Pz (arrows show the P3b).

ERP Measures

Contour. The ANOVA on latency revealed only that the P3a was earlier than the P3b, $F(1, 18) = 8.93, p < .008$. There were no significant differences between the musician and nonmusician groups, and no interactions involving group. Because of the large variability in latency across participants (mean P3a latency = 312 ms, $SD = 40$; mean P3b latency = 383 ms, $SD = 87$), in Figure 2 we show standard and oddball waveforms for one musician and one nonmusician at Fz and Pz rather than grand averages. (Group averages are shown in the topologies in Figure 3.)

The ANOVA on amplitude revealed no effect of group and no interactions involving group, indicating that the size and topologies of the P3a and P3b components were similar in musicians and nonmusicians. There was a main effect of component, $F(1, 18) = 5.25, p < .04$, and a main effect of site, $F(3, 468) = 12.54, p < .0001$. Of most interest, there was an interaction between component and site, $F(26, 468) = 16.29, p < .0001$, indicating that the topologies of the P3a and P3b components were different. Because there was large variability in the latency of the peaks, topologies were generated by lining up the peaks of the individual participants. As can be seen in the group average topologies in Figure 3, for both musicians and nonmusicians, the P3a had a frontal midline focus whereas the P3b had a parietal midline focus. It is also interesting that, compared to studies using single tone stimuli, both groups generated large P3a components and relatively small P3b components in this task (mean P3a amplitude at Fz = 3.34 uV, $SD = 1.66$; mean P3b amplitude at Pz = 2.69 uV, $SD = 1.59$ for musicians and nonmusicians together).

Interval. As with the contour task, individual waveforms clearly show an earlier frontal P3a and a later parietal P3b in

**Figure 3**

Contour task. Spherical spline isocontour voltage maps looking down on the head with the front of the head at the top for the P3a and P3b components for musicians and nonmusicians. For the P3a, the topologies are calculated at the peak of the P3 at Fz for each individual participant; for the P3b, the topologies are calculated at the peak of the P3 at Pz for each individual participant.

both groups (Figure 2), which was reflected in a significant effect of component in the ANOVA on latency, $F(1, 16) = 34.23, p < .0001$. Unlike in the contour task, however, there was a main effect of group, $F(1, 16) = 4.68, p < .05$, reflecting the fact that the peaks of musicians were earlier than those of nonmusicians. The interaction between component and group was not significant ($p > .8$), indicating that both the P3a and P3b components were delayed in the nonmusicians compared to the musicians: mean P3a latency at Fz = 311 ms ($SD = 21$) in musicians and 340 ms ($SD = 27$) in nonmusicians, and mean P3b latency at Pz = 406 ms ($SD = 47$) in musicians and 441 ms ($SD = 79$) in nonmusicians.

Unlike in the contour task, the ANOVA on amplitude revealed a main effect of group, $F(1, 16) = 8.99, p < .009$, reflecting larger amplitudes in the musicians than in the nonmusicians. There was also a main effect of site, $F(26, 390) = 9.93, p < .0001$, and an interaction between component and site, $F(26, 416) = 17.73, p < .0001$, again indicating that the P3a and P3b had different topologies. The absence of significant interactions involving group suggests that, although the magnitudes of the P3a and P3b were different for musicians and nonmusicians, the topologies were similar. As in the contour task, the P3a had a frontal midline focus whereas the P3b had a parietal midline focus (Figure 4). Again, compared to studies using single tone stimuli, a relatively large P3a and a relatively small P3b were generated in both groups: mean P3a amplitude at Fz = 3.93 uV ($SD = 2.00$) in musicians and 1.80 uV ($SD = 1.23$) in nonmusicians, and mean P3b amplitude at Pz = 2.57 uV ($SD = 2.44$) in musicians and 2.50 uV ($SD = 1.12$) in nonmusicians.

Contour versus interval processing. Because the same 11 musicians completed both tasks, their ERPs could be compared across the contour and interval tasks. The ANOVA on amplitude revealed a main effect of site, $F(26, 234) =$

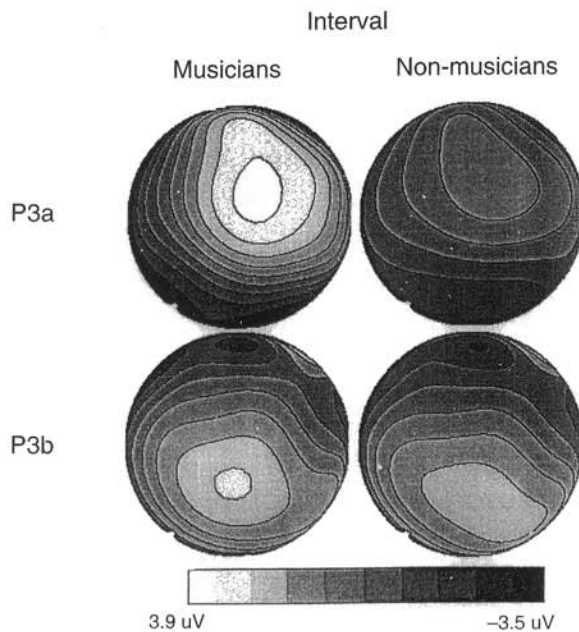


Figure 4
Interval task. Spherical spline isocontour voltage maps looking down on the head with the front of the head at the top for the P3a and P3b components for musicians and nonmusicians. For the P3a, the topologies are calculated at the peak of the P3 at Fz for each individual participant; for the P3b, the topologies are calculated at the peak of the P3 at Pz for each individual participant.

