Automatic and Controlled Processing of Melodic Contour and Interval Information Measured by Electrical Brain Activity

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Abstract

■ Most work on how pitch is encoded in the auditory cortex has focused on tonotopic (absolute) pitch maps. However, melodic information is thought to be encoded in the brain in two different "relative pitch" forms, a domain-general contour code (up/down pattern of pitch changes) and a music-specific interval code (exact pitch distances between notes). Event-related potentials were analyzed in nonmusicians from both passive and active oddball tasks where either the contour or the interval of melody–final notes was occasionally altered. The occasional deviant notes generated a right frontal positivity peaking around 350 msec and a central parietal P3b peaking around 580 msec that were present only when participants focused their attention on the auditory stimuli. Both types of melodic information were encoded automatically in the absence of absolute pitch cues, as indexed by a mismatch negativity wave recorded during the passive conditions. The results indicate that even in the absence of musical training, the brain is set up to automatically encode music-specific melodic information, even when absolute pitch information is not available. ■

INTRODUCTION

How sound information is represented in the auditory cortex is not entirely understood. It is clear that there are tonotopic maps in the primary auditory cortex whereby different pitches are represented in different cortical areas in an orderly fashion (e.g., Woods, Alho, & Allgazi, 1993; Pantev, Hoke, Lutkenhoner, & Lehnertz, 1989; Pantev et al., 1995). However, the information in melodies is not so much in the absolute frequencies or pitches of the tones, but rather in the pitch relations or pitch distances between the tones—a melody retains its identity whether rendered in a high or a low pitch range, as long as the relative pitch relations are maintained. At present, the stage of processing at which relative pitch information is extracted is not known. We investigate this question in a group of nonmusicians.

There are reasons to expect that the auditory cortex might be setup up to extract music-specific information. Music is an integral part of every human society (Wallin, Merker, & Brown, 2000), and there is evidence that melodic music-making has a long history in human cultural evolution (Kuneg & Turk, 2000). There is also evidence that across languages and cultures parents use music to communicate to young infants long before they understand language (Trehub & Trainor, 1998). At the same time, music is often considered to be a "frill," an evolutionarily unimportant accident in the development of speech perception (e.g., Pinker, 1994). Brain imaging studies (PET and fMRI) have clearly shown that a large number of brain regions are involved in melodic processing, including the temporal and frontal regions, the supplementary motor areas, and the thalamus (e.g., Halpern & Zatorre, 1999; Mirz et al., 1999; Platel et al., 1997; Zatorre, Halpern, Perry, Meyer, & Evans, 1996). Although more studies implicate the right than the left hemisphere in musical processing, both hemispheres are clearly involved (e.g., Peretz & Herbert, 2000; Patel & Peretz, 1997; Zatorre, 1984; Zatorre et al., 1996), and musical input stimulates the perceptual, cognitive, memory, and emotional systems.

Melodic information is thought to be encoded in two basic forms (e.g., Liegeois-Chauvel, Peretz, Babaie, Laguitton, & Chauvel, 1998; Peretz & Morais, 1987; Peretz, Morais, & Bertelson, 1987; Peretz, 1990; Peretz & Babaie, 1992; Edworthy, 1985; Dowling, 1978, 1982; Bever & Chiarello, 1974). The contour code consists of the up/down pattern of pitch changes without regard to the size of those changes. The interval code consists of the exact pitch distances between successive tones. Contour information is not specific to music, but is crucial to both speech prosody and melodic structure (Patel, Peretz, Tramo, & Labrecque, 1998), whereas exact interval information is specific to music. Contour detection appears to be a more universal process than interval

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detection in that both infants and musically untrained adults readily detect when the contour changes, but have more difficulty perceiving changes between the intervals of consecutive notes in unfamiliar melodies (e.g., Trehub, Trainor, & Unyk, 1993; Bartlett & Dowling, 1980; Dowling, 1978; Cuddy & Cohen, 1976). Moreover, young children correctly reproduce the contour of simple melodies before they correctly reproduce the intervals (Dowling, 1982). At the same time, the interval representation is vitally important in musical structure because, unlike the contour representation, it allows the emergence of the specific scale structures, musical keys, and harmonic structures that distinguish different musical systems and must be learned (e.g., Trainor & Trehub, 1992, 1994).

Basic sound features, such as pitch, duration, and loudness are encoded automatically in the auditory cortex. In humans, this has been established primarily with studies of the mismatch negativity (MMN) component of the event-related brain potential (ERP) (Näätänen, Tervaniemi, Sussman, Pääviläinen, & Winkler, 2001; Picton, Alain, Otten, Ritter, & Achim, 2000). This component is elicited in an oddball paradigm in which a repeating standard sound occasionally deviates in pitch, duration, loudness, timbre, or location. The deviant sounds generate activity in the auditory cortex between about 150 and 250 msec after stimulus onset, which is measured as an increased negativity at the front of the scalp and an increased positivity at sites below the Sylvian fissure, in comparison to the frequent standard sounds (e.g., Picton et al., 2000; Schroger, 1998; Näätänen, 1992). MMN is typically recorded when subjects are not paying attention to the sounds, as it can overlap with, and thus be obscured by, components modulated by attention. Recent evidence indicates that not only are there circuits in the auditory cortex that respond automatically to differences in basic sound features, but that there are also circuits that respond to changes in sound patterns (Näätänen et al., 2001; Picton et al., 2000), such as when one tone of a repeating sequence is altered (e.g., Alain, Cortese, & Picton, 1999). MMN even occurs to pattern deviants in which no new tones are introduced, such as when one note of the pattern is repeated (e.g., Alain, Woods, & Ogawa, 1994; Alain, Achim, & Woods, 1999).

Of most interest in the present context are reports that the pitch contour of tone pairs (i.e., whether rising or falling) is encoded (i.e., MMN is seen) even when the absolute pitch changes from instance to instance (Pääviläinen, Jaramillo, & Näätänen, 1998; Tervaniemi, Maury, & Näätänen, 1994; Säärinen, Pääviläinen, Schröger, Tervaniemi, & Näätänen, 1992). This suggests that "relative" pitch contour is encoded automatically. Given the central role of contour in both speech and musical prosody, this is perhaps not surprising. As stated above, however, the essence of musical pitch is the pitch interval—the exact pitch distance between tones, regardless of the absolute pitch of the tones. Whether the auditory cortex encodes pitch intervals in the absence of attention has not been tested previously, although it is a fundamental question in the study of how music is processed in the brain. If nonmusicians process changes in pitch interval automatically and without attention, it would indicate that their auditory cortex is set up, whether through innate processes or incidental musical exposure, to process music-specific information.

