Cognitive Neuropsychology

Amusic does not mean unmusical: Beat perception and synchronization ability despite pitch deafness

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Amusic does not mean unmusical: Beat perception and synchronization ability despite pitch deafness

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Pitch deafness, the most commonly known form of congenital amusia, refers to a severe deficit in musical pitch processing (i.e., melody discrimination and recognition) that can leave time processing—including rhythm, metre, and "feeling the beat"—preserved. In Experiment 1, we show that by presenting musical excerpts in nonpitched drum timbres, rather than pitched piano tones, amusics show normal metre recognition. Experiment 2 reveals that body movement influences amusics' interpretation of the beat of an ambiguous drum rhythm. Experiment 3 and a subsequent exploratory study show an ability to synchronize movement to the beat of popular dance music and potential for improvement when given a modest amount of practice. Together the present results are consistent with the idea that rhythm and beat processing are spared in pitch deafness—that is, being pitch-deaf does not mean one is beat-deaf. In the context of drum music especially, amusics can be musical.

Keywords: Pitch deafness; Beat; Meter; Dance; Synchronization.

Musical rhythm and dance abilities are not the privilege of a few, but an endowment of human nature (Brown, 2003; Darwin, 1896/1871; Miller, 2000; Wallin, 1991). Many of the world's musics showcase a prevalent role for drumming, marching, and clapping, as observed in African drum circles, Flamenco clapping, American gospel choirs, and military drills and marches. These bodily rhythmic productions are observed from early childhood, and often with an important role of communal participation, as in preschoolers' playground rhymes like "Ring Around the Rosie",

children's clapping and jump rope rhymes like "Miss Lucy had a baby", and adults' folk dances like country and urban line dancing, Gaelic *Céilidh*, and Cuban *Rueda de Casino*. Participation in such activities reveals the pleasing impulse to move to music, known as "groove" (Janata, Tomic, & Haberman, 2012; Madison, Gouyon, Ullén, & Hörnström, 2011). A common underlying element of these activities is the perception and production of a musical beat.

The ability to detect a beat is present from infancy (Winkler, Háden, Ladinig, Sziller, &

Honing, 2009), as is categorization of metrical structures (Hannon & Johnson, 2005; Hannon & Trehub, 2005). Infants show evidence of the multisensory nature of musical beat processing, by *feeling* the beat of auditory rhythm patterns through body movement as adults do (Phillips-Silver & Trainor, 2005, 2007), reflecting the contribution of auditory, motor, and vestibular systems in beat finding (Phillips-Silver & Trainor, 2008). Infants and children produce bodily movements spontaneously to music, more so than to other complex auditory stimuli such as language (Zentner & Eerola, 2010). The propensity to move to music is related to the positive affect observed in response to musical activity (Zentner & Eerola, 2010), which may explain why rhythmic drumming in young children is improved in a social context (Kirschner & Tomasello, 2009). Such musical foundations are preparation for a lifetime of music and dance activity.

Not all individuals develop normal musical skills, however. Around 4% of the population fail to develop a normal musical pitch processing system (Hyde & Peretz, 2004). The affected behavioural musical abilities include fine-grained pitch discrimination, dissonance perception, melody discrimination, and melody recognition, as well as vocal production of pitch intervals and familiar tunes (see Peretz, 2001; Stewart, 2011, for reviews). This condition is the most frequently documented type of congenital amusia and is best qualified as pitch deafness since the disorder mostly affects the musical pitch dimension. Pitch deafness has a hereditary component (Drayna, Manichaikul, de Lange, Snieder, & Spector, 2001; Peretz, Cummings, & Dube, 2007) and is associated with impoverished connectivity between the auditory cortex and the inferior frontal gyrus, mostly on the right side of the brain, which reflects an abnormal action−perception network (Hyde et al., 2007; Hyde, Zatorre, Griffiths, Lerch, & Peretz, 2006; Hyde, Zatorre, & Peretz, 2011; Loui, Alsop, & Schlaug, 2009).

The pitch-deaf profile leaves rhythm processing relatively intact at a basic level, though performance on temporal tests tends to be variable in this population. Anisochronies can be detected normally in this group (Hyde & Peretz, 2004). Yet the pitch deficit can interfere with duration (Pfeuty & Peretz, 2010) and musical rhythm discrimination (Ayotte, Peretz, & Hyde, 2002; Foxton, Nandy, & Griffiths, 2006). When rhythm is isolated by removing pitch variations, amusics perform normally (Foxton et al., 2006). Furthermore, amusics sing the rhythm of a highly familiar song as well as normals do (Tremblay-Champoux, Dalla Bella, Phillips-Silver, Lebrun, & Peretz, 2011). The foregoing results are consistent with the idea that prior failures to demonstrate normal perception of the temporal aspects of music might be attributed to interference from simultaneous demands on pitch processing (Foxton et al., 2006).

