

Research Report

Brains That Are out of Tune but in Time

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ABSTRACT—It is estimated that about 4% of the general population may have amusia (or tone deafness). Congenital amusia is a lifelong disability for processing music despite normal intellectual, memory, and language skills. Here we present evidence that the disorder stems from a deficit in fine-grained pitch perception. Amusic and control adults were presented with monotonic and isochronous sequences of five tones (i.e., constant pitch and intertone interval). They were required to detect when the fourth tone was displaced in pitch or time. All amusic participants were impaired in detecting the pitch changes, and showed no sign of improvement with practice. In contrast, they detected time changes as well as control adults and exhibited similar improvements with practice. Thus, the degraded pitch perception seen in the amusic individuals cannot be ascribed to nonspecific problems with the task or to poor hearing in general. Rather, the data point to the presence of a congenital neural anomaly that selectively impairs pitch processing.

Humans appear to be born musical. Before 1 year of age, infants display remarkable perceptual abilities that are similar, in many respects, to those of adults. In particular, infants show enhanced processing for scales with unequal pitch steps (Trehub, Schellenberg, & Kamenetsky, 1999) and for regular rhythms (e.g., Bergeson, 2002). These initial preferences for encoding pitch along musical scales and for ascribing a regular pulse to incoming events are essential to the hierarchical organization of music. This type of organization facilitates music processing by creating expectancies and feelings of surprise or satisfaction. The fact that these skills appear precociously, well before they have obvious utility, is consistent with the proposal of music-specific predispositions (Trehub, 2001).

Some individuals appear to lack such predispositions for music. Their musical failure cannot be explained by low intelligence nor environmental circumstances (e.g., hearing impairment, lack of stimulation). For example, Che Guevara (the highly educated revolutionary) and Milton Friedman (Nobel Prize in Economics) reported lifelong musical handicaps despite having taken music lessons in

childhood (Friedman, 1998; Taibo, 1996). The prevalence of this disorder, which we term *congenital amusia* (Peretz et al., 2002), has been estimated at about 4% in the United Kingdom (Kalmus & Fry, 1980) and about 5% in the United States (D. Drayna, personal communication, December 10, 2002). However, these estimates are based on performance on a single measure of musical ability, which may have both poor validity and poor reliability. This may explain why most researchers and educators do not consider amusics as genuine anomalies, but rather as “dropouts” of music-education systems that favor the musical elite (Kazez, 1985).

Recent evidence suggests that congenital amusia is a real disorder (Ayotte, Peretz, & Hyde, 2002; Peretz et al., 2002). According to a basic neuropsychological principle, a slight but congenital neural deviation may produce selective learning deficits. Thus, in a previous study (Ayotte et al., 2002), we searched for individuals with lifelong musical difficulties in order to study them in detail. From a large pool of 45 volunteers with confirmed musical disorders on objective testing, we selected the most clear-cut 11 cases and were able to document, across multiple tests, that their deficit in discriminating and memorizing music was a genuine learning disability. Their music disorder was remarkably selective. Their language skills, including recognition of song lyrics and of speech intonation, were intact. Moreover, their processing of rhythm was much less affected than their processing of pitch. Specifically, the only test on which all 11 amusic participants failed to obtain normal scores was a pitch-based test, similar to that used in the large prevalence surveys mentioned in the previous paragraph. The test required listeners to detect the presence of an anomalous note (i.e., played on a pitch that is out of scale) in conventional melodies. Amusics seem to lack the musical predisposition for encoding pitch in terms of musical scales.

Nonetheless, the musical deficiency might arise from a more elemental defect. This hypothesis was suggested by the discovery of a deficit in basic pitch discrimination in our first documented case of congenital amusia, Monica (Peretz et al., 2002). Monica could barely detect a rising pitch change as large as 2 semitones. The semitone is the smallest pitch distance represented by two adjacent keys on a keyboard and is well above the limit of normal pitch acuity, which is on the order of a quarter of a semitone (e.g., Olsho, Schoon, Sakai, Turpin, & Sperduto, 1982). Moreover, Monica could barely perceive falling pitch changes across a wide range of pitch distances. This peculiar and systematic defect points to the presence of an aberrant pitch perception system.

