ON-LINE IDENTIFICATION OF CONGENITAL AMUSIA

ISABELLE PERETZ & NATHALIE GOSSELIN
Université de Montréal and International Laboratory for Brain, Music, and Sound Research (BRAMS), Montréal, Canada

BARBARA TILLMANN
Université Claude Bernard Lyon I and CNRS-UMR 5020, Lyon, France

LOLA L. CUDDY
Queen's University, Kingston, Canada

BENOÎT GAGNON
Université de Montréal and International Laboratory for Brain, Music, and Sound Research (BRAMS), Montréal, Canada

CHRISTOPHER G. TRIMMER
Queen's University, Kingston, Canada

SÉBASTIEN PAQUETTE & BERNARD BOUCHARD
Université de Montréal and International Laboratory for Brain, Music, and Sound Research (BRAMS), Montréal, Canada

RECENTLY, WE POINTED OUT THAT A SMALL number of individuals fail to acquire basic musical abilities, and that these deficiencies might have neuronal and genetic underpinnings. Such a musical disorder is now termed "congenital amusia," an umbrella term for lifelong musical disabilities that cannot be attributed to mental retardation, deafness, or lack of exposure. Congenital amusia is a condition that is estimated to affect 4% of the general population. Despite this relatively high prevalence, cases of congenital amusia have been difficult to identify. We present here a novel on-line test that can be used to identify such cases in 15 minutes, provided that the cohort of the participant is taken into account. The results also confirm that congenital amusia is typically expressed by a deficit in perceiving musical pitch but not musical time.

Received September 13, 2007, accepted December 21, 2007.

Key words: Congenital amusia, on-line test, tone deafness, pitch, time

NEUROLOGICALLY INTACT INDIVIDUALS APPEAR to be born musical. Before one year of age, the prelinguistic infant displays remarkable musical abilities that are similar, in many respects, to those of adults. Like mature listeners, infants display sensitivity to musical scales and meter (see Trehub & Hannon, 2006, for a recent review). With prolonged exposure to music, the infant becomes a musical expert, although s/he may be unaware of this. This expertise is best revealed by indirect methods that do not require judgments of the musical structure (Bigand & Poulin-Charronnat, 2006). These indirect tests reveal that nonmusicians and proficient musicians generate similar expectancies based on syntax-like relationships among tones, chords, and keys (Shepard & Jordan, 1984; Tillmann, Bharucha, & Bigand, 2000), perceive similar relations between theme and variations (Bigand, 1990), and can discriminate equally well the styles of classical music (Dalla Bella & Peretz, 2005). Mere exposure with an inclination for music is sufficient for ordinary adult listeners to appreciate music in a sophisticated manner, even in situations that are often regarded as only accessible to the musical elite.

Yet, a minority of individuals have never acquired this musical knowledge, in part or in totality. This condition has been variously termed note-deafness (Allen, 1878), tone deafness (Fry, 1948), tune deafness, dysmelodia (Kalmus & Fry, 1980), and more recently congenital amusia (Peretz, 2001a). The term *amusia* seems preferable to acknowledge the possibility that there may exist as many forms of *congenital amusias* as there are forms of *acquired amusias* following accidental brain damage (Stewart, von Kriegstein, Warren, & Griffiths, 2006). The term "congenital" only means present from birth; it defines a likely time period, not the etiology.

The etiology of congenital amusia is probably neurogenetic (e.g., Hyde, Zatorre, Griffiths, Lerch, & Peretz,

Music Perception VOLUME 25, ISSUE 4, PP. 331–343, ISSN 0730-7829, ELECTRONIC ISSN 1533-8312 DOI:10.1525/MP.2008.25.4.331

2006; Peretz, Cummings, & Dubé, 2007). As a consequence of neuro-genetic anomaly, affected individuals experience lifelong failures to acquire basic musical abilities, such as normal music perception and music recognition abilities, despite normal hearing, normal language, and normal intelligence (Ayotte, Peretz, & Hyde, 2002). For these individuals, listening to a musical performance is like listening to foreign speech (Allen, 1878). Congenital amusia appears to be not only specific to the musical domain, but also to be monosymptomatic (or nonsyndromic) because there is no concurrent neurodevelopmental disorder such as dyslexia, autism, or language impairment that is systematically associated (but see Douglas & Bilkey, 2007, for highlighting deficits in visuospatial abilities).

Amusic individuals appear to have a normal understanding of speech and prosody (but see Patel, Wong, Foxton, Lochy, & Peretz in this issue, for certain difficulties in prosody discrimination in a minority of amusics). They can recognize speakers by their voices and can identify all sorts of familiar environmental sounds such as animal cries. What distinguishes them from ordinary people is their inability to recognize a familiar tune without the aid of the lyrics, and their inability to detect when someone sings out-of-tune, including themselves (Peretz & Hyde, 2003). They also show little sensitivity to the presence of obvious dissonant chords in classical music (Ayotte, Peretz, & Hyde, 2002), a sensitivity that is normally present in infants (Zentner & Kagan, 1996). Most notably, amusics fail to detect out-of-key notes in conventional but unfamiliar melodies (Ayotte, Peretz, & Hyde, 2002; Hyde & Peretz, 2005; Peretz, Cummings, & Dubé, 2007). This behavioral failure is diagnostic since there is no overlap between the distributions of the scores of amusics and controls (Ayotte, Peretz, & Hyde, 2002; Hyde & Peretz, 2005). What amusics seem to be lacking is the (implicit) knowledge and procedures required for mapping pitches onto musical scales.

Supportive evidence for the notion that musical pitch processing is a good target for diagnosis comes from two earlier studies. In their pioneer study, Kalmus and Fry (1980) suggested that the detection of out-of-key pitches in melodies may be a discriminant factor. They administered a test to which they referred as the Distorted Tune Test (DTT) to 600 participants in the United Kingdom. Approximately 4% of participants performed as poorly as 20 adults who considered themselves to be amusic or were so considered by others. In a more recent study, the DTT was administered to twins (Drayna, Manichaikul, de Lange, Snieder, & Spector, 2001). Genetic model-fitting indicates that the influence of shared genes was more important than shared environments, with heritability of 70-80%. These findings suggest that 4% of the population may suffer from a genetically determined defect in perceiving musical pitch in melodies and that this disorder can be transmitted genetically. Recently, we found support for this notion. We observed that the musical pitch disorder was expressed in 39% of first-degree relatives in amusic families, whereas it was only present in 3% in control families. Thus, congenital amusia appears to be an heritable disorder (Peretz, Cummings, & Dubé, 2007).