Demands on a faulty pitch processing system are likely to interfere with detection of a regular beat and its organization into musical metre, as has been suggested by poor performance by pitch-deaf individuals on the Montreal Battery of Evaluation of Amusia (MBEA) test of metre discrimination (Ayotte et al., 2002). Theoretical accounts of metre assume that onset-to-onset intervals are assimilated into an internal periodic pulse (Povel, 1981; Povel & Essens, 1985). On hearing a rhythmic musical stimulus, the listener tends to infer a primary musical pulse that can be hierarchically structured in terms of metrically strong and weak beats. This enables metre discrimination (as in distinguishing a march from a waltz). Thus, in the absence of pitch variations, metre discrimination should be normal in the pitch-deaf population. We tested this idea in Experiment 1 by presenting MBEA metre stimuli in novel drum timbres, rather than piano timbres.

If the pitch-deaf amusics could succeed in distinguishing metres based on the pattern of auditory strong and weak beats of drum rhythm patterns, we predicted that they would then show an ability to perceive the pattern of strong and weak beats as indicated by full body movement. In Experiment 2, we tested whether body movement on either every second or every third beat of an ambiguous drum rhythm pattern would

determine the perception of the rhythm in either duple or triple metre (i.e., march versus waltz), as it has been shown in typically developing infants and non-amusic adults (Phillips-Silver & Trainor, 2005, 2007). This situation would illustrate the tight coupling between auditory–motor systems that underlies beat processing.

Another important expression of auditory–motor beat processing is synchronization to a musical pulse. Tapping to the regular strong beat of musical excerpts is impaired to varying degrees in pitch-deaf individuals, which once again has been attributed to interference from pitch variations (Dalla Bella & Peretz, 2003). However, entrainment to a musical beat may be enhanced in whole-body movements relative to tapping because body movements recruit multiple sensory inputs, including from motor, proprioceptive, and vestibular sources (Phillips-Silver & Trainor, 2008). Thus, we tested in Experiment 3 whether in the context of full body motion the pitch-deaf amusics could succeed in synchronizing their movement to a musical pulse. This task is nonetheless a challenging one for an amusic, as the ability to move the body in a dance-like manner is a complex auditory–motor behaviour that relies on some amount of practice. As the amusic population typically have less experience with music and dancing (as with singing) over the course of their lifetimes, we finally considered in the exploratory study the role that practice might play in synchronization of body movement to music.

METHOD

Participants

The amusic group consisted of 10 amusic individuals with normal executive functioning and digit span scores, whose global score was below a mean score of 23/30 or 77% on the Montreal Battery of Evaluation of Amusia (MBEA; Peretz, Champod, & Hyde, 2003). Individual scores on the MBEA test battery are provided in Table 1. All reported that they "never", "rarely",

or only "sometimes" dance. The control group consisted of a group of eight individuals of low variability who were individually matched for age, education level, and music experience to each amusic. The controls all scored in the normal range on the MBEA (Table 1) and reported similar dance habits to the amusic group overall, though a couple of them reported to dance often. No amusic or control subjects reported dancing very often.

In comparison with the matched controls, all amusic participants had obtained scores at least 2 standard deviations below the mean on the three MBEA tests involving pitch processing (i.e., scale, contour, and interval tests), with the exception of Subject A7 who scored 1 standard deviation below the mean on the MBEA contour test alone. The scores on the temporal tests of the MBEA (i.e., rhythm and metre tests) were more variable. Yet eight amusics scored below 2 standard deviations of the mean on the metre test, hence suggesting a deficit in metre processing.

EXPERIMENT 1: JUDGING METRE IN THE ABSENCE OF PITCH VARIATION

The metre test provided in the MBEA (Peretz et al., 2003; Table 1) presents short, harmonized piano stimuli to be categorized as a *march* with a duple grouping of the beat ("ONE, two; ONE, two"), or a *waltz* with a triple grouping of the beat ("ONE, two, three; ONE, two, three"). In these stimuli, the metrical structure is derived from the accents provided by the harmonic chords containing low bass notes on the strong beats of the pattern (i.e., the "ONE" beat). We used here the same material without pitch variations, by transcribing the metrical stimuli into a score for unpitched percussion instruments (snare and bass drums). We predicted that amusics would show normal metre discrimination ability in the context of musical stimuli that are of similar complexity to the MBEA metre stimuli, but have reduced pitch variations.