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The presence of an inborn and basic defect in pitch perception may well account for the emergence of a lifelong musical impairment. Poor pitch perception is likely to prevent the normal internalization of musical scales that have steps of 1 or 2 semitones between consecutive notes. Most Western melodies are constructed with small pitch distances between consecutive tones; 70% of these distances are 0 (repeated pitches), 1, or 2 semitones in size (Vos & Troost, 1989). Similar distributions of pitch distances are observed across musical styles and cultures (Dowling & Harwood, 1986). In short, a perceptual system that is unable to detect small pitch changes is likely to miss an essential part of musical structure.

The goal of the present study was to assess the generality of this account. We tested a group of 10 congenital amusic individuals and matched control adults in tasks that required basic pitch and temporal discrimination. The participants heard *standard* sequences of five piano tones presented monotonically (constant pitch) and isochronously (constant intertone interval), as well as *comparison* sequences in which the fourth tone was displaced in pitch or time. Their task was to detect a change in the fourth tone of a sequence. We expected amusic individuals to experience greater difficulties on the pitch dimension than on the time dimension.

METHOD

Participants

The amusic group consisted of 8 adults who had participated in a previous study (Ayotte et al., 2002) and 2 new volunteers. As shown in Table 1, there was a high proportion of aged female participants, as is generally the case in educated volunteers. Each amusic individual was matched in age, gender, education, and handedness to a normal control participant (4 from Ayotte et al., 2002, and 6 new recruits) with no formal musical education. None of the participants had any previous neurological or psychiatric history.

Objective testing confirmed the presence of a musical deficiency in the amusic participants, who scored significantly below the matched control participants in two series of tests taken from the Montreal

Battery of Evaluation of Amusia (MBEA; Peretz, Champod, & Hyde, 2003). The battery involves six tests; average results of four are presented in Table 1. Three of these tests assess the ability to discriminate changes in melody (by pitch contour, scale, and interval size) and one assesses rhythmic discrimination (by temporal grouping). The melodic and the rhythmic tests all use a same/different discrimination task and the same set of novel but conventional-sounding music. Examination of individual data indicated that each amusic participant was impaired in the melodic tests, whereas about half of these participants showed normal performance in the rhythmic test. To illustrate the domain-specificity of their disorder, Table 1 also presents scores obtained on tests of recognition of familiar spoken lyrics and of the corresponding song tunes (without lyrics). Further details about these tests can be found in Ayotte et al. (2002).

Stimuli, Apparatus, and Procedure

Stimuli consisted of 21 different sequences, each containing five successive tones. In the standard sequence, all tones were 100 ms long, played at the pitch level of C6 (1047 Hz), and synthesized with a piano timbre (on a Roland SC 50 sound canvas; Roland Corporation, Los Angeles, California); the intertone interval (ITI; onset to onset) was 350 ms. In the comparison sequences, the fourth tone was altered. In the 10 pitch-altered sequences, the fourth tone was displaced by one of five pitch distances upward or downward from C6; the five pitch distances used ranged from 25 to 300 cents (100 cents = 1 semitone). In the 10 time-altered sequences, the fourth tone was displaced by one of five temporal increments earlier or later than its isochronous position; the five temporal increments used ranged from 8 to 16% of the ITI.