In order to be able to identify cases of amusia in families, we designed an on-line auditory test that aims at uncovering a deficit in detecting an out-of-key pitch in a melodic context. This test is an improvement over previous versions that attempted to assess the same ability, including the DTT, in a number of aspects. First, and unlike the DTT, the on-line test uses unfamiliar melodies instead of popular tunes. This feature allows us to ascertain that a deficit is not related to a lack of appropriate exposure to the material. Second, and unlike the DTT, we added a control condition. The on-line control condition consists of presenting the same unfamiliar melodies, but with an off-beat change instead of pitch changes. Since amusics can detect such time irregularities as well as non-amusic individuals (Hyde & Peretz, 2004; Hyde & Peretz, 2005), this time condition allows us to discard general auditory deficiencies as the source of the pitch problem. In sum, the on-line test that we designed for identifying cases of congenital amusia presents a number of advantages over prior tests. Yet, we do not know how sensitive it is to detect the presence of amusia. The primary goal of the present study is to assess its diagnostic value.

The evaluation of the efficacy of this new on-line test for the identification of amusic cases is facilitated by the fact that we already have an adequate tool: the Montreal Battery of Evaluation of Amusia (the MBEA; Peretz, Champod, & Hyde, 2003). This battery involves six subtests evaluating music perception and memory and takes about two hours to complete. Congenital amusia is confirmed if the individual performs 2 standard deviations below the mean performance of musically intact controls on the MBEA. Furthermore, the MBEA is currently the primary tool that is used for the identification of cases with congenital amusia across laboratories (Cuddy, Balkwill, Peretz, & Holden, 2005; Douglas & Bilkey, 2007; Foxton, Dean, Gee, Peretz, & Griffiths, 2004; Patel, Foxton, & Griffiths, 2005; Sloboda, Wise, & Peretz, 2005). Therefore, the MBEA will serve here to both validate the adequacy of the on-line test as a diagnostic tool for amusia and to distinguish amusic from non-amusic individuals.

1. The On-line Test

The on-line auditory test includes 72 melodies derived from 12 stimuli taken from the MBEA (Peretz, Champod, & Hyde, 2003). The melodies are all constructed in a major mode according to Western tonal-harmonic conventions. They contain 9.6 successive tones, on average, and are computer generated at a tempo of 120 beats/min. The 12 melodies were modified so that the same critical tone was altered either in terms of pitch or time (see Figure 1). The tone to be changed always fell on the first downbeat in the third bar of the four-bar melody (hence, was metrically stressed) and was 500 ms long. The time change (Figure 1B) consisted of introducing a silence of 5/7 of the beat duration (i.e., 357 ms) prior to the critical tone, thereby locally disrupting the meter or introducing an off-beat tone, without changing anything else. In the pitch conditions, the change consisted of using either a tone that was mistuned by half a semitone, hence introducing a "sour" note, or a tone that was outside the key of the melody, hence introducing a "foreign" or "wrong" pitch in the musical context (Figure 1C and D). The melodies were presented with 10 different timbres (e.g., piano, saxophone, clarinet, recorder, harp, strings, guitar) to make the auditory test more interesting.

The stimuli and experimental set-up were presented using standard Web browser technologies (i.e., HTML, PHP, and Flash). The melodies were converted from files in WAV format to MP3 in order to guarantee optimal sound quality on different computer platforms and at different data transmission rates while keeping file sizes low. The stimuli and experimental set-up were generated using the open source LAME MP3 encoding package. The responses were automatically recorded and tabulated for further analysis using Microsoft Excel and DataFinder (Digimed Systems Inc., 2006).

Participants were invited to visit a nonpublic computer to log on to the on-line test. First, they had to give an access code, test their computer (download the Flash program if missing), and adjust the volume of the audio system to a comfortable level. Thus, there is no control or requirement regarding the appropriate loudness level or speakers quality. Next, the participant entered the web page containing the actual test and filled in a consent form.

Participants then were first tested with the "off-beat" condition followed by the "mistuned" condition and finally the "out-of-key" condition. In each condition, participants were presented with 24 melodies (12 containing no incongruity and 12 containing an incongruity) one at a time, in a random but fixed order. The task was to detect whether an incongruity occurred in each melody, by way of clicking a "yes" button whenever there was an anomaly, and a "no" button when there was none. Participants received 2 examples before each condition and were provided with feedback after these two trials only. The auditory test lasted 15 minutes. After the test, the participants completed

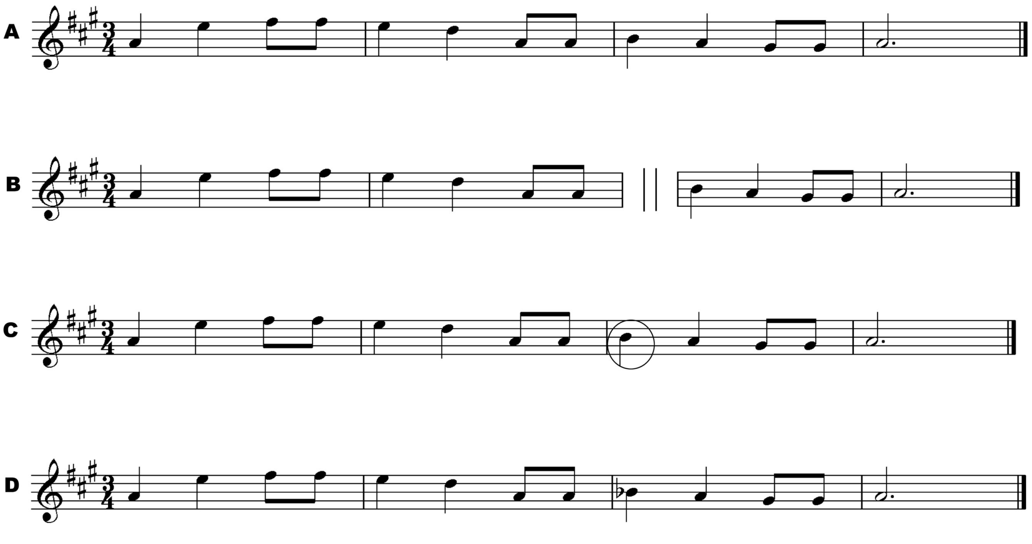

FIGURE 1. Example of melody with no incongruity (A), with a time incongruity (B: || refers to the silence of 5/7 of the beat duration), with a mistuned pitch incongruity (C: the circled note refers to the mistuned pitch), and with an out-of-key pitch incongruity (D).

TABLE 1. Characteristics of Tested Participants.