Table 1. *Characteristics of amusic subjects and matched controls*

Characteristic	A1	A2	A3	A4	A5	A6[a]	A7	A8	A9[b]	A10	Matched controls (SD)
Gender	M	M	M	M	F	F	F	F	F	F	6F 2M
Age (years)	68	61	67	65	69	69	68	64	59	68	65.5 (5)
Education (years)	19	19	19	14	15	15	14	20	19	21	16 (2)
Music ed. (years)	1	1	1	1	2	0	2	1	3	4	2.6 (2)
Dancing[c]	2	1	1	2	0	0	2	2	1	1	2.3 (1)
MBEA											
Scale	17	16	15	19	20	17	14	17	16	23	28 (2)
Contour	20	17	15	18	21	19	23	20	16	20	27 (3)
Interval	12	20	15	16	21	15	21	22	16	17	27 (2)
Rhythm	21	24	15	23	20	16	23	29	19	27	27 (2)
Metre	13	17	17	15	20	20	18	21	22	26	27 (3)
Memory	19	20	15	17	23	21	17	22	20	21	26 (2)
Global score	17.0	19.0	15.3	18.0	20.8	18.0	18.8	21.8	18.2	22.3	26.8 (1)

Note: M = male; F = female; ed. = education; MBEA = Montreal Battery of Evaluation of Amusia. Maximum scores on the MBEA = 30; chance = 15.
[a]Subject A6 did not participate in Experiment 1. [b]Subject A9 participated in Experiment 4. [c]0 = never, 1 = rarely, 2 = sometimes, 3 = often, 4 = very often.

Method

Stimuli
Stimuli for this experiment were constructed by taking the musical notation of the original stimuli of MBEA metre test (Peretz et al., 2003) and rendering them in drum timbres using Sibelius software (to hear examples of these metre stimuli in the original piano, and the drum timbres, hear Supplementary Materials 1 and 2). The original stimuli (Figure 1, top panel) consisted in two-phrase melodies with harmonic chords marking the beat, by accentuating either the duple (march) or the triple (waltz) metrical

Figure 1. *Metre test stimulus notation: an original Montreal Battery of Evaluation of Amusia (MBEA) metre stimulus (top panel) and the drum version of the same stimulus (bottom panel).*

structure of the melodies (15 stimuli of each). The new drum stimuli had the "melody" played on snare drum and the chords rendered in tenor and bass drum timbres (Figure 1, bottom panel). The snare, tenor, and bass drum timbres had different relative pitch heights; however, within each instrument line there was no pitch variation. These percussion timbres are called "unpitched" or "untuned", because the resultant sound of the instrument contains complex frequencies that do not have a well-defined fundamental frequency (Herrera, Dehamel, & Gouyon, 2003), unlike the piano, which is a "pitched percussion" instrument whose sounds result in definite pitches. Quarter note tempo markings varied between 100 and 200 beats per minute (bpm).

Procedure

Nine amusics and seven matched control subjects were instructed to determine for each stimulus whether it was a march or a waltz. It was explained to them that, in the first case, the strong beat occurs on every second beat ("ONE, two, ONE, two, . . . ": march), and, in the second case, the strong beat occurs on every third beat ("ONE, two, three, ONE, two, three, . . . ": waltz). As in the original MBEA metre test, participants were encouraged to tap along if it helped them. The test commenced with four example stimuli, and subjects were given feedback on their performance. During the test, 30 stimuli were presented in the same order as in the original MBEA metre test, with a 5-s intertrial interval and no feedback. The test was run in Eprime on a PC computer, in a sound booth with the experimenter present. Subjects listened to the auditory stimuli presented free field from Genelec speakers (at approximately 70 dB). The duration of the test was approximately 10 minutes.

Results and comments

As predicted, amusics improved on the drum metre test (mean = 23, SD = 5) over the original MBEA metre test (mean = 19, SD = 4). This improvement reached significance according to a Wilcoxon signed ranks test, $Z = 19.58$, $p = .01$.

All but one of the amusics (A3) performed better on the drum version as compared to their individual performance on the original metre test. A Mann−Whitney test showed that there was no significant difference between the scores of the amusic group and those of the matched control group on the drum metre test (mean = 25, SD = 5), $Z = -0.962$, $p = .336$. Thus, amusics may show normal metre discrimination ability provided that pitch variations are removed from the music. Hence, presenting musical stimuli in drum timbres is an ecological approach to probe temporal processing abilities in pitch deafness.

EXPERIMENT 2: FEELING THE BEAT THROUGH WHOLE-BODY MOVEMENT

Determining the metrical structure of musical excerpts is a task that relies on being able to extract the underlying pattern of strong and weak beats. While the pattern of strong beats can be derived from acoustical accents, it has also been shown that it can be inferred from full body motion (Phillips-Silver & Trainor, 2005, 2007, 2008). Since amusics appear to be able to extract the beat structure from drum music, we predicted that they would similarly demonstrate the ability to "feel the beat" of a drum pattern from movement cues only. Specifically, we predicted that amusics and their matched controls would show an effect of body movement on the auditory representation of a drum rhythm pattern that was ambiguous in its grouping of metrical strong and weak beats.