Participants were tested individually, with separate sessions for the pitch and time tasks. In both tasks, they were asked to press a “yes” button when they detected a change and a “no” button when they were unable to detect a change. Trials were randomized, and half contained no change (i.e., the standard monotonic, isochronous sequence), but participants were informed about the nature of the possible change and the location where it could occur. They also received 40 practice trials with feedback after each trial. Each test session comprised 360

TABLE 1
Characteristics of the Participants and Their Mean Percentage Correct on Key Musical Tests

Measure	Group		<i>p</i> ^b
	Amusic ^a (<i>n</i> = 10)	Control (<i>n</i> = 10)	
Demographic characteristics			
Age (years)	57 (1.6)	58 (1.7)	n.s.
Gender	3 male, 7 female	3 male, 7 female	—
Education (years)	15 (0.6)	17 (0.7)	n.s.
Musical discrimination			
Melodic tests (MBEA)	59.8 (2.3)	88.1 (2.9)	<.001
Rhythmic test (MBEA)	71.9 (4.9)	90.4 (3.6)	<.05
Song memory (recognition)			
Melodies	63.1 (3.5)	84.8 ^c (2.2)	<.001
Lyrics	90.5 (1.6)	88.0 ^c (1.7)	n.s.

Note. Standard deviations are in parentheses. MBEA = Montreal Battery of Evaluation of Amusia (Peretz, Champod, & Hyde, 2003).

^aIncluded subjects A2, A3, A4, A7, A8, A9, A10, and A11 from Ayotte, Peretz, and Hyde (2002). ^bSignificance levels of *t* tests comparing the two groups. ^cData from 20 control participants in Ayotte et al. (2002).

sequences (180 standard sequences, 18 of each of 10 altered sequences). So that we could assess for a possible learning effect, 8 amusic and 6 control participants were presented with an additional series of 240 trials in the pitch task.

The stimuli were presented bilaterally through Sennheiser HD450 headphones in a quiet room, at an intensity level of 70 dB SPL(A).

RESULTS

The percentage of hits (corresponding to a “yes” response when there was a change) minus false alarms (i.e., a “yes” response when there was no change) was computed for each participant as a function of the type, direction, and size of change.

A 2 (group) × 2 (direction) × 5 (distance) mixed-design analysis of variance (ANOVA) was computed on the data obtained in the pitch task. It revealed a highly significant interaction between group and pitch distance, $F(4, 72) = 95.4, p < .0001$; no main effect of pitch direction; and no interactions involving pitch direction ($F < 1$). Because pitch direction did not influence performance, the scores presented in Figure 1 were averaged for upward and downward pitch changes. As the figure shows, the amusic group detected pitch changes of 200 cents and above as well as the control group, but exhibited difficulties at smaller pitch distances. They performed below normal control participants at the finest pitch distances of 25 and 50

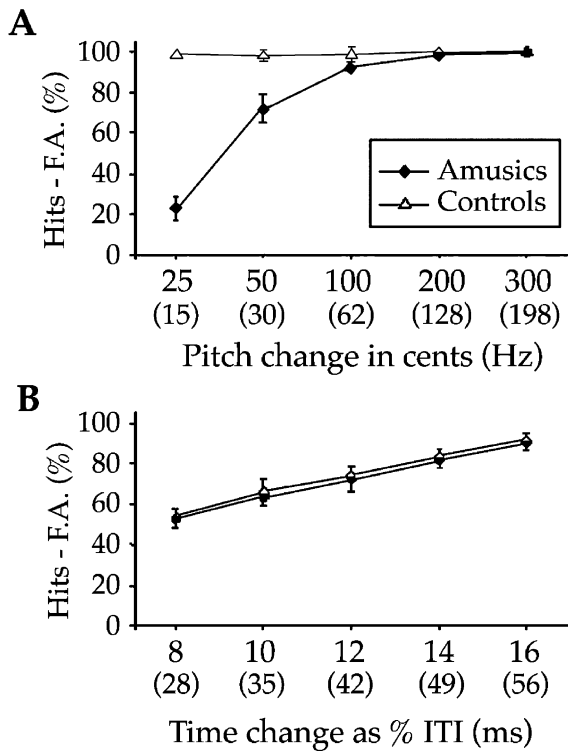


Fig. 1. Performance of the amusic and control groups in the pitch (a) and time (b) discrimination tasks, as a function of change in pitch and intertone interval (ITI), respectively. Performance is expressed as the mean percentage of hits minus false alarms (F.A.) for each group of participants. Error bars represent standard errors.

cents, as well as at the most musically relevant pitch distance of 100 cents, $t(18) = 2.32, p < .05$, for the latter distance. Although the pitch impairment was observed in each amusic individual, control participants obtained perfect scores over all pitch distances.