The neural correlates supporting contour and interval processing have been examined recently in two separate studies using ERPs, but neither included a passive condition to allow the assessment of automatic processing. Using an oddball paradigm, Schiavetto, Cortese, and Alain (1999) found that a larger N2 wave (peaking at about 200 msec) was elicited for the identification of contour deviants than for interval deviants in nonmusicians. The N2 complex consists of two components: the N2a or MMN, which occurs whenever the brain detects an occasional deviant stimulus in a sequence of standard auditory stimuli, whether or not the auditory stimuli are task-relevant, and the N2b, which is also elicited by deviant stimuli but only when they are task-relevant (Rugg & Coles, 1995). Because the ERPs in the Schiavetto et al. study were measured only during an active listening task (i.e., participants attended to the stimuli and pressed buttons to identify the deviant stimuli), it is difficult to evaluate whether the enhanced N2 wave for contour over interval deviants reflects differences in task-relevant stimulus categorization (N2b) or in an automatic change-detection process (MMN). Previous studies have shown that the MMN amplitude increases with increasing deviant discriminability (Näätänen, 1992). Given that response times were slower for detecting interval than contour deviants in the Schiavetto et al. study, it is possible that the enhanced N2 for contour deviants reflects a larger MMN wave associated with contour than with interval deviants. Alternatively, it is possible that neither contour nor interval deviants are processed automatically and the N2 difference found reflects solely differences in controlled processes and stimulus categorization.

Trainor, Desjardins, and Rockel (1999) compared ERPs from musicians and nonmusicians across contour and interval tasks using an oddball paradigm, but examined later ERP components. In separate blocks of trials, participants responded as to whether or not there was an occasional change (deviant) in the contour of a set of melodies with rising contours, or whether or not there was an occasional change (deviant) in the interval of a melody presented in transposition (i.e., starting at different pitches). The detection of both contour and interval violations was associated with a positive wave over the frontal lobe peaking between 311 and 340 msec. This wave, referred to as a P3a, preceded the P3b recorded over the parietal region, which peaked between 383 and

441 msec. While the P3a and P3b recorded during the contour task were similar in amplitude, latency, and topography in musicians and nonmusicians, they were delayed and smaller in nonmusicians during the interval task. These findings suggest that melodic contour is processed similarly in musicians and nonmusicians, but that discriminating changes in interval depends on musical training.

The frontal positivity reported by Trainor et al. (1999) bears more investigation. A frontal positivity is typically elicited either by occasional salient stimuli that occur in an unattended channel (e.g., Escera, Alho, Winkler, & Näätänen, 1998; Alho, Escera, Diaz, Yago, & Serra, 1997; Alho et al., 1998; Squires, Squires, & Hillyard, 1975) or by occasional salient stimuli in an attended channel that are to be ignored (i.e., not responded to) (e.g., Comerchero & Polich, 1998; Katayama & Polich, 1998; Holdstock & Rugg, 1993, 1995; Knight, 1984). Thus, this component is thought to be related to the inadvertent capture of attention by salient events, and so it is of great interest to an investigation of automatic versus controlled processes for melody. Although frontal P3 components have not been studied often in relation to musical processing, robust frontal positivities have also been observed in one other study (Janata, 1995), and frontal positivities are evident in the waveforms from other musical studies, although they were not analyzed (e.g., Besson & Faita, 1995). This suggests that both contour and interval changes may trigger automatic attentional P3a processes. However, this interpretation needs to be treated with caution because the frontal positivities observed in these musical studies were generated to occasional attended stimuli that were targets, not to stimuli that were to be ignored. Furthermore, in nonmusical processing, P3as are not always found in all subjects (Polich, 1988; Squires et al., 1975) and are strongest for deviants that are very different from the standard stimuli (e.g., Comerchero & Polich, 1998; Katayama & Polich, 1998; Schroger & Wolff, 1998). On the other hand, the targets in the musical cases were sometimes rather subtly different from the standards, (e.g., the interval task of Trainor et al., 1999), again suggesting that the frontal positivities in the musical case may not map directly onto P3as described in other literatures. In the present study we examine the frontal positivity in both active and passive musical tasks, in order to determine whether it functions like the P3a described for other stimuli, or whether it reflects some other process.

The final ERP component of interest in the present investigation is the P3b, the large parietally centered peak that is found to infrequent target stimuli (i.e., stimuli requiring a response) in an attended channel, but not to infrequent stimuli in an unattended channel. This component is thought to be related to conscious stimulus evaluation and the updating of working memory (e.g., see Katayama & Polich, 1998; Verleger, 1997; Stuss, Picton, Cerri, Leech, & Stethem, 1992; Donchin & Coles, 1988; Johnson-Laird, 1988) and has been found in many studies requiring the detection of various deviants in musical stimuli (e.g., Schiavetto et al., 1999; Trainor et al., 1999; Besson & Faïta, 1995; Besson, 1998; Janata, 1995; Cohen, Granot, Pratt, & Barneah, 1993; Levett & Martin, 1992; Paller, McCarthy, & Wood, 1992; Besson & Macar, 1987).

In order to examine both early and later cortical components related to the processing of pitch contour and interval information, we used the set of five-note contour melodies from the Trainor et al. (1999) study. Each of these melodies started on a different pitch and contained different pitch intervals, but all melodies had a rising contour (see Figure 1). On 20% of trials, the last tone was changed so that the final interval descended rather than ascended. Thus, this task cannot be done by relying on an absolute pitch representation of the melodies. For the interval task, we created a melody consisting of the first five notes of the rising major scale (see Figure 1). On different trials, this melody was randomly transposed to start on any of the 12 notes of the Western scale. On 20% of trials, the final note of the melody was changed to form a different final interval, such that the contour always ascended. As in the contour task, this interval task cannot be performed using an absolute pitch representation.

Each participant completed both an active (button pressed as to whether a standard or deviant melody was presented) and a passive (read a book while the melodies were presented) version of each of the contour and interval tasks. The passive task allowed us to examine whether contour and interval information are encoded automatically (presence of MMN) as well as whether the frontal P3 reported in the Trainor et al. (1999) study indexes automatic or controlled processes of musical information.