Method

Stimuli and procedure

Ten amusics and eight controls were trained to feel the beat, by bouncing for two minutes with an experimenter to an ambiguous six-beat rhythm pattern (stimuli can be heard and details found in the supplementary materials of Phillips-Silver & Trainor, 2005). The training rhythm was ambiguous because no auditory accents to beat
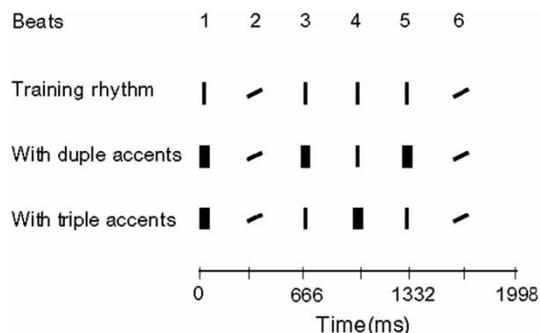
Figure 2. *Stimulus patterns consisted of snare drum sounds (vertical lines) and time-marking slapstick sounds (oblique lines). The training pattern had no auditory accents. The testing patterns included the duple accented form with accents every second beat versus the triple accented form with accents every third beat. Figure reproduced from Phillips-Silver and Trainor (2005).*

structure were provided (Figure 2). The rhythm could be accented on every second beat, producing three groups of two beats each (duple form), or on every third beat, producing two groups of three beats each (triple form). In this paradigm, the perception of a "strong beat" was predicted to arise from body movement; that is, the movement cues, rather than the auditory cues, should result in an unambiguous representation of the beat structure. During training, half of the subjects bounced on every second beat (i.e., in duple form, as in: "ONE, two, THREE, four, FIVE, six, . . . "), and half bounced on every third beat (triple form, as in: "ONE, two, three, FOUR, five, six, . . . "). After training, the subjects sat facing a computer screen and were presented with a two-alternative forced choice task. On each trial, they heard two acoustically accented versions of the bouncing rhythm: one with accents in duple form (on every second beat), and one with accents in triple form (on every third beat; see Figure 2). The stimuli were presented in a pseudorandom order so that half of the trials began with a duple stimulus and half with a triple. Across 20 trials, subjects indicated which test stimulus matched the one they had heard during bouncing. The duration of the experiment was approximately 10 minutes and employed the procedure of Phillips-Silver and Trainor (2007).

Results and comments

The amusics who bounced in duple and triple form were compared on the proportion of trials they chose the "duple" test stimulus as most similar to that which they heard during training, versus the "triple" test stimulus. As predicted, amusics who bounced in duple versus triple form differed significantly in the proportion choosing the duple test stimulus, as measured by an independent-samples Mann–Whitney test, $Z = -2.660$, $p = .008$. Examining the movement groups for their percentage of correct (i.e., matching their movement) stimulus choice (whether duple or triple), we found that each group recognized the auditory rhythm form that matched their own movement experience, with mean performance accuracy of 84%, $SD = 0.157$ (Figure 3). There was no significant difference between the number of duple bouncers choosing the duple rhythm and triple
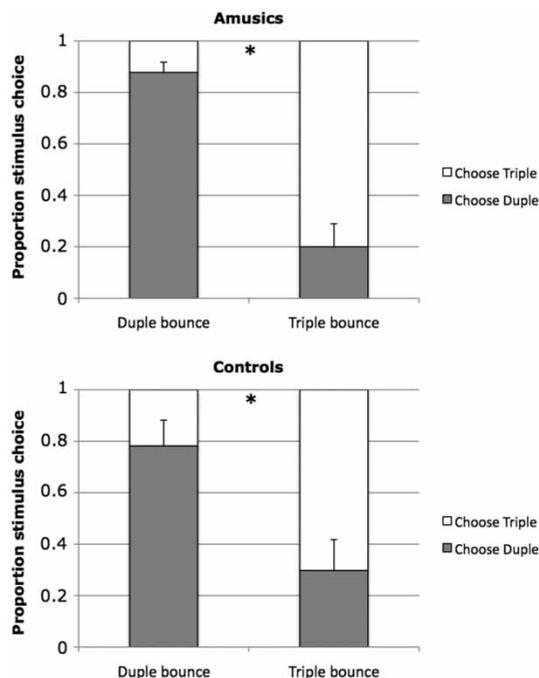

Figure 3. *Results of encoding the beat of an ambiguous rhythm through movement. The graph shows the proportion of test stimulus choice, for amusics (top panel) and controls (bottom panel). Error bars represent standard error of the mean.*

bouncers choosing the triple rhythm, $Z = -0.542$, $p = .690$. Thus bouncing on either every second or every third beat influenced whether the amusics perceived the ambiguous rhythm in duple or triple form.