	Non-amusic *N* = 223	Amusic *N* = 28	Potential Amusic *N* = 46
Male/female	83/140	11/17	20/26
Mean age (range)	33.0 (14–84)	47.4 (18–68)	49.4 (16–73)
Mean education year (range)	16.3 (6–33)	17.4 (11–25)	16.0 (8–24)
Musical training level*	2.8 (1–5)	2.3 (1–5)	2.5 (1–5)
Unmusical by self-report	19.0%	88.9%	78.3%
Dyslexia	5.9%	7.4%	13.0%
Speech disorders	2.9%	3.7%	6.5%
Spatial orientation problems	4.9%	22.0%	10.9%
Problems in maths	7.3%	3.7%	13.0%
Attentional problems	8.3 %	0%	8.7%
Memory problems	2.9%	0%	13.0%

*1 = less than one year; 2 = 1-3 years; 3 = 4-6 years; 4 = 7-10 years; 5 = more than 10 years

101 questions about their personal history and musical background. At the end of the session, the participants obtained their test scores (see www.brams.umontreal.ca/amusia-demo for test examples and the full questionnaire). The whole procedure could be completed in 25 minutes.

2. Recruitment of Participants

Participants were selected either because they reported a musical problem or because they volunteered as non-amusic controls. Eight individuals were excluded because they also reported a trauma episode or a cerebrovascular accident. In line with our prior work (Peretz, Champod, & Hyde, 2003), 28 participants were considered as amusic because they obtained, on the MBEA administered in the laboratory, a composite test result below 2 *SD* from the global mean of 285 non-amusic individuals (the cut-off score corresponds to 75.9% of correct responses; the norms are available at www.brams.umontreal.ca/plab/publications/article/57#extras). There was a second group of 46 potential amusics who did not complete the full MBEA. These participants were considered as potentially amusic because they obtained a score below 22.4 (of 30 possible correct responses) on the scale subtest of the MBEA administered via Internet (22.4 corresponds to 2 *SD* below the mean of non-amusics; Peretz, Champod, & Hyde, 2003). The remaining 223 participants were considered non-amusic; 89 of them also completed the full MBEA in the laboratory.

The characteristics of the three groups of participants are presented in Table 1. As can be seen, 19% of the non-amusic participants self-declared as unmusical. This relatively high rate is similar to the rate of 17% self-reported "tone-deaf" in a sample of over 1500 students (Cuddy et al., 2005). Since most of the self-reported tone-deaf students tested by Cuddy and collaborators did not have low scores on the MBEA, the present rate of 19% can be considered as representative of the low esteem that members of the general population may have regarding their musical abilities. In contrast, most amusics are aware of their difficulties. As can be seen in Table 1, 89 and 78% of the confirmed and potential amusics self-declared as unmusical. However, self-evaluation is not sufficient for the diagnosis of amusia since 11-22% were unaware of a musical problem. Lack of previous musical exposure is not sufficient for diagnosis either since each group of participants reported, on average, one to three years of music lessons in a range of one to five years. Each groups also seemed to have a similar level education, with, on average, 16 years of general education. However, the potential amusics reported a higher percentage of learning disorders (47%), such as dyslexia, than the general population (22%), $\chi^2(1, N = 250) = 5.71$, $p < .05$.[1] The *confirmed* amusics did not report developmental disorders any more often than the non-amusic group with the notable exception of spatial orientation problems. Amusics reported two to four times more often spatial problems than non-amusics, $\chi^2(1, N = 232) = 8.10$, $p < .05$ (see Table 1). This observation is consistent with a recent study showing that potential amusics may have

---

[1] This difference appears due to a difference in recruitment between Lyon and Montreal. The French participants (45 potential amusics and 7 *confirmed* amusics) reported learning problems with much higher frequency (25/52) than Canadians (60/226).

visuo-spatial processing difficulties (Douglas & Bilkey, 2007). Nonetheless, there was no systematic association between amusia and any particular disorder. Therefore, congenital amusia can still be considered as a domain specific, nonsyndromic disorder.

3. Psychometric Properties of the On-line Test

The responses of the 223 non-amusic participants who completed the on-line test were analyzed in terms of raw scores (each condition comprised 24 trials) and, for comparison with the MBEA, percentages of correct responses. We also analyzed the results in terms of hits and false alarms, whereby a response was considered a hit when the participant detected an incongruity when there was one, and a false alarm when s/he detected an incongruity in a melody that contained no incongruity. Because the outcome was very similar with both types of measures, we report and analyze here the raw scores and percentages of correct responses only.

Sensitivity

The distribution of the on-line test scores of the 223 non-amusics averaged across the three conditions is presented in Figure 2 (scores are separated for the young and old participants, as explained later). As can be seen, the on-line global scores are close to a normal curve with a long lower tail and no perfect score. Thus, the on-line test appears sensitive to the extremes. While the scores in the off-beat condition appear normally distributed (Figure 2), it is not significantly so, $D(223) = 1.88$, $p < .005$ (Kolmogorov-Smirnov test). The results on both the mistuned and the out-of-key condition are skewed towards the higher scores. However, note that there is an interesting long lower tail of the distribution, particularly in the out-of-key condition.

Because the test is administered on-line, it might be more sensitive to participant characteristics than tests such as the DTT and MBEA, which are generally administered in the laboratory. To this aim, we examined whether gender, education, and age might influence the scores on the on-line test. Gender did not seem to matter. The mean percentage of correct responses obtained by the 140 women (87%) tested on-line did not differ from the scores obtained by the 83 men (86.8%), $F(1, 221) = 0.46$, *n.s.* General education did not appear to have an influence either. There was no correlation between years of education and performance on the on-line test, $r(220) = .12$, *n.s.* This is probably due to the fact that many participants (43%) had a university degree. In contrast, music training had a significant impact. Level of training (coded as 1 = less than one year, 2 = 1-3 years, 3 = 4-6 years, 4 = 7-10 years, and 5 = more than 10 years[2]) was highly correlated with the scores obtained on the on-line test, $r(203) = .37$, $p < .001$.[3] What is important to highlight here is that the younger participants had more music training. This cohort effect was supported by a negative correlation between the age of the participant and the level of music training, $r(203) = -.38$, $p < .001$.

We also reported such a cohort effect in the study of the amusic families (Peretz, Cummings, & Dubé, 2007). The generation of the amusic participants (mean age = 58) had less music training than their offspring (mean age = 31). Most (65/73) offspring had music lessons during childhood and 73% were still playing at the time of testing. Therefore, we examined here whether we could find the same pattern in the larger sample. The older generation (40 years and more) had also less musical experience. The large majority (77%, 61/79) had no music lessons or just the mandatory lessons in primary school. In contrast, the younger generation had, on average, 3-4 years of music lessons and 91% (137/151) reported that they were still playing or singing. As can be seen in Table 2 and in Figure 2, this cohort effect had an impact on on-line test performance. The older generation had lower scores than the younger generation in all but one condition; the interaction between Generation and Condition was significant, $F(2, 442) = 7.71$, $p < 0.001$. The older generation scored less well on the off-beat, $t(221) = 5.71$, $p < .001$, and the mistuned, $t(221) = 2.99$, $p < .005$, condition but performed as well on the out-of-key test, $t(221) = 0.54$, *n.s.*

This cohort effect is important to consider when determining a cut-off score for the identification of amusic cases. We used here the same criterion of 2 *SD* below the mean averaged across the three conditions (global score) as the on-line cut-off score below which an individual score will be indicative of amusia, as employed with the MBEA (Peretz, Champod, & Hyde, 2003). The cut-off scores correspond here to 73.7% and 70.1% for the young and older generation, respectively. These cut-off scores will be used when assessing the diagnostic value of the on-line test (in section 4 below).