11.16, $p < .0007$, and an interaction between site and component, $F(26, 260) = 19.04$, $p < .0001$, reflecting the different topologies of the P3a and P3b that have been discussed above. Neither the ANOVA on latency or the ANOVA on amplitude revealed a main effect of or interaction involving task (all $ps > .7$), suggesting that the amplitude and latency of the P3a and P3b components are similar across the contour and interval tasks in musicians.

Correlations with age of onset of music lessons. All musicians had started music lessons between 4 and 7 years of age. Because the amplitude of the P3a and P3b components did not differ significantly across the contour and interval tasks for musicians, we collapsed across task and determined the amplitude of the P3a component at Fz and of the P3b component at Pz for each musician. The amplitude of the P3b component, but not that of the P3a component, was negatively correlated with age of onset of music lessons, $r = -.68$, $n = 11$; $p < .025$. To ensure that the effect was not due to outliers, Spearman rank order correlations were also performed. The results were identical, with the age of onset of music lessons only correlating significantly with the P3b component, $r = -.72$, $n = 11$; $p < .02$ (Figure 5). Thus, the earlier the onset of music lessons, the larger the P3b component.

DISCUSSION

In both musicians and nonmusicians, and across both contour and interval processing, we found clearly separable P3a and P3b components. Neither the topology of the P3as (with frontal midline focus) nor that of the P3b (parietal midline focus) differed across groups or tasks, suggesting that, at the levels of automatic attention switching and stimulus evaluation, common brain regions are used by both groups in these tasks. In the contour task, the amplitude and latency of these components did not differ across musicians and nonmusicians,

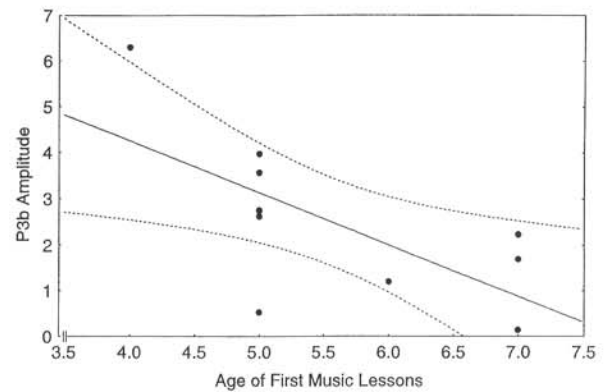


Figure 5
Scatterplot showing the correlation between age of onset of music lessons and P3b amplitude. The solid line shows the regression line ($r = -.68$) and the dotted lines represent 95% confidence intervals.

whereas for the interval task, these components were smaller and delayed in the nonmusicians compared to in the musicians, which is consistent with the hypothesis that contour is a more fundamental process than interval.

Music seems to be particularly good at activating the automatic attention switching system. Across both musicians and nonmusicians we found robust P3as to *attended* deviants in both melodic contour and interval using a simple standard/oddball paradigm. Substantial P3as have also been reported to attended deviant endings in sequences of musical chords (Janata, 1995). In contrast, when the stimuli are single tones, P3as are often only seen to rare stimuli that are to be ignored (Polich, 1988; Squires et al., 1975). It is possible that P3as were clearly seen in the present study because the use of complex time-varying stimuli led to relatively small, broad P3bs. Alternatively, a musical context with rich time-varying information may generate large expectancies that, when violated, result in the obligatory triggering of the automatic attention-switching mechanism.

Scalp topologies of the P3as and of the P3bs were similar across contour and interval processing in both groups, with a frontal midline focus for P3as and a parietal midline focus for P3bs. Some behavioural studies have suggested that contour information might be processed in the right hemisphere whereas interval information might be processed in the left hemisphere (Bever & Chiarello, 1974; Peretz, 1990; Peretz & Morais, 1988), although these effects change with the strategy adopted by the listener (Peretz & Morais, 1987; Peretz et al., 1987). Laterality effects might emerge at earlier stages of processing, but our results suggest that there are no major differences in the brain regions used in contour and interval processing at the levels of automatic attention switching and stimulus evaluation.

On the contour task, the amplitude and latency of the P3as and P3bs did not differ across musicians and nonmusicians, suggesting that melodic contour processing is very basic and influenced little by experience or genetic differences. In the interval task, these components were smaller and delayed in the nonmusicians relative to the musicians, suggesting that experience and/or genetic factors may affect both automatic attentional and more analytic stimulus-evaluation mechanisms in interval processing. Despite the amplitude and latency differences on the interval task, no significant differences in topology were found between musicians and nonmusicians on either the P3a or the P3b, suggesting that both the automatic attentional and analytic stimulus evaluation processes rely on similar brain regions in the two groups, but that nonmusicians

are less efficient in their processing, perhaps using fewer neurones or less synchronised activity, and/or receiving more ambiguous input from earlier stages of processing.

Although it is virtually impossible to distinguish between effects of experience and intrinsic musical ability without controlling who gets what experience, it is nonetheless interesting that the age of onset of music lessons was negatively correlated with the amplitude of the P3b, but not with the amplitude of the P3a component. A study using magnetoencephalography has suggested that musical experience affects the size of the dipole moment of the early N1 response, which indexes initial processing in the primary auditory cortex (Pantev, Oostenveld, Engelien, Ross, Roberts, & Hoke, 1998). Our results suggests that early musical training may result in enhanced analytic stimulus-evaluation processes, although it is possible that children with advanced analytical skills for music are often given music lessons at an earlier age.

In summary, changes in both melodic contour and interval information activate the automatic attention-switching mechanism as reflected in large frontal P3as, as well as the stimulus evaluation mechanism as reflected in parietal P3bs. Musicians and nonmusicians do not differ in these components in contour processing, but nonmusicians show smaller, later components than musicians in interval processing, suggesting that contour processing is the more basic melodic process and that interval processing is more efficient in musicians.

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