Controls who bounced in duple versus triple form differed marginally in the proportion choosing the duple test stimulus, $Z = -1.888$, $p = .057$. The two movement groups (duple, triple) did not differ in accuracy; that is, there was no significant difference between the number of duple bouncers choosing the duple rhythm and triple bouncers choosing the triple rhythm, $Z = -0.147$, $p = .886$. Both movement groups recognized the auditory rhythm form that matched their own movement experience with mean performance accuracy 75%, $SD = 0.25$ (Figure 3).

Although the score for mean overall accuracy was higher for amusics than for controls, this difference was not significant according to a Mann–Whitney test, $Z = -0.597$, $p = .573$ (duple mean rank = 10.15, triple mean rank = 8.69; overall mean percentage accuracy 80%, $SD = 0.207$).

In summary, both the amusic and control groups showed the effect that body movement—bouncing on either every second or every third beat—influenced whether the subjects perceived the ambiguous rhythm in duple or triple form. These results show that pitch-deaf amusics can "feel the beat" of music through body movement.

EXPERIMENT 3: SYNCHRONIZING WHOLE BODY MOVEMENT TO MUSIC

The results of Experiments 1 and 2 show that in the context of stimuli without pitch variations (i.e., drum timbres), pitch-deaf amusics are capable of distinguishing metres and of feeling the beat of a rhythm pattern through body movement. Often in music the beat is accentuated acoustically and in turn is manifest in the regular, pulsing movement of the listener, as in head bobs, foot taps, and dance movements. In the following experiments we ask: Can amusics produce dancelike movement to music? The

amusic population is often regarded as "unmusical" and is thus discouraged from dancing. It is thus unclear whether the pitch-deaf population may have suffered from a lack of practice in this skill. In this final experiment, and the subsequent exploration, we had two aims: to assess the synchronization of amusics' dancelike movement to real dance music, and to gauge the potential role of practice in bringing this skill to a normal level of performance.

In a test of tapping, pitch-deaf amusics showed an impaired ability to tap on the beat of real music excerpts, while they were normal in their ability to tap in time to noise bursts (Dalla Bella & Peretz, 2003). It is possible that amusics would show a similar impairment in the context of dance; however, it has been suggested that full-body motion recruits a combination of sensory inputs in eliciting entrainment, including motor, proprioceptive, and vestibular inputs. With the aim of eliciting full-body entrainment, we provide in Experiment 3 an assessment of dancelike movement to an excerpt of dance music as well as to an isochronous beat.

In a previous study it was observed that the general population synchronized full-body movement (by bending at the knees and bouncing up and down in place) to a popular merengue song, which is a dedicated dance music form (Phillips-Silver et al., 2011). Here, we measured synchronization of bouncing to the same merengue song, to a simple drum version of the song, and to a metronome as a control condition.

Method

Stimuli and procedure

Ten amusics and eight matched controls bounced to the merengue song *Suavemente* (by Elvis Crespo) chosen for its regular, duple beat structure and its popularity as a dance song (hear Supplementary Material 3). The song duration was 64 beats, and it was played at two tempi (124 bpm, or a period of 480 ms, and 116 bpm, or a period of 520 ms) around the common preferred tempo for adult human motion (Moelants,

2002) and a central tempo for a variety of musical genres (Madison et al., 2011). Tempi and beats of audio files were derived by the algorithm of the MIR Toolbox (Burger & Toiviainen, 2013; Lartillot & Toiviainen, 2007). The drum condition used a four-part version of the merengue music score, created using Sibelius software to transcribe the rhythmic structure of the song in four percussive timbres (as in Experiment 1). The drum version was meant to reduce pitch variations, and so four prominent vocal and instrumental lines of the music were extracted and then transcribed onto a score for drum set in four parts, on three staves (see Figure 4; hear Supplementary Material 4). The first voice (first staff) was played on snare drum, the second and third voices (second staff) were played in tenor drum timbres, and the fourth voice (third staff) was played on bass drum. This drum version was played at the same tempi as the original music stimuli. As a control condition, an auditory metronome (64 beats) was presented at approximately the same tempi as the music. This control was provided to ensure that subjects could produce a bouncing motion to the tempo of a single isochronous beat.

Motion capture data analysis, results, and comments

Beat period

Bouncing motion was captured with the accelerometer contained in the remote control of the Nintendo Wii, which was strapped to the trunk of the body. This device measured acceleration of body movement (bouncing) with a temporal resolution of 100 frames per second (10 ms), from which the beat-by-beat period of the vertical movement was computed. The zero crossing of the vertical acceleration marked the bounces (Toiviainen, Luck, & Thompson, 2010). We calculated the number of bounces for each subject on each 64-beat auditory stimulus by low-pass filtering the vertical acceleration at 3 Hz and counting the number of zero crossings of the filtered data during the presentation of the stimulus. On average, the amusic subjects produced 65 bounces for the merengue, 65 for the drum, and 60 bounces for the metronome. The matched controls produced on average 50 bounces for the merengue, 50 for the drum, and 47 bounces for the metronome. The control subjects produced fewer bounces on average than amusic subjects because

Figure 4. *Music notation for the drum version of the merengue stimulus.*

they tended to begin bouncing several beats later in the stimulus.