---

[2] Level of training could not be refined further because participants had to select among these 5 categories (1= less than one year, 2 = 1-3 years, 3 = 4-6 years, 4 = 7-10 years or 5 = more than 10 years) instead of entering number of years.

[3] Degree of freedom may vary depending on the number of participants who responded to the corresponding question. Here, the *df* are 221 and not 223 because 2 participants did not respond to that question.

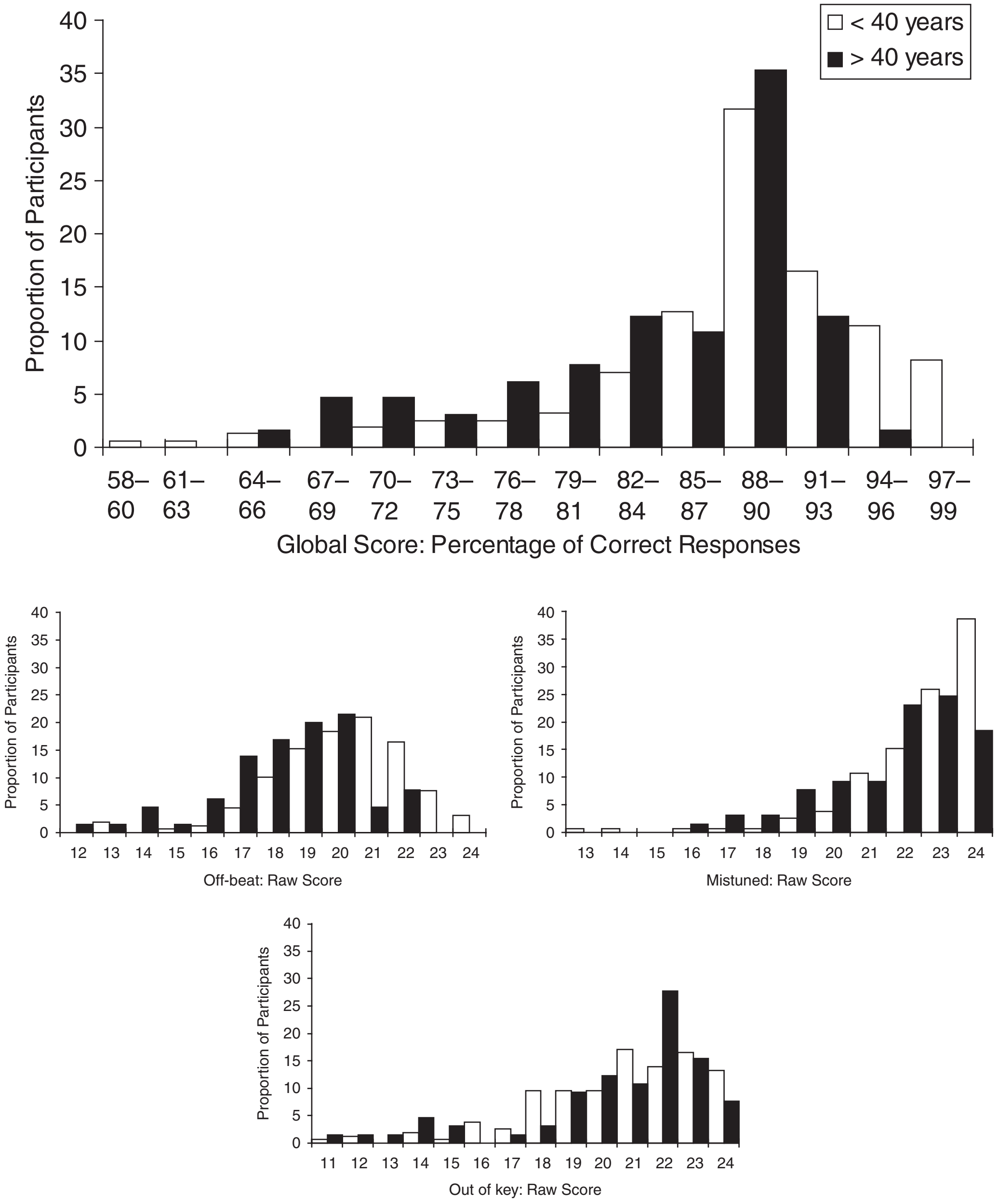

FIGURE 2. In the upper part, the distribution of the percentage of correct responses averaged across the three on-line conditions (global scores) obtained by the 223 non-amusic participants as a function of their cohort. Below are the distributions of raw scores obtained in each on-line condition obtained by the 223 non-amusic participants as a function of their cohort.

TABLE 2. Mean (*SD*) of Raw Scores and Mean Global Score Expressed in Percentage of Correct Responses Obtained in Each Generation for Each Condition.

Generation	Off-beat	Mistuned	Out-of-key	Global Score	Cut-off Score
Young (*N* = 158)	20.2 (2.1)	22.6 (1.8)	20.7 (2.7)	88.1% (7.2)	73.7%
Old (*N* = 65)	18.4 (2.2)	21.7 (2.0)	20.4 (3.1)	84.1% (7.0)	70.1%

Note: The young generation (< 40 years) had more musical experience than the older generation (> 40 years) and their cut-off scores differ accordingly.

It is noteworthy that among the 223 unselected participants who took the on-line test, 5.8% (4 and 9 participants from the old and young generation, respectively) scored below the cut off scores. Such a prevalence rate of amusia (6%) is similar to the British prevalence rate of 4% (Kalmus & Fry, 1980).

Validation with the MBEA

The validation of the on-line test as a tool for the evaluation of musical abilities in Western adults was assessed with the MBEA. As mentioned earlier, the MBEA is currently the most widely used test battery for the evaluation of amusia. Moreover, the MBEA provides an index of musical abilities that is normally distributed in the population and is reliable on test-retest. The MBEA comprises six tests, referred to as scale, contour, interval, rhythm, meter, and memory (see Peretz, Champod, & Hyde, 2003, for more detail). Each subtest comprises 30 trials and uses the same pool of 30 unfamiliar melodies that are written according to the rules of the Western system. Among the six tests used in the MBEA, two might tap the same cognitive ability as the on-line test. These are the scale test and the meter test. The scale test would be linked to the on-line out-of-key condition because both involve the insertion of an out-of-key note in a conventional melody. However, the MBEA tasks might be more demanding in terms of memory than the on-line version. For the scale test (as well as the contour, interval, and rhythm tests) the participant must remember a standard melody on each trial for comparison in a same-different classification task (note, however, that the out-of-key note stands out in a melodic context and thus might be detected without further demand on memory). The other MBEA test that might be related to the on-line test is the meter test, which requires participants to judge whether the melody is a march or waltz. In order to perform this meter task, one needs to find the beat as is the case for the on-line off-beat condition. Therefore, we expected to find a significant correlation between the MBEA and the on-line test overall, mostly due to the MBEA scale and meter tests and the out-of-scale and off-beat conditions of the on-line test.