In summary, we investigated automatic and controlled processes in sensory and working memory representations of melodic contour and interval information. On the basis of previous simple two-tone contour (Pääviläinen et al., 1998; Tervaniemi et al., 1994; Säärinen et al., 1992) and the domain-general nature of contour processing, we expected contour violations to elicit MMN. However, because interval processing depends to a much greater extent on musical experience (e.g., Peretz & Babaie, 1992; Dowling, 1982; Bever & Chiarello, 1974) and tonality (Edworthy, 1985), and because it is thought to be specialized to the musical system (Patel & Peretz, 1997), an automatic, relative-pitch encoding of interval information as reflected by MMN would be more surprising in nonmusicians. The absence of an MMN response in nonmusicians to interval violations would suggest that automatic interval processing does not develop universally, and would be consistent with the idea that musical processing is not important enough for the allocation of extensive resources for

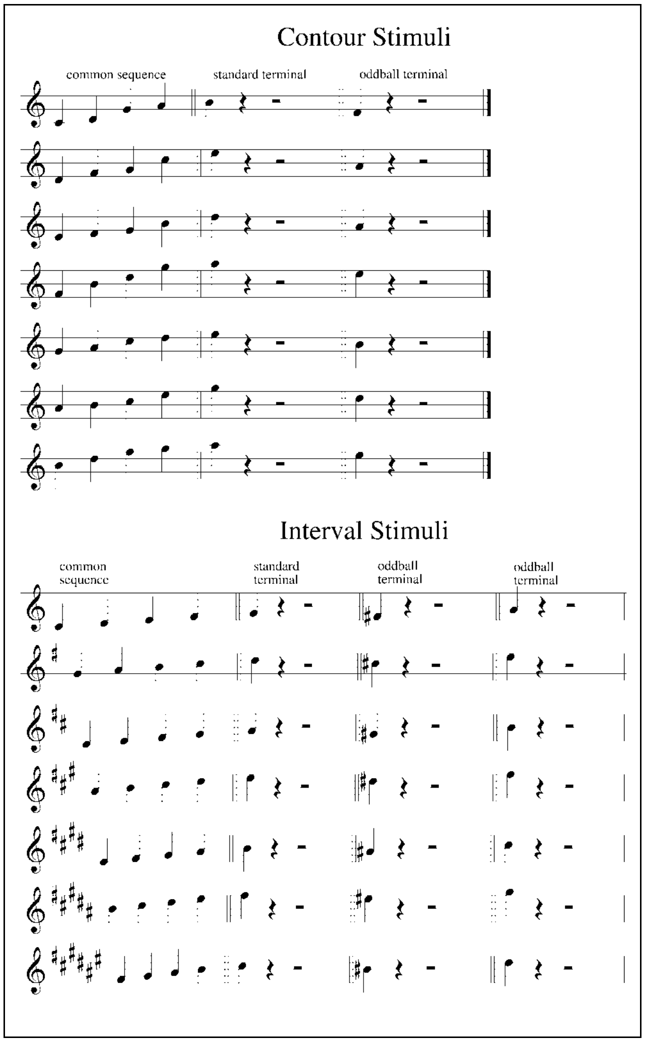


Figure 1. The contour (upper panel) and interval (lower panel) stimuli. In each case, the first four notes of the melodies (common sequence) are shown followed by the standard and deviant (oddball) terminal notes. In the contour case, interval size changes from melody to melody, but the standard terminal notes always rise whereas the oddball terminal notes always fall. In the interval case, deviant terminal notes either go outside the key of the common sequence (second–last bar) or remain in the key of the common sequence (last bar), but the contour is always rising.

automatic extraction of musical features at sensory levels of auditory processing. On the other hand, if the nonmusically trained person extracts interval information automatically in the absence of absolute pitch information, this would suggest that the brain places high value on music-specific pitch pattern information.

RESULTS

Performance

The tasks were relatively easy with participants correctly identifying the melody as standard or deviant in more than 90% of the trials in both contour and interval tasks (Table 1). Although performance was high in both cases, it was significantly better for the contour than for the interval task, $F(1,10) = 6.09, p < .05$. The difference in reaction times (RTs) between the contour and interval tasks was not significant, although the trend was for shorter response time in the former case (Table 1). In the interval task, the final note could either be in key or out of key. There were no significant differences in either accuracy or RT between these conditions.

ERP Results

Passive Listening

Figure 2 shows group mean ERPs during passive listening for the contour and interval tasks. In both tasks, standards and deviants generated an N1. An analysis of variance (ANOVA) at Fz with task (contour, interval) and stimulus type (standard, deviant) as factors revealed that the N1 was later in deviant than in standard stimuli [main effect of stimulus type, $F(1,10) = 6.17, p < .05$], and that this difference was larger in the contour (means of 127 msec, $SD = 5.5$, and 117 msec, $SD = 15.8$, respectively) than in the interval (means of 122 msec, $SD = 12.6$, and 121 msec, $SD = 12.9$, respectively) task [Task × Stimulus Type interaction, $F(1,10) = 6.75, p < .05$].

Using the mean amplitude between 95 and 135 msec as the dependent measure, a similar ANOVA revealed that the N1 was larger in the contour than in the interval task, $F(1,10) = 15.53, p < .01$, and that it was larger for deviant than for standard stimuli, $F(1,10) = 11.17, p < .01$. The latter effect is likely due to overlap between the N1 and MMN (see below) components elicited by oddball stimuli.

Contour and interval deviant stimuli generated an MMN that was maximal at the frontal sites and reversed polarity at the mastoids (Figure 3). The MMN recorded at the midline electrode (Fz) was delayed in the interval (mean = 180 msec, $SD = 27.0$) compared with the contour (mean = 150 msec, $SD = 22.7$) task, $F(1,10) = 10.77, p < .01$. Within the interval task, the MMN was earlier for the whole tone than for the semitone changes, $F(1,10) = 9.89, p < .01$ (means of 146.6 and 190.6 msec, respectively).