Synchronization

We assessed synchronization of dancelike bouncing movement by measuring the tempo (rate) and phase of movements with respect to the musical beat. In accordance with prior work (Phillips-Silver et al., 2011), data were submitted to a Fourier analysis to measure the overall proportion of power at the musical beat level, as well as at related frequencies (i.e., 0.5 and 2 times the musical beat level), within the range of 0 to 5 Hz.

Figure 5 shows the data in proportion of synchronized power, for amusics and matched controls in the merengue, drum, and metronome conditions.

We calculated the root-mean-square amplitude of acceleration across all stimuli for each individual. By this measure, the amusics showed a larger value on average, but the difference between amusics and controls is not significant ($t =$ 0.693; $p = .498$). This was due to the fact that only two amusic participants showed larger amplitudes than the rest of their group.

The amusics showed significant power at the one-beat level, and peaks at the two-beat level, on the metronome condition and on one drum trial (at 1.86 Hz), but did not show significant power at the musical beat level or related frequencies on the merengue music (see Figure 6). Thus, the only music stimulus in which the amusics approached their level of performance on the metronome was the drum stimulus (drum trial at 1.86 Hz). The reason for the amusics' success on the drum trial 1.86 Hz and not drum trial 2 Hz may be because the drum 1.86 Hz trial was the second of the two drum trials in the order of testing.

Like amusics, the matched control subjects showed significant power at the one-beat level of the metronome and drum conditions, with smaller peaks at the two-beat level. In contrast with amusics, however, the matched controls showed significant power at the one-beat level of the merengue music.

Phase-locking

We next measured whether the body movements were phase-locked to the auditory beat in each stimulus. As in Phillips-Silver et al. (2011), the
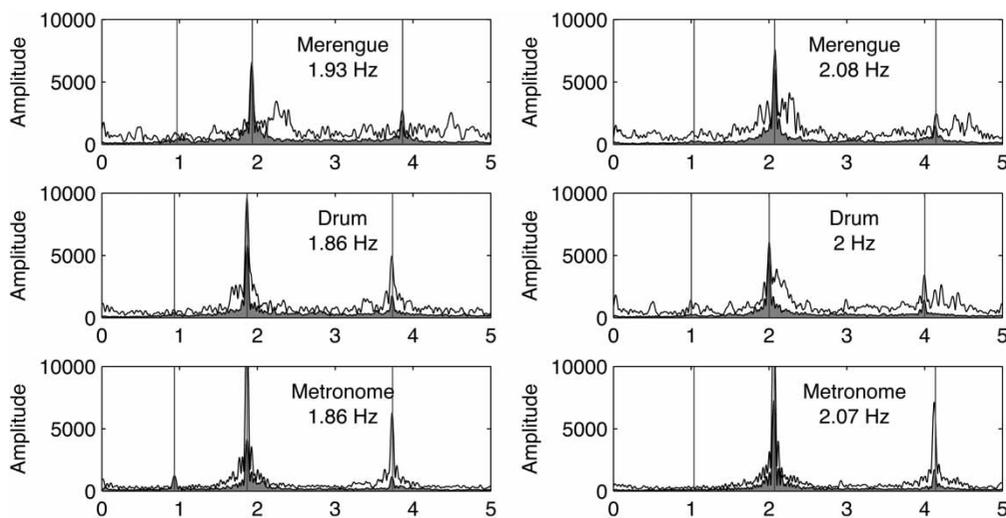