Eighty-nine of the 223 non-amusic participants tested on-line also completed the MBEA in the laboratory. Their scores are presented in Figure 3. This non-amusic group obtained similar levels of performance on the on-line test and the MBEA, with 88.2% and 89.4% correct, respectively. The cohort effect was again present but limited to the on-line test; the Generation by Test interaction reached significance, $F(1, 115) = 7.17$, $p < 0.01$ (see Table 3). Moreover, the scores were positively correlated, $r(87) = .38$, $p < .001$. That is, overall, participants achieved similar levels of performance on the on-line test and the MBEA (see Figure 3). As expected, the on-line out-of-key condition correlated with the MBEA scale test, $r(87) = .24$, $p < .05$ (see Figure 3), and the interval test, $r(87) = .22$, $p < .05$, but not with the contour test, $r(87) = .13$, *n.s.* Similarly, the on-line off-beat condition correlated better with the MBEA meter test, $r(87) = .29$, $p < .01$ (see Figure 3), than with the rhythm test, $r(87) = .13$, *n.s.* Thus, the MBEA and the on-line test appear to tap, at least in part, a common pool of abilities, and the targeted pitch-related and time-related processes in particular.

TABLE 3. Mean Global Percentage of Correct Responses (*SD*) Obtained by the Young (<40 years) and *Old* (>40 years) Generations on the MBEA and the On-line Test.

Generation	MBEA	On-line
Young ($N = 64$)	89.9 (4.8)	89.8 (6.3)
Old ($N = 25$)	88.1 (4.9)	84.0 (7.9)

4. Diagnostic Value of the On-line Test

The main objective of the on-line test is to diagnose the presence of amusia. In order to determine the diagnostic value of the on-line test, we first consider here the performance on the on-line test of the 28 amusic cases whose diagnosis was confirmed with the MBEA (see Table 1 for their general characteristics). As can be seen in Table 4 and in Figure 3, amusics performed similarly on the on-line test and the MBEA tests, $r(26) = .71$, $p < .001$, with the most severe cases being the most impaired on both sets of tests. The ANOVA computed on the global scores confirmed that amusics performed below controls, $F(1, 54) = 115.51$, $p < 0.001$, while both groups obtained similar levels of performance on both sets of tests; the effect of test sets was not significant, $F(1, 54) = 1.45$. As expected and as found with non-amusics, performance on the out-of-key condition was correlated with the scores on the MBEA scale test, $r(26) = .42$, $p < .05$. Contrasting with non-amusics, performance on the out-of-key condition also correlated with the MBEA contour test, $r(26) = .51$, $p < .01$, and with the interval test, $r(26) = .46$, $p < .05$. There were also significant correlations between the scores in the mistuned condition and those of the MBEA scale test, $r(26) = .56$, $p < .005$, but not with the contour test, $r(26) = .28$, *n.s.*, and the

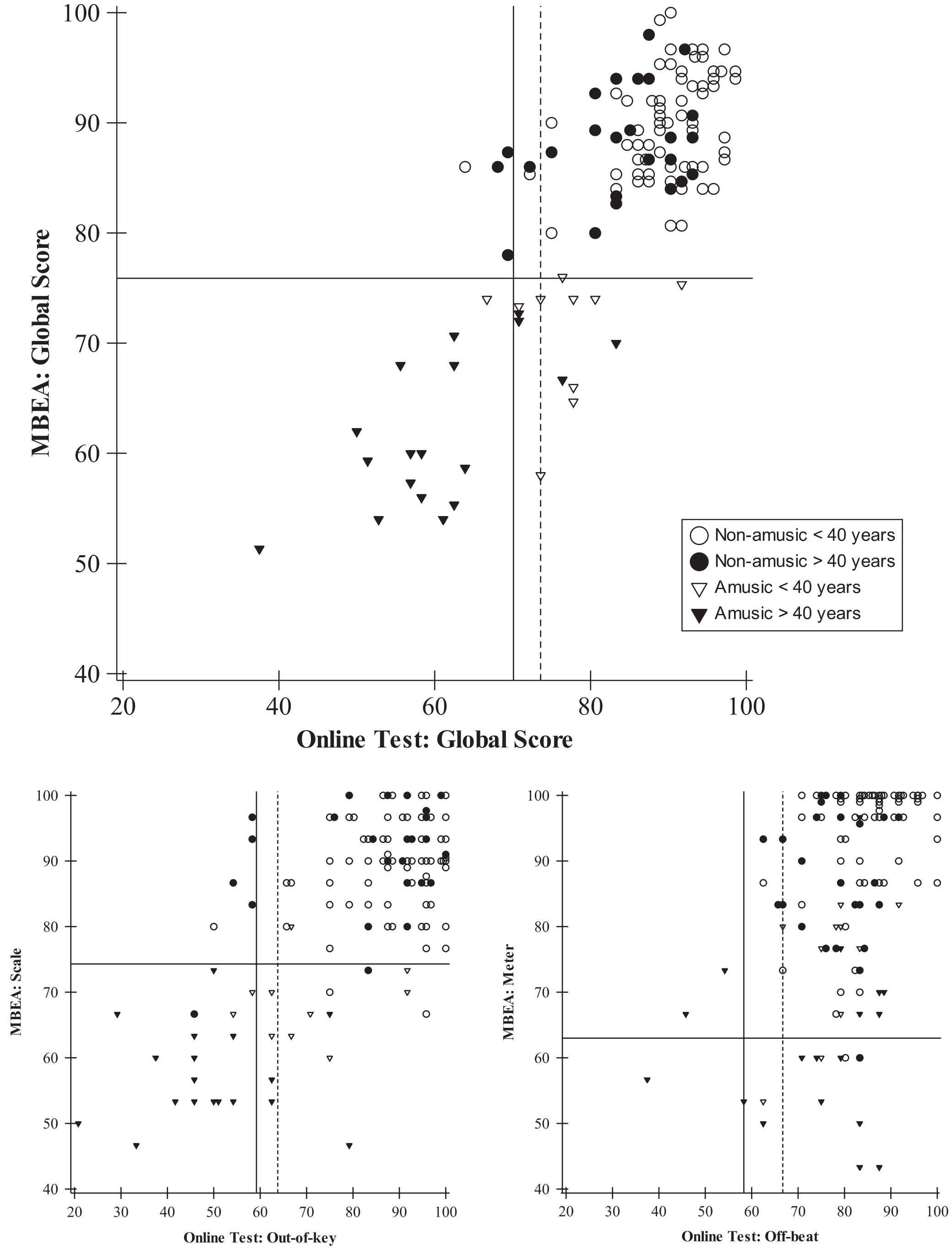

FIGURE 3. Global percentage of correct responses obtained by all participants on the on-line test as a function of their performance on the MBEA are presented in the upper part. The correlation between scores is relatively high, $r(115) = .82$, $p < .001$. Below is the percentage of correct responses for the on-line out-of-key condition as a function of performance on the MBEA scale test (left) and for the on-line off-beat condition as a function of performance on the MBEA meter test (right). Circles represent 89 non-amusic participants; white circles stand for participants less than 40-years-old and black circles for participants with more than 40 years of age. The 28 amusic cases are represented with triangles, the white ones representing the young generation and the black ones, the older generation. Cut-off scores are represented by a horizontal line for the MBEA and by vertical lines for the on-line test (the dotted line is for the young cohort).