In contrast, in the time task, the amusics’ performance matched that of the normal control participants, even at subtle time differences (Fig. 1b). The ANOVA revealed no group effect, $F(1, 18) = 2.9, p > .10$, and no significant interactions with temporal distance ($F < 1$) or time direction (early vs. late; $F < 1$).

As shown in Figure 2, the amusic participants demonstrated no clear improvement over blocks (each comprising 120 trials) in the pitch task. In contrast, they seemed to benefit from prior experience as much as control participants did in the time task. The data obtained in the first three blocks of trials were submitted to an overall mixed-design ANOVA with group, task, and block as factors. The analysis

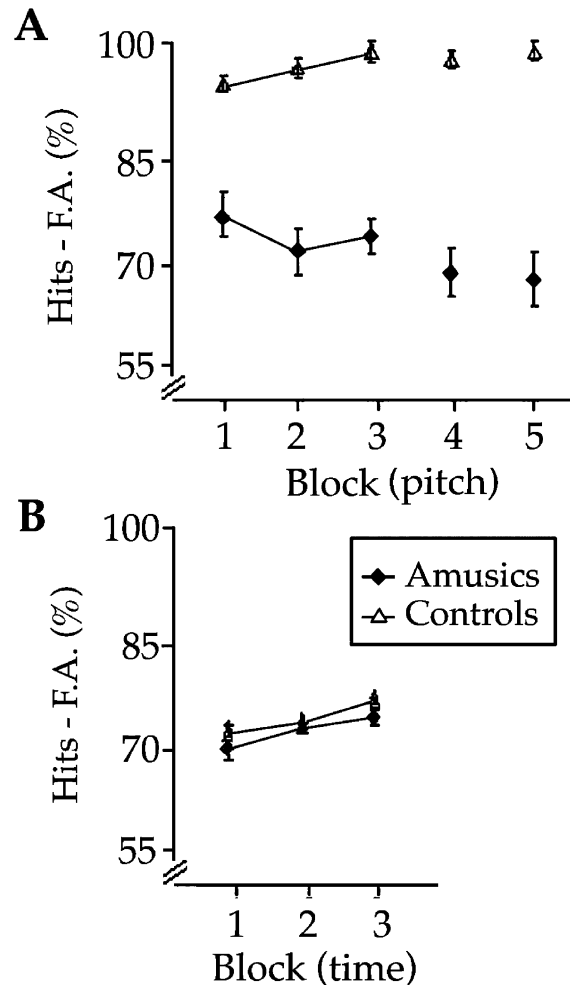


Fig. 2. Performance of the amusic and control groups in the pitch (a) and time (b) discrimination tasks as a function of block of 120 trials. Performance is expressed as the mean percentage of hits minus false alarms (F.A.) for each group of participants. Error bars represent standard errors. Three blocks of each test were presented to all participants; 8 amusic and 6 control participants were tested in two additional blocks of the pitch task.

revealed a significant interaction of the three factors, $F(2, 36) = 9.6$, $p < .001$. This interaction reflected the fact that only for the amusic participants in the pitch task did performance decline rather than improve over blocks of trials. The decline was significant, $F(2, 18) = 4.3$, $p < .03$. Performance significantly improved with practice in all other conditions: $F(2, 18) = 89.56$, $p < .001$, for amusics in the time task and $F(2, 18) = 4.3$ and 10.77 , $p < .03$, for control participants in the pitch and time tasks, respectively.