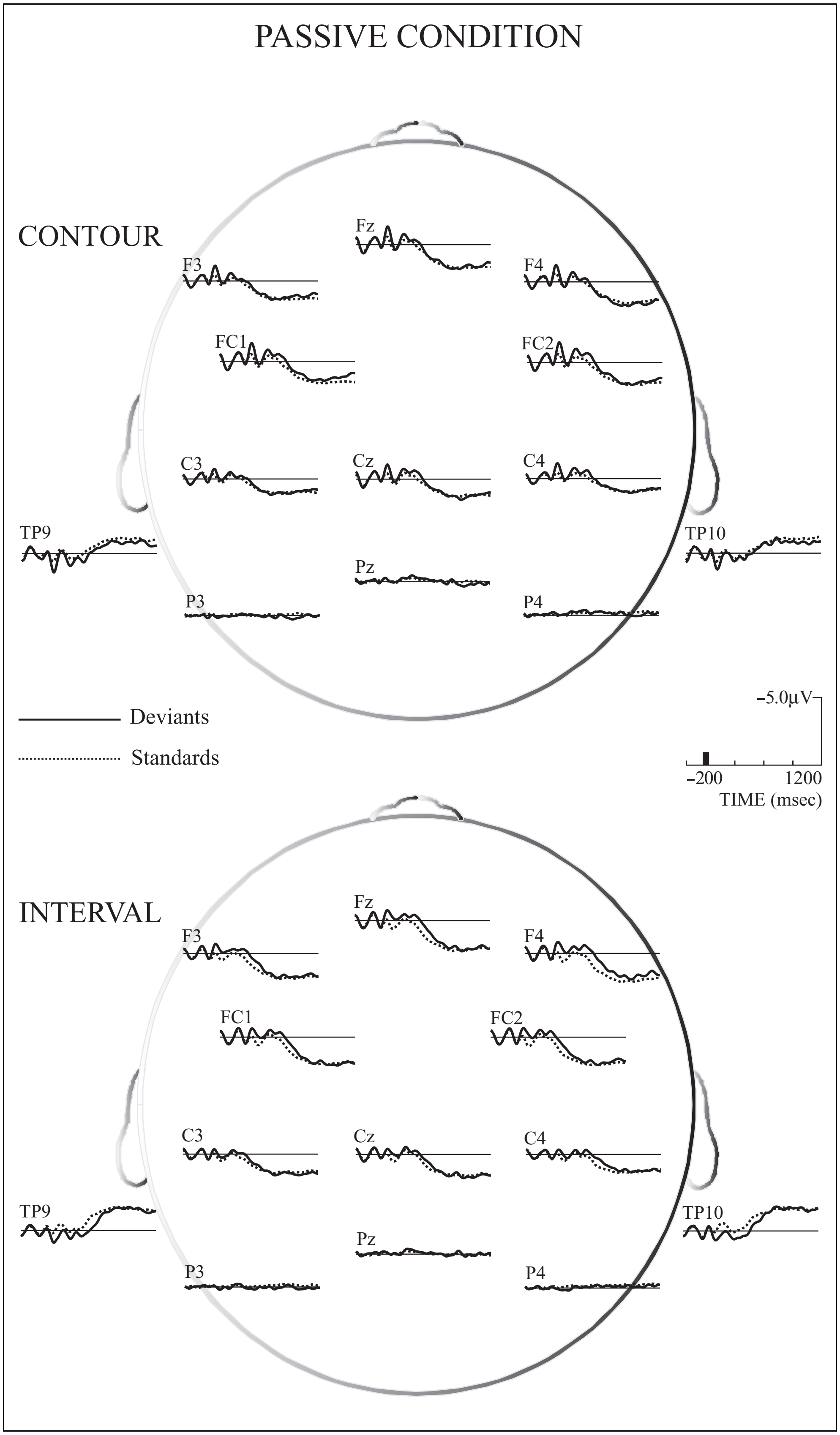
The mean amplitude was calculated for 40-msec windows around the contour and interval means for standard and deviant stimuli. There were no differences

Table 1. Behavioral Performance for the Contour and Interval Tasks

	Contour Task	*Interval Task*
% Correct	94.96 (4.44)	91.75 (7.03)
RT (msec)	570 (113)	604 (80)

Standard deviations are shown in parentheses.

Figure 2. Grand average standard (dashed line) and deviant (solid line) ERPs at selected electrode sites across the scalp for the passive contour and interval tasks. In this and the subsequent figures, the thick bar shows the onset of the final melody note.



in amplitude between the whole-tone and semitone changes in the interval task, so the data were collapsed across this factor. An ANOVA with task (contour, interval) and stimulus type (standard, deviant) revealed that deviants were indeed more negative than standards, $F(1,10) = 50.83$, $p < .001$, and that contour was more

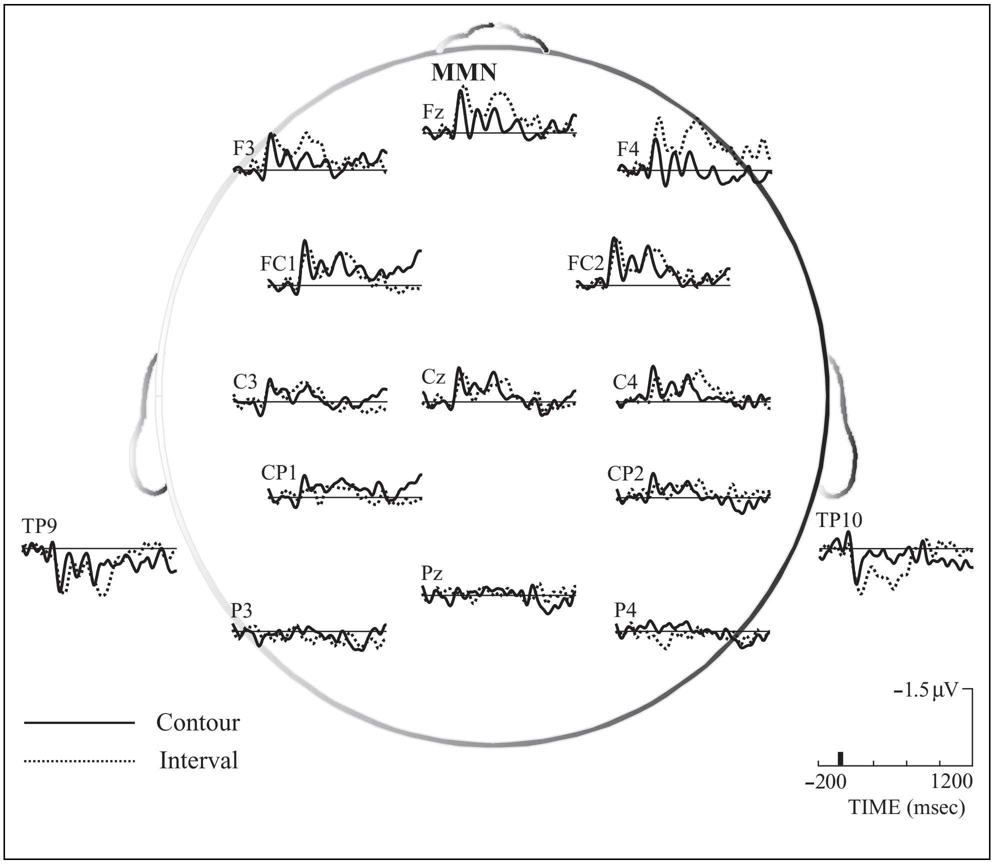


Figure 3. Difference waves (deviant − standard) for the contour (solid line) and interval (dashed line) tasks during passive listening.

negative than interval, $F(1,10) = 27.94$, $p < .001$. There was no interaction between task and stimulus type, however, indicating that the MMN was of comparable size in the contour and interval tasks (see Figure 3).