Figure 5. *Power spectra for synchronization performance of 10 amusics (unshaded area) and 8 matched controls (shaded area), on merengue and metronome stimuli. Vertical lines indicate stimulus components at the half-beat, beat (quarter note; middle line), and twice-beat frequencies.*
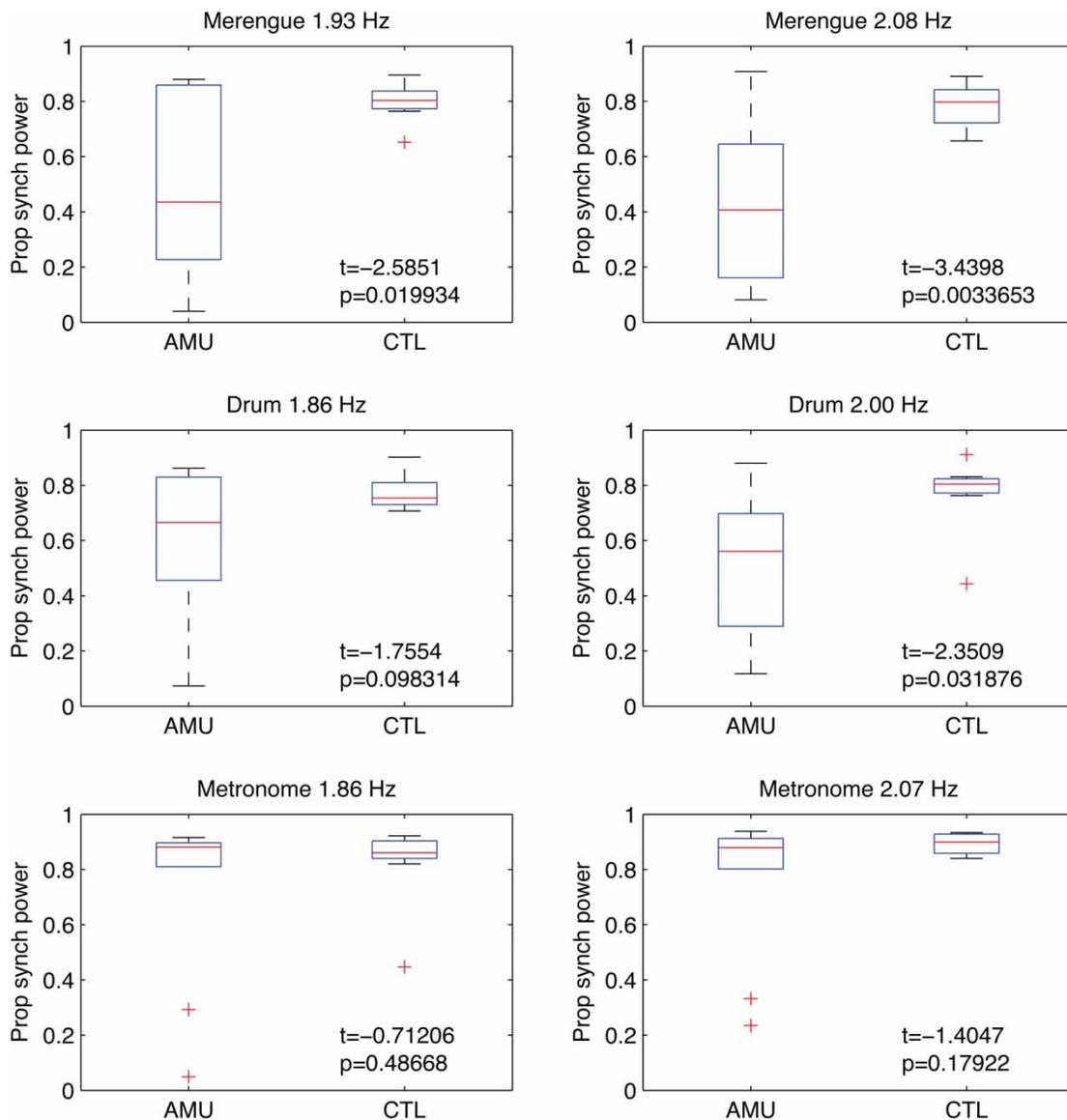
Figure 6. *Boxplots of the amount of significant power across amusic (AMU) and control (CTL) subjects at the beat and twice-beat frequency for each stimulus condition. Results of t-tests are shown for each boxplot. To view this figure in colour, please visit the online issue of the Journal.*

vertical component of acceleration of movement was bandpass filtered using a zero-phase Fourier frequency transform filter and Gaussian frequency response with a centre frequency equal to the beat frequency of each stimulus, and a bandwidth of 20% of the respective centre frequency. A

Hilbert transform was used to estimate the instantaneous phase of the filtered signal. Subsequently, the instantaneous phase was sampled at time points that corresponded to every beat in the stimulus within the interval of 5 to 30 s from the start of the stimulus, resulting in a set of discrete

Table 2. *From Experiment 3, the results of the Kruskal–Wallis test*

Stimulus	Tempo (Hz)	Median CV amusics	Median CV controls	H	p
Merengue	1.93	.3894	.1321	5.7553	**.0164**
Merengue	2.08	.5876	.172	4.5474	**.033**
Drum	1.86	.3151	.1213	5.7553	**.0164**
Drum	2	.6305	.0992	7.1053	**.0077**
Metronome	1.86	.1063	.0798	2.8529	.0912
Metronome	2.07	.1615	.1115	5.7612	**.0164**

Note: CV = circular variance. Significant values shown in bold.

phase values for each participant. The circular variance (a measure of phase-locking) was then calculated from these phase values, and a Kruskal–Wallis test was used to test for significant differences in the circular variances between amusics and controls (Table 2). The median values of the circular variances were larger for the amusic group than for the controls with each stimulus (see Figure 7 for an example), indicating that the amusics showed worse phase-locking in all conditions, including one trial of the metronome.