DISCUSSION

The results confirm the presence of a basic pitch defect in individuals with congenital amusia. Amusics have difficulty detecting changes in pitch that are smaller than 2 semitones (200 cents), whereas normal acuity is at least four times more fine grained. Lack of task understanding or auditory attention problems cannot account for the deficit because amusics were able to detect large pitch changes (> 2 semitones). The disorder also appears to be irreversible because practice impaired rather than facilitated pitch judgments. Finally, the disorder is specific to pitch processing. When the change to be detected involved a time deviation from synchrony, rather than a pitch deviation from monotony, amusics were as accurate as control participants. Their thresholds conformed to typical values, with 75% correct detection for an asynchrony of about 40 ms (Ehrlé, Samson, & Baulac, 2001; Hirsh, Monahan, Grant, & Singh, 1990; Schulze, 1989). Thus, the results provide compelling evidence that amusic adults have an impaired ability to discriminate pitch changes.

Although the pitch defect was less severe in the present sample of amusic participants than in our first case, Monica, it interfered with discrimination of the crucial musical interval of 1 semitone. Moreover, the problem was revealed in the context of a single repeating tone. When additional uncertainty is added—as in a musical context—the same defect is likely to be greatly amplified. Given that amusics are probably born with this deficit, they likely never assimilate the structure of musical scales nor acquire the sophisticated tonal knowledge that every normally developing individual builds on scales, albeit implicitly (Tillmann, Bharucha, & Bigand, 2000).

The importance of pitch for the musical domain is obvious. However, pitch also contributes to speech communication. Yet amusic individuals have no problem detecting pitch changes in speech intonation (Ayotte et al., 2002). This is because pitch variations in speech are very coarse compared with those used in music. For example, the final pitch rise that signals a question is typically larger than 7 semitones in both French and English (e.g., Fitzsimons, Sheahan, & Staunton, 2001). Hence, a deficient pitch perception system may compromise music perception exclusively, not because it is specialized for that domain, but because music requirements are more fine grained.

Music is organized temporally as well as in pitch. As shown here, amusic individuals seem to be able to perceive a regular pulse just as normal individuals do. Thus, they should be able to keep time to music by tapping or dancing. However, most amusics report difficulties with these activities. Moreover, about half of them are impaired in rhythmic discrimination of musical excerpts. One possible explanation of these facts is that such an ensemble of musical deficits would be a cascade effect of a faulty pitch-processing system. In fact, in all previous tests that probed the ability to process temporal structure in a

musical context (Ayotte et al., 2002; Peretz et al., 2002), pitch variations were present. It is possible that pitch variations create noise in the processing system of amusic listeners, preventing them from extracting temporal structure and regularity reliably. As shown here, when no pitch variations are present in the auditory pattern, timing skills seem normal in amusics.

To conclude, congenital amusia is best understood as a developmental disorder that arises from failures to encode pitch with sufficient resolution to allow acquisition of core knowledge regarding the pitch structure of music. This conclusion implies that, initially, the disorder is not specific to music, but rather is related to a more general, psychoacoustic difficulty in fine pitch resolution. Hence, one may consider congenital amusia as a mirror image of some developmental disorders of language. Indeed, certain language-specific disorders seem to result from a difficulty hearing fine acoustic temporal variations (e.g., Tallal, Miller, & Fitch, 1993). From this perspective, pitch might be to music what time is to speech (Zatorre, Belin, & Penhune, 2002).

Acknowledgments—This work was supported by a grant from the Canadian Institutes of Health Research to I.P. and by a postgraduate scholarship from the Canadian Fonds de la Recherche en Santé du Québec to K.L.H. We thank our subjects for their continued cooperation and Robert Zatorre, Kate Stevens, and Glenn Schellenberg for insightful comments on an earlier draft.

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(RECEIVED 2/28/03; REVISION ACCEPTED 5/2/03)