An examination of the head maps (Figure 4) shows that the MMN was fronto-centrally distributed over the scalp in the contour task, while it was greater over the right hemisphere in the interval task. However, there were no significant topological differences between contour and interval MMN, as revealed in analyses using all electrodes as well as analyses using only midline or only lateral line electrodes.

As expected, no P3b was evident in the passive listening tasks of either contour or interval. Interestingly, there was also no evidence of a frontal positivity in the passive listening task.

Active Listening

Figure 5 shows group mean ERPs during active listening for the contour and interval tasks. Because no significant differences were found for any ERP components between the whole tone and semitone conditions in the interval task, the following analyses are collapsed across this factor.

In both contour and interval tasks, standards and deviants generated an N1 peaking at 119 msec (*SD* = 12.7) poststimulus. An ANOVA with task (contour, interval) and stimulus type (standard, deviant) as factors showed that the N1 measured at Fz was larger (mean amplitude between 95 and 135 msec post stimulus) in the contour than in the interval task, $F(1,10) = 8.86$, $p < .02$, and larger for deviants than for standards, $F(1, 10) = 9.20$, $p < .02$. The latter effect is probably due to the fact that the N2 wave elicited by the oddball stimuli was partly superimposed on the N1 deflection (see below).

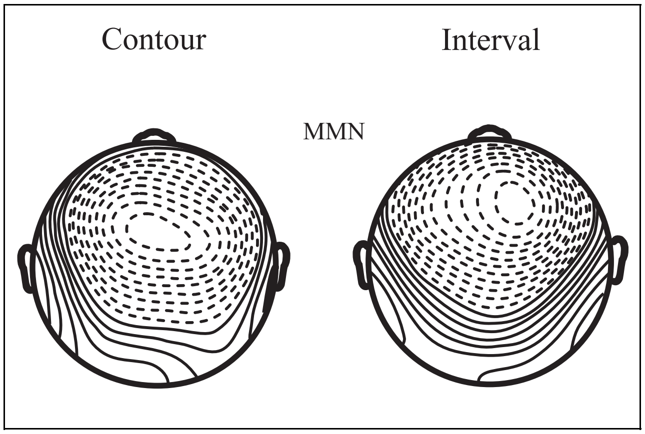
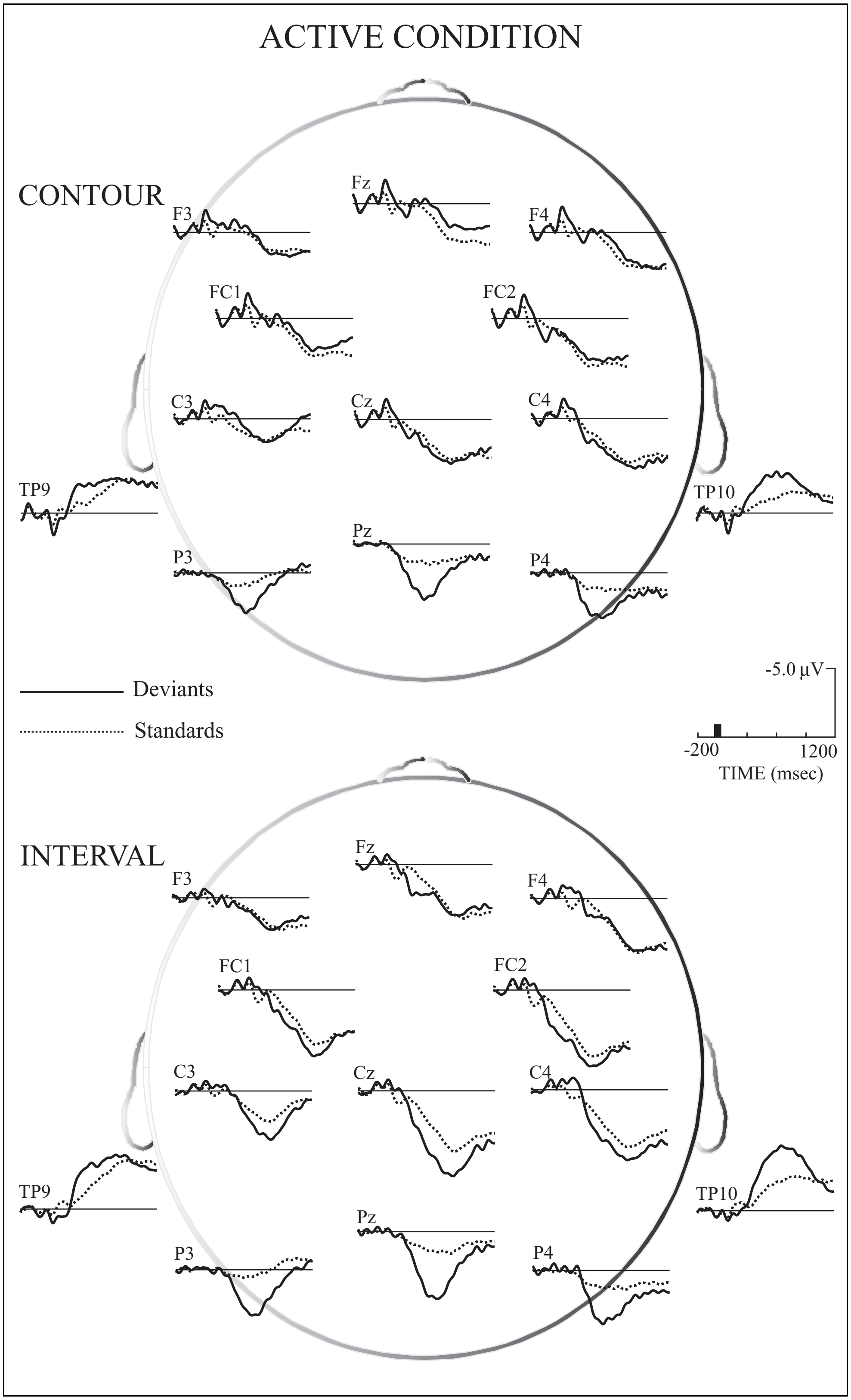