TABLE 4. Mean Global Percentage of Correct Responses (*SD*) Obtained by the Amusics and Their Matched Controls on the MBEA and On-line Test.

	MBEA	On-line Test
Amusics (*N* = 28)	65.2 (7.8)	66.4 (12.0)
Controls (*N* = 28)	88.7 (4.7)	84.9 (7.1)

interval test, $r(26) = .36$, *n.s.* Thus, in amusics, the mistuned condition appears to tap into similar mechanisms as those involved in mapping pitch onto scale but less so in extracting pitch contour or interval sizes. Lastly, as found with non-amusics, the on-line off-beat condition was correlated with the MBEA meter test, $r(26) = .47$, $p < .05$, and not with the MBEA rhythm test, $r(26) = .21$, *n.s.* In other words, the degree of severity of musical impairments was captured by both sets of tests.

The performance of the 28 amusics in each condition of the on-line test is presented in Table 5 along with the data of the 46 potential amusics and their 74 matched controls. The latter were matched in age (mean = 47.9 years; range = 17-71), education (mean = 16.4; range = 10-25) and music training level (mean = 2.22; range = 1-5) to the amusics. As can be seen in Table 5 and as predicted, the amusics performed as controls in the off-beat condition and were impaired in the two pitch-based conditions. This was confirmed by an ANOVA considering the three groups (amusics, potential amusics, matched controls) as the between-subjects factor and the three on-line conditions (off-beat, mistuned, out-of-key) as the within-subjects factor, computed on the raw scores. The interaction between Group and Condition was highly significant, $F(4, 290) = 24.65$ $p < 0.001$. Amusics performed significantly lower than controls in both the mistuned and out-of-key conditions, $t(100) = 11.12$, $p < .001$, and $t(100) = 9.92$, $p < .001$, respectively, but not in the off-beat condition, $t(100) = 1.43$, *n.s.* As can be seen in Table 5, the pattern of results obtained by potential amusics is similar to the pattern seen in *confirmed* amusics. Potential amusics were also impaired as compared to controls in the mistuned and out-of-key conditions, $t(118) = 7.59$, $p < .001$, and $t(118) = 8.15$, $p < .001$, respectively. However, they performed significantly lower in the off-beat condition as well, $t(118) = 2.07$, $p < .05$. Thus, some potential amusics may suffer from general auditory problems. Nevertheless, the similarity of the outcome obtained in amusic participants confirmed with the full MBEA, and in potential amusics who were screened with the MBEA scale test, suggests that the scale test alone can be as adequate as the full MBEA to signal the presence of the same type of amusia.

TABLE 5. Mean Raw Scores (*SD*) Obtained by the Amusics (Confirmed by Scores below the MBEA Cut-off), Potential Amusics (as Diagnosed by MBEA Scale Scores < 22), and Matched Controls per On-line Condition.

	Off-beat	Mistuned	Out-of-key
Amusics (*N* = 28)	17.9 (3.2)	16.3 (3.8)	13.6 (4.1)
Potential amusics (*N* = 46)	17.8 (2.6)	17.9 (3.6)	15.3 (3.6)
Matched controls (*N* = 74)	18.7 (2.2)	22.1 (1.5)	20.4 (2.6)

These results confirm that amusic participants are impaired in the detection of pitch anomalies but not of time deviations in the same melodies (Hyde & Peretz, 2004, 2005; Peretz, Cummings, & Dubé, 2007). Therefore, the off-beat condition can serve as a useful control condition for determining whether an individual is amusic, or rather suffers from more general auditory impairments. Note that here there were three amusics who were impaired in the off-beat condition (see Figure 3), including one who failed on all musical tests. In such cases (10% of amusics), additional neuropsychological testing is required to determine if general auditory problems are the source of the deficit. Conversely, there were three amusics who scored below cut-off on the full MBEA, but scored relatively high on the on-line test, with 80.6, 83.3, and 91.7% of correct responses. Similarly, 11 potential amusics who had failed on the MBEA scale test obtained on-line global test results well above 80%. Thus, 19% (14 of 74) of amusic individuals would be missed by the on-line test alone. More generally, if we use cut-off scores of 2 *SD* below the mean of non-amusic participants, as determined for each cohort in Table 2, 10 of the 28 amusics (Figure 3) and 18 of the 46 potential amusics would be missed too because they scored above the cut-off.

One possible reason for the discrepancy between the high profile on the on-line test and the low scores on the MBEA is that musical impairments are best expressed when the task requirements are more demanding on memory. As mentioned previously, the MBEA is more demanding in terms of memory than the on-line test because most tests of the MBEA require the participant to hold pitch information in working memory in order to perform a same-different classification task (Ayotte, Peretz, & Hyde, 2002; Foxton, Dean, Gee, Peretz, & Griffiths, 2004). There are two major conclusions to be drawn from this observation. First, the musical pitch deficit of amusics is probably best revealed by a task that requires memory. Secondly, the MBEA scale test might have more diagnostic power than the on-line test. One solution is to include the MBEA scale test in the online test. In that case, fewer amusics would be missed.

Note that we also found individuals who showed the reverse pattern. That is, in the previous validation section, we observed that 5 out of the 89 participants failed on the on-line test (with global performance below cut-off) but obtained normal scores on the MBEA (Figure 3). This raises the question as whether these 5 participants should be considered as false positives or as genuine cases of amusia, although of a different type than the ones identified by the MBEA. However, inspection of their scores on the three on-line conditions does not reveal a different pattern. These 5 subjects performed better on the off-beat condition (75.8%) than on the out-of-key condition (55.8%). Furthermore, only one of these participants scored below cut-off on the MBEA scale test. Thus, it is not clear why these five participants with a typical amusic profile on the on-line test performed so well on the MBEA (with global scores between 78 and 87.3% correct).