Measuring amusics' performance against chance
The phase-locking data showed that the amusics' synchronization to music was not up to par with that of controls, yet this did not answer the question of whether amusics showed evidence of

musical synchronization. In order to determine whether the tempo of amusics' movement was due to the tempo of the music (i.e., not to chance, or to some other tempo), and whether they indeed showed synchronization, we tested all subjects' degree of phase-locking against chance level. To this end, we used the phase values obtained at the musical beat locations from the Hilbert transform on the motion capture recordings (5–30 s) to perform a nondirectional Rayleigh test (Z-statistic) against a uniform distribution for each individual recording. This required a high degree of internal consistency of phase angle within each individual subject (refer to the Appendix for phase-locking data of individual amusic subjects). In both the amusic and control groups, the majority of participants
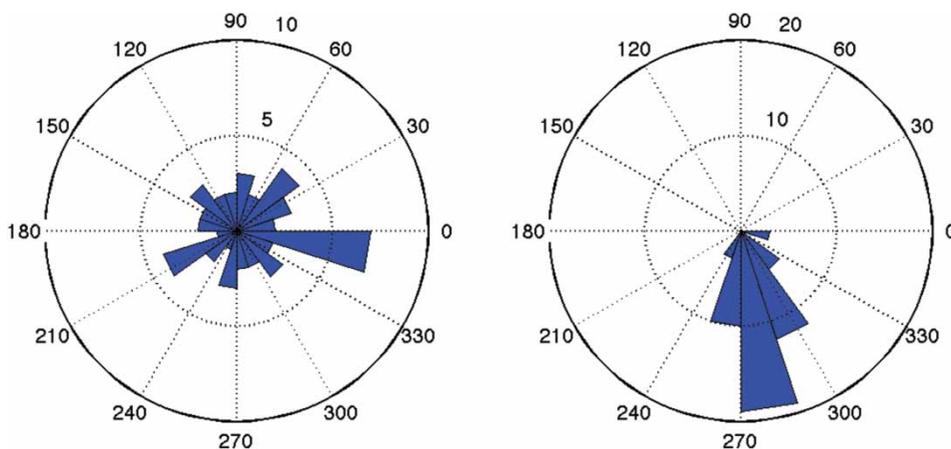

Figure 7. *Circular histograms of phase angle values for a representative amusic (Émilie) and her matched control subject. Each histogram shows the distribution of bouncing phases for the subject bouncing to the metronome stimulus at 1.93 Hz. To view this figure in colour, please visit the online issue of the Journal.*

Table 3. *From Experiment 3, the results of the amusic and control groups' data tested against chance levels*

Group	N	Tempo	Merengue	Drum	Metronome
Amusic	10	2 Hz/2.07 Hz/2.08 Hz	8/10	10/10	9/10
		1.86 Hz/1.93 Hz	7/10	7/10	9/10
Control	8	2 Hz/2.07 Hz/2.08 Hz	8/8	8/8	7/8
		1.86 Hz/1.93 Hz	8/8	7/8	8/8

Note: Calculated with Rayleigh tests. Shows the proportion of subjects who are significantly synchronized ($p < .05$) in each condition.

showed significant synchronization across all conditions (see Table 3). This means that the tempo of the amusics' bouncing was not due to chance, but rather due to the beat period of the music.

Correlation between synchronization performance and MBEA metre tests

We ran correlations between amusics' performance in synchronizing to music and on the MBEA metre tests. To this aim, we took the circular variance as an index of phase-locking during bouncing: the higher the circular variance, the worse the phase-locking. A strong negative correlation was found in amusic subjects between phase-locking performance to merengue music and performance on the original MBEA metre test with pitch variations on the ($r = -.51$), as well as between performance in bouncing to drum music and performance on the MBEA drum test of Experiment 1 ($r = -.53$). These correlations suggest that performance on the synchronization test and on the MBEA metre tests are coupled.

Summary of Experiment 3

Amusics show an ability to synchronize to music—that is, they perform above chance, which is consistent with the idea that they are extracting a musical beat from the auditory stimulus. Nevertheless, the synchronization performance of amusics is worse, and more variable, than that of controls. This result—that amusics' synchronization ability is not on par with controls—is not surprising. There are pitch variations in the majority of music that is typical of Western culture. Given their pitch deficit, amusics are less likely

to engage in such activities and hence to learn synchronization skills as are normal individuals. Our experimental drum music stimulus, which was intended to remove the pitch variations while maintaining some level of rhythmic complexity, resulted in a slight increase in the proportion of amusics who showed significant phase-locking. However, the stimulus was artificial and contained a reduction in two features