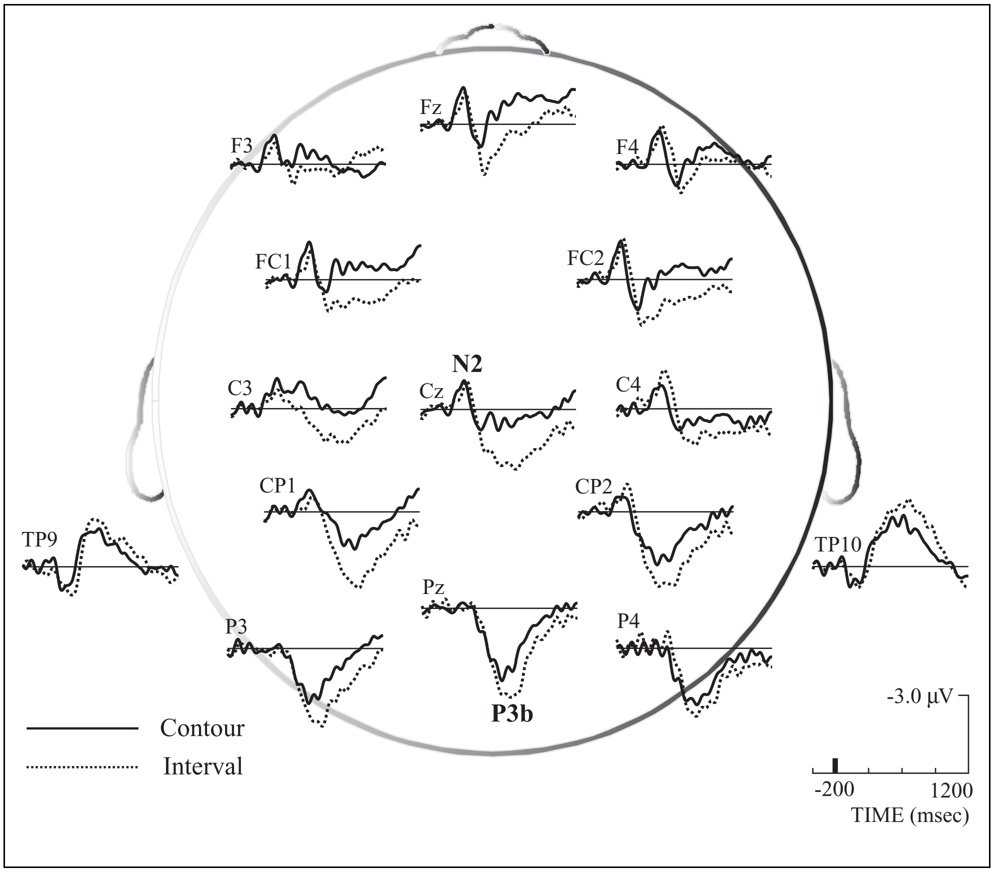
Figure 4. Isocontour voltage maps, where dashed lines represent negativity and solid lines positivity for the peak MMN during contour (150 msec) and interval (180 msec) tasks. Isocontour spacing is 0.1 µV.

Figure 5. Grand average standard (dashed line) and deviant (solid line) ERPs at selected electrode sites across the scalp for the active contour and interval tasks.



The ERPs to deviant stimuli were characterized by an N2 wave that was superimposed on the P2 deflection. The N2 wave was maximal over the fronto-central region so the following analyses were done at Fz. The N2 peaked earlier for the contour than for the interval task, $F(1,10) = 17.91$, $p < .002$. The mean amplitude, calculated in 40-msec windows around the grand average peaks for contour (170–210 msec) and interval

Figure 6. Difference waves (deviant − standard) for the contour (solid line) and interval (dashed line) tasks during active listening.



(195–235 msec) tasks, did not differ between tasks, but was larger for deviants than for standards, $F(1,10) = 17.59$, $p < .002$ (see Figures 5 and 6). There were no significant differences in scalp distribution for N2 components between the contour and interval tasks.

At the frontal sites, measured N2 waves in active tasks are thought to reflect superimposed MMN and N2b components, whereas the concurrent positivity at mastoid sites (TP9, TP10) is thought to be a more pure measure of MMN because the N2b does not reverse polarity here (Näätänen, 1992). An ANOVA with condition (passive, active) and task (contour, interval) as factors yielded an almost significant effect of condition, $F(1,10) = 4.79$, $p = .053$, on the amplitude of the N2/MMN peaks at Fz. On the other hand, an ANOVA with condition (passive, active), task (contour, interval), and electrode (TP9, TP10) as factors yielded no significant effects. Thus, no significant effect of listening condition on MMN was found, but there was an N2b effect that was modulated by attention.

Deviant stimuli also generated a frontal positivity peaking at about 350 msec poststimulus (Figures 5 and 6). At Fz, the frontal positivity peaked earlier for the contour task than for the interval task, $F(1,10) = 10.77$, $p < .008$, with means of 317 ($SD = 44.2$) and 379 msec ($SD = 57.7$), respectively. An ANOVA with task (contour, interval) and stimulus type (standard, deviant) as factors, and the mean amplitude in 40-msec windows around the peak as the dependent measure, revealed that deviants were indeed more positive than standards [main effect of stimulus type, $F(1,10) = 13.87$, $p < .004$], and that the interval stimuli were more positive than the contour stimuli [main effect of task, $F(1,10) = 5.36$, $p < .04$]. The Task × Stimulus Type interaction approached significance, $F(1,10) = 4.60$, $p < .06$, indicating that the frontal positivity tended to be bigger in the interval than in the contour task.

There were no significant topographical differences in the frontal positivity across the scalp between the contour and interval tasks according to an ANOVA with mean amplitude in a 40-msec window around the peak (i.e., 297–337 msec for contour and 359–399 msec for interval) as the dependent measure and task (contour, interval), hemisphere (left, right), and electrode (F3/4, F7/8, AF3/4, FC1/2) as factors (Figure 7, upper panel). The frontal positivity was centered on the right side for both contour and interval tasks, however, as indicated by a significant effect of hemisphere, $F(1,10) = 5.31$, $p < .05$.

Deviant stimuli generated a large P3b wave maximal over the posterior regions (Figures 5 and 6). Although the P3b at Pz tended to be earlier in the contour (mean = 548 msec, $SD = 70.6$) than in the interval (mean = 612 msec, $SD = 107.7$) task, the large variance precluded this effect from reaching significance. Using the mean in

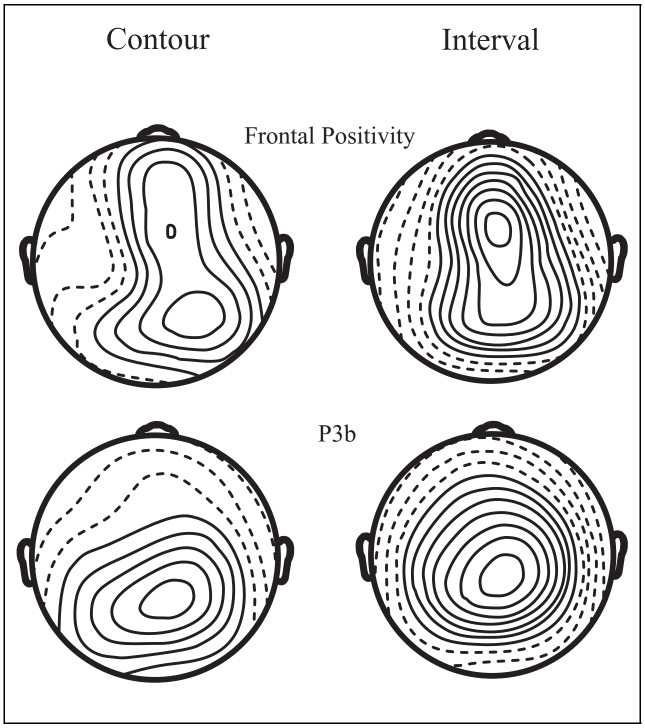


Figure 7. Isocontour voltage maps, where dashed lines represent negativity and solid lines positivity, for frontal positivity (isocontour spacing of 0.3 μV) and P3b (isocontour spacing of 0.8 μV), at the peak of each component (contour and interval latencies are 318 and 379 msec for frontal positivity and 547 and 613 msec for P3b).

a 100-msec windows centered at the peak, an ANOVA with task (contour, interval) and stimulus type (standard, deviant) as factors revealed that deviants were significantly larger than standards, $F(1,10) = 14.08$, $p < .004$, but that there was no difference in P3b amplitude between the contour and interval tasks.

Figure 7, lower panel, shows the P3b scalp distribution. ANOVAs using all electrodes as well as analyses using only midline and only lateral line electrodes revealed no significant differences in topography between the contour and interval tasks.

DISCUSSION

Changes in both contour and interval were processed automatically in the auditory cortices of nonmusicians in the absence of absolute frequency information, as revealed by the presence of MMN. Contour processing is important in both the music and the speech domains (Patel et al., 1998), so it is not very surprising that there are automatic mechanisms for its extraction. The present finding extends previous reports of MMN for contour changes in two-tone sequences (Pääviläinen et al., 1998; Tervaniemi et al., 1994; Säärinen et al., 1992) to multitone sequences. Precise interval processing, on the other hand, is specific to the musical system and is greatly affected by musical training (Patel et al., 1998; Peretz & Morais, 1988; Bever & Chiarello, 1974). Thus, the existence of automatic interval extraction mechanisms in musically untrained listeners suggests that musical information is important to the brain; otherwise, there would be no need for the automatic extraction of such detailed information about musical pitch patterns. This finding is new and indicates that not only does the auditory cortex encode sound features (pitch, duration, loudness, location, timbre), sequential pattern information, and abstract contour information, but it also encodes the exact pitch distances between tones in the absence of absolute pitch information.

In general, it might be expected that the magnitude of the MMN should reflect the magnitude of the deviation. Interestingly, there were no significant differences between contour and interval deviants in this regard, suggesting that interval changes are just as salient as contour changes at this level of processing. There were, however, speed-of-processing differences, with earlier MMN for contour than for interval changes, suggesting that more time is needed to extract interval than contour information. Within interval processing there were no significant differences in the magnitude of the MMN for the larger whole tone over the smaller semitone differences. This could potentially reflect the interaction of two forces: Because the whole tone difference is larger than the semitone difference, larger MMN might be expected in the whole tone case; however, the semitone difference might be more salient because it goes outside the key of the melody whereas the whole tone difference does not, leading to the expectation for larger MMN in the semitone case. In terms of speed of processing, the size of the interval change appears to be most important because the larger whole tone changes generated earlier MMN than the smaller semitone changes. It would be interesting to examine these issues in musicians, for whom musical key relations are likely to be more salient.

No evidence of attentional modulation of the MMN was found for either contour or interval processing. However, it could be argued that the passive task (reading a book) was not sufficiently distracting to elicit a complete lack of attention to the stimuli. It is possible that with a more demanding distracter task, the effects of attention on MMN might have emerged (Woldorff, Hillyard, Gallen, Hampson, & Bloom, 1998; Alain & Woods, 1997). In any case, the effects of controlled processing on MMN for melodic processing are small if they exist at all. On the other hand, the effect of controlled processing on both the frontal positivity and the P3b was profound—these components were completely absent in the passive tasks.

Changes in both contour and interval produced a frontal right-sided positivity around 350 msec after stimulus onset, consistent with the findings of Trainor et al. (1999) and Janata (1995). This component was present, however, only in the active and not in the passive condition. It is unlikely that this frontal positivity represents the same processes as those of the P3a that have been described in the literature. As discussed in the Introduction, P3as are typically elicited either by occasional salient stimuli that occur in an unattended channel (e.g., Escera et al., 1998; Alho et al., 1997, 1998; Squires et al., 1975) or by occasional salient stimuli in an attended channel that are to be ignored (e.g., Comerchero & Polich, 1998; Katayama & Polich, 1998; Holdstock & Rugg, 1993; Holdstock & Rugg, 1995; Knight, 1984). The frontal positivity in the present study occurred only in an attended channel and not in an unattended channel, and it occurred to deviants that were targets.

There are likely several generators of P3a waveforms, including the frontal, temporoparietal, and hippocampal regions (e.g., Halgren, Marinkovic, & Chauvel, 1998; Chao & Knight, 1996; Alain, Richer, Achim, & Saint-Hilaire, 1989; Knight, Scabini, Woods, & Clayworth, 1989; Knight, 1984) and one recent ERP study has separated two P3a components, a centrally dominant component peaking at 230 msec, and a right frontally dominant component peaking at 315 msec (Escera et al., 1998). Escera et al. (1998) suggest that the later component is generated primarily in the right frontal areas and reflects the actual orienting of attention whereas the earlier component reflects the capture of attention. It is possible that the right-sided frontal positivity observed in the present study reflects the actual orienting of attention. In this case, it would seem that musical stimuli are particularly powerful in their ability to engage the attentional system. Further research will have to address whether the frontal positivities observed in the present study are specific to musical processing, specific to complex pattern processing, or are simply produced in forced choice tasks with complex stimuli.

Some researchers have argued that contour and interval information are processed separately in the brain, perhaps even in different hemispheres (e.g., Liegeois-Chauvel et al., 1998; Peretz & Morais, 1987; Peretz et al., 1987; Peretz, 1990; Peretz & Babaie, 1992; Edworthy, 1985; Dowling, 1978, 1982; Bever & Chiarello, 1974). However, using ERPs as the measure, we found no significant topographical differences in MMN, frontal positivity, or P3b when participants processed contour versus interval information (see also Schiavetto et al., 1999; Trainor et al., 1999). It is possible that ERP measures are simply not sensitive enough to pick up small differences in the locations of the brain activity. Indeed, the head maps of Figure 5 suggest a more right-sided focus for interval than for contour MMN. However, the lack of significance suggests that differences in the location of the underlying generators, if they exist, are likely to be small and may vary considerably from person to person. The results do appear to be inconsistent with the exclusive use of different hemispheres to perform contour and interval processing.

The results of the present study show that both pitch contour and music-specific pitch interval information are processed automatically in nonmusicians. Thus we have discovered a new type of information, relative pitch distance or pitch interval, that elicits MMN. In other words, although there are tonotopic (absolute) pitch representations in the auditory cortex, the present results imply that there are also cortical circuits encoding interval information independent of the absolute pitch information. Because interval information is specific to musical processing, the present results imply that the auditory system is set up to extract music-specific melodic information.

METHODS

Participants

Fifteen nonmusically trained adults participated in the study but four were excluded from the data analysis (one participant was unavailable for the interval portion of the study and three responded correctly to less than 50% of deviants). The 11 remaining subjects (5 men, 6 women) ranged in age from 21 to 42 years (mean = 28.9 years). All participants had no more than 4 years of musical training (mean = 1.36 years; range = 0–4) and none had perfect pitch. For those subjects who did have some musical training, an average of 11.4 years (range 8–14 years) had passed since training stopped. All participants were right-handed and reported normal hearing.

Stimuli, Apparatus, and Procedure

In both the contour and the interval tasks, there were standard and oddball sets of melodies. Each melody consisted of five notes. Each note was a digitally recorded file created with the Korg MIDI Tonefile 01R/W using piano timbre and sampled at 44.1 kHz. The appropriate five notes for each melody were played in succession, with note-to-note onsets of 300 msec for a total melody length of 1,500 msec. Stimuli were presented with a 16-bit Tucker Davis System and TDH 50P headphones at about 75 dB SPL.

In the contour task, all seven standard melodies were ascending in pitch, but had different starting notes and contained different intervals between notes (see Figure 1). For each standard melody, an oddball melody was created in which the last note was changed to form a descending interval. In other words, the contour and interval information was identical between standard and deviant melodies up to the last note. In the interval task, the standard set consisted of one melody (the first five notes of the major scale) that was transposed to the 12 major keys on different trials. In order to maintain a sense of Western tonality, on successive trials, the transposition was either by a perfect fifth (seven semitones) or a perfect fourth (five semitones). There were two oddball melodies for each transposition of the standard melody, one in which the final note was raised by a tone (and thus stayed within the key of the melody) and one in which it was lowered by a semitone (and thus went outside the key of the melody). Again, the contour and interval information was identical between standard and deviant melodies up to the last note.

For both contour and interval tasks, standard and deviant melodies were played on 80% and 20% of trials, respectively (Figure 1). The order of trials was pseudorandom with the constraints that at least two standard trials occurred between each oddball trial, and that the same melody did not occur twice in succession. Melodies were separated by 2000 msec.

All participants completed a passive and an active listening task for both the contour and interval tasks; half participated in the contour task first and half in the interval task first, and within those groups half were presented with the passive versions first and half the active versions first. In the passive listening task, the participants read a book of their choice and ignored the stimuli. In the active listening task, the participants were required on each trial to make a response as to whether the melody was from the standard or oddball set by pressing the number "1" or "2" on the number pad of the keyboard with their right hand. No feedback was provided on their performance.

Electrophysiological Recording and Analysis

The electroencephalogram was recorded from an array of 47 electrodes including those from the standard 10–20 placement. Vertical and horizontal eye movements were recorded with electrodes at the outer canthi and at the superior and inferior orbit. Electrophysiological signals were digitized continuously (bandpass 0.05–50 Hz; 250-Hz sampling rate) via NeuroScan SynAmps and stored for offline analysis. During the recording, all electrodes were referenced to Cz; for data analysis, they were re-referenced to an average reference and the electrode Cz was reinstated.

The analysis epoch included 200 msec of baseline activity before the onset of the final melody note of the sequence and 1,200 msec of poststimulus activity. Trials contaminated by excessive peak-to-peak deflection (± 150 μV) at the channels not adjacent to the eyes were automatically rejected before averaging. The ERPs were then averaged separately for each site, stimulus type, and listening task. ERPs were digitally lowpass-filtered to attenuate frequencies above 32 Hz.

Prior to the experiment, a set of ocular calibration signals was obtained from the participant. From this set, averaged ERPs were calculated for vertical and horizontal eye movements as well as for eyeblinks. Using principal component analysis, a set of components that best explained the eye movements was extracted using brain electrical source analysis software. The ocular source components were then subtracted from the experimental ERPs to minimize ocular contamination (Berg & Scherg, 1994; Lins, Picton, Berg, & Scherg, 1993).

ERP components were quantified by computing mean values in selected latency regions, relative to the mean amplitude of the 200-msec prestimulus activity. Scalp topographies using 40 electrodes (omitting the periocular electrodes) were statistically analyzed after scaling the amplitudes to eliminate amplitude differences between tasks (McCarthy & Wood, 1985). All measurements were subjected to ANOVAs with repeated measures. The original degrees of freedom for all analyses are reported throughout the article. Type I errors associated with inhomogeneity of variance were controlled by decreasing the degrees of freedom using the Greenhouse–Geisser epsilon, and the probability estimates are based on these reduced degrees of freedom.

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