To conclude, the value of the on-line test for distinguishing amusic from non-amusic cases is relatively high. Since there are relatively few false positives (5 of 89) and few misses (3 of 28 if we do not use a strict cut-off but a global score below 80% as indicative of probable amusia), the on-line test can categorize amusic from non-amusic cases with about 93% accuracy (i.e., 109 of 117 participants; see Figure 3). This is an excellent hit rate given that the data collected via Internet are less controlled than those obtained in the laboratory, and given that there are less than half as many trials in the on-line test (72 trials) than in the MBEA (180 trials).

5. Self-Assessment Questionnaire

Another important part of the on-line test consists of collecting biographical data as done previously off-line by Cuddy and collaborators (2005). We computed the responses to the 101 questions presented on-line given by the amusic cases and compared these to the answers provided by their matched controls. We report here the responses that best describe and distinguish amusic from non-amusic individuals.

As mentioned in the introduction, three self-descriptions have been considered as key for the diagnosis of congenital amusia in our past research (e.g., Peretz, Champod, & Hyde, 2003). These descriptions are: "I cannot recognize tunes without the help of the lyrics" and "I cannot tell if I sing out of tune" and "I have been told I sing out of tune." As can be seen in Table 6, the amusics' responses to the three corresponding questions do discriminate from controls' responses. Most amusics (confirmed on the full MBEA) and more than a third of the potential amusics can never, rarely, or sometimes recognize a familiar tune without the help of the lyrics while controls rarely report such failures. When questioned on their vocal production abilities, most amusics (89-93%) agree that the statement "I sing out-of-tune" corresponds to their situation. However, about half the controls[4] reported that they sing out-of-tune (Table 6). Thus, this particular question may not be discriminant. Rather, the key question concerns the ability to detect when someone else sings out-of-tune; most amusics acknowledge that they cannot whereas all control participants claim that they can. Thus, responses to the two discriminant questions related to perception can correctly identify between 35 to 85% of amusics.

In general, amusics[5] rated their overt music behavior more negatively than their music receptive behavior. For example, most amusics (88%) said that they could not sing back notes played on a piano while only 1 out of 24 controls (4%) responded the same way. When questioned on their singing habits, 88% of amusics said that they rarely sang in private and all of them (25/25) responded that they never, rarely, or sometimes sang in public. The reverse situation was reported by the matched controls. All controls responded that they often or very often sing in public. Similarly, 85% of the amusics reported that they never, rarely, or sometimes dance, whereas nearly every control (93%) answered that they often or very often dance. Most amusics (73%) described themselves as poor dancers while only 7% of controls felt the same way about their dancing skills. Regarding their music appreciation attitudes, amusics seemed more reluctant to acknowledge their difficulties. For example, only half of them (13/27) reported that they never, rarely, or sometimes listened to music. In face-to-face interviews, every amusic individual we have tested so far declared to rarely listen to music if given the choice. As pointed out by Peretz (2001b), amusics might be reluctant to publicly acknowledge their lack of music interest because this might be perceived as a lack of human sensitivity. Moreover, it might be more difficult to self-evaluate perceptual and memory abilities as compared to performance skills, which receive more feedback from the environment. Alternatively, it might be the case that congenital

---

[4] 42.7% (91/213) of the unselected participants to the on-line test declare to sing out of tune.

[5] These responses come from the 28 amusics confirmed on the full MBEA and their 28 matched controls.

TABLE 6. Percentage of Responses (Proportion of Participants) to Questions Relevant for the Identification of Amusic Individuals.

	Amusics $N = 28$	Potential amusics $N = 46$	Controls $N = 74$
Unable to detect when someone sings out-of-tune	85% (23/27)	28% (13/44)	0% (0/64)
Can rarely recognize a very familiar melody without the help of lyrics	74% (20/27)	35% (30/46)	8% (5/63)
Sings out-of-tune	93% (25/27)	89% (41/46)	43% (27/63)

amusia is best expressed in vocal and dancing skills than in perceptual and memory abilities. Comparison between production and perception skills should be the goal of future research in congenital amusia.

6. Advantages and Limitations of the On-line Test

The on-line test presents a number of advantages. It takes from 15 to 30 minutes to complete, depending on the willingness of the participant to fill out the 101 self-assessment questions. It can be administered at a distance and record responses automatically, without the intervention of an experimenter. It only requires Internet access.

The on-line test also presents a number of psychometric properties that make it an adequate tool for the assessment of basic musical perceptual abilities on a large scale. The global scores provide quantitative data that are sensitive to the extremes by being relatively normally distributed in the population. In this respect, the on-line test is clearly a better tool than the Distorted Tune Test (DTT), which is skewed towards the high extreme (Drayna, Manichaikul, de Lange, Snieder, & Spector, 2001; Kalmus & Fry, 1980). The on-line test is also valid for the rapid assessment of music perception in Western individuals who are older than 14, with various musical backgrounds. Although the scores are sensitive to a cohort effect, reflecting the fact that the younger generation is both more musical and familiar with the use of Internet, the scores correlate fairly well with the global scores obtained on the MBEA in the laboratory. In particular, the on-line test seems to tap the same ability to map pitch onto scales and the same ability to find regularity and metricality, two essential processing components that give rise to the normal musical capacity (Peretz & Hyde, 2003).

The on-line test also permits the distinction between amusic and non-amusic individuals in up to 93% of the cases. Since there were as few misses as false positives, the on-line test may provide a fairly accurate estimate of the prevalence of amusia. By giving open access to the on-line test and adding the MBEA scale test, which has proven to be diagnostic on its own, we will be in a position to re-examine the prevalence of amusia currently estimated at 4% based on the DTT of Kalmus & Fry (1980). We predict that the prevalence of amusia is lower than 4%. Indeed, we noted here that 5.8% of the unselected participants scored below 2 *SD* from the mean. However, many unselected participants were motivated to take the test because they suspected a musical problem and hence might be true amusic cases. By encouraging a target population such as university undergraduates to participate to the on-line testing, a more accurate estimate of congenital amusia should be obtained. The web-based experimental set-up is optimal to recruit large numbers of participants simply because of the widespread availability of the Internet and current high-quality audio playback facilities. This study will be undertaken soon.

Finally, another advantage of the on-line test is that it provides important biographical information immediately. In particular, self-assessment of tune recognition and singing accuracy permits the identification of a significant proportion of amusic cases (see the first two key items in Table 6). Moreover, it allows the rapid identification of unsuspected difficulties such as problems with spatial orientation that were reported by more than 20% of the amusics (Douglas & Bilkey, 2007). Self-assessment also gives precious indications regarding unexplored musical behaviors, such as dancing and singing. Thus, the on-line questionnaire may open new avenues for research on congenital amusia.

Conclusions

From a practical and educational perspective, the on-line test is a novel tool that can estimate the presence of amusia at an individual level with fair accuracy, and the prevalence of amusia in a large population with efficacy. Furthermore, the on-line test can help to reveal false amusics described by both Cuddy et al. (2005) and Sloboda et al. (2005) as individuals who think that they are unmusical but are capable of normal musical functioning. This applies to a significant proportion of the participants who participated in the present study since 19% of them self-declared as unmusical. In revealing an absence of musical deficiency, test results can be used to promote encouragement of further musical activity.

From a theoretical perspective, the on-line test confirms that congenital amusia is expressed by a deficit in processing musical pitch rather than musical time (Hyde & Peretz, 2004, 2005; Peretz, Cummings, & Dubé, 2007). It further suggests that congenital amusia is a relatively isolated developmental disorder that can be associated in 20% of cases (6 of 27) to problems in spatial orientation. Although the spatial difficulties reported by amusics have not been assessed here, these are consistent with the findings of Douglas & Bilkey (2007) that pitch deficits can be related in some cases to problems in visuo-spatial processing. Future studies should assess to what extent this is a systematic association because it may shed light on the origin of the pitch problem experienced by amusic individuals, and above all, may help to uncover the neural and genetic origins of congenital amusia.

Author Note

We thank Aliette Lochy and Jean Gautier for the pilot testing of the Internet test and Annie Magnan for assistance with the data analyses. We also thank Jessica Foxton, Olivier Bertrand, Vincent Farget and Géraldine Lebrun-Guillaud, the collaborators on the amusia project in Lyon. This work was supported by a grant from the Canadian Institutes of Health Research to Isabelle Peretz and a Discovery Grant from the Natural Sciences and Engineering Council of Canada to Lola Cuddy.

Correspondence concerning this article should be addressed to Isabelle Peretz, BRAMS-Pavillon 1420 Mont-Royal, Université de Montréal, Montréal, Quebec, Canada H2V 4P3. E-MAIL: isabelle.peretz@umontreal.ca

References

ALLEN, G. (1878). Note-deafness. *Mind, 10,* 157-167.

AYOTTE, J., PERETZ, I., & HYDE, K. (2002). Congenital amusia: A group study of adults afflicted with a music-specific disorder. *Brain, 125*, 238-251.

BIGAND, E. (1990). Abstraction of two forms of underlying structure in a tonal melody. *Psychology of Music, 18*, 45-59.

BIGAND, E., & POULIN-CHARRONNAT, B. (2006). Are we "experienced listeners"? A review of the musical capacities that do not depend on formal musical training. *Cognition, 100*, 100-130.

CUDDY, L. L., BALKWILL, L.-L., PERETZ, I., & HOLDEN, R. R. (2005). Musical difficulties are rare: A study of "tone deafness" among university students. *Annals of the New York Academy of Sciences, 1060*, 311-324.

DALLA BELLA, S., & PERETZ, I. (2005). Differentiation of classical music requires little learning but rhythm. *Cognition, 96*, B65-78.

DIGIMED SYSTEMS INC. (2006). DataFinder (Version 5). [Research and clinical database software]. Montreal, Canada.

DOUGLAS, K. M., & BILKEY, D. K. (2007). Amusia is associated with deficits in spatial processing. *Nature Neuroscience, 10*, 915-921.

DRAYNA, D., MANICHAIKUL, A., DE LANGE, M., SNIEDER, H., & SPECTOR, T. (2001). Genetic correlates of musical pitch recognition in humans. *Science, 291*, 1969-1972.

FOXTON, J. M., DEAN, J. L., GEE, R., PERETZ, I., & GRIFFITHS, T. D. (2004). Characterization of deficits in pitch perception underlying 'tone deafness.' *Brain, 127*, 801-810.

FRY, D. B. (1948). An experimental study of tone deafness. *Speech, 2,* 1-7.

HYDE, K. L., & PERETZ, I. (2004). Brains that are out of tune but in time. *Psychological Science, 15*, 356-360.

HYDE, K. L., & PERETZ, I. (2005). Congenital amusia: Impaired musical pitch but intact musical time. In J. Syka & M. Merzenich (Eds.), *Plasticity and signal representation in the auditory system* (pp. 291-296). New York: US Springer Publishing Co.

HYDE, K. L., ZATORRE, R. J., GRIFFITHS, T. D., LERCH, J. P., & PERETZ, I. (2006). Morphometry of the amusic brain: A two-site study. *Brain, 129*, 2562-2570.

KALMUS, H., & FRY, D. B. (1980). On tune deafness (dysmelodia): Frequency, development, genetics and musical background. *Annals of the Human Genetics, 43*, 369-382.

PATEL, A. D., FOXTON, J. M., & GRIFFITHS, T. D. (2005). Musically tone-deaf individuals have difficulty discriminating intonation contours extracted from speech. *Brain and Cognition, 59*, 310-313.

Patel, A. D., Wong, M., Foxton, J. M., Lochy, A., & Peretz, I. (2008). Speech intonation deficits in musical tone deafness (congenital amusia). *Music Perception*, *25*, 357-368.

Peretz, I. (2001a). Brain specialization for music: New evidence from congenital amusia. *Annals of the New York Academy of Sciences, 930,* 153-165.

Peretz, I. (2001b). Listen to the brain: The biological perspective on musical emotions. In P. Juslin & J. Sloboda (Eds.), *Music and emotion: Theory and research* (pp. 105-134). New York: Oxford University Press.

Peretz, I., Champod, A. S., & Hyde, K. (2003). Varieties of musical disorders. The Montreal Battery of Evaluation of Amusia. *Annals of the New York Academy of Sciences, 999*, 58-75.

Peretz, I., Cummings, S., & Dubé, M.-P. (2007). The genetics of congenital amusia (or tone-deafness): A family aggregation study. *American Journal of Human Genetics*, *81*, 582-588.

Peretz, I., & Hyde, K. L. (2003). What is specific to music processing? Insights from congenital amusia. *Trends in Cognitive Sciences, 7*, 362-367.

Shepard, R. N., & Jordan, D. S. (1984). Auditory illusions demonstrating that tones are assimilated to an internalized musical scale. *Science, 226*, 1333-1334.

Sloboda, J. A., Wise, K. J., & Peretz, I. (2005). Quantifying tone deafness in the general population. *Annals of the New York Academy of Sciences, 1060*, 255-261.

Stewart, L., von Kriegstein, K., Warren, J. D., & Griffiths, T. D. (2006). Music and the brain: Disorders of musical listening. *Brain, 129*, 2533-2553.

Tillmann, B., Bharucha, J. J., & Bigand, E. (2000). Implicit learning of tonality: A self-organizing approach. *Psychological Review, 107*, 885-913.

Trehub, S. E., & Hannon, E. E. (2006). Infant music perception: Domain-general or domain-specific mechanisms? *Cognition, 100*, 73-99.

Zentner, M. R., & Kagan, J. (1996). Perception of music by infants. *Nature, 383*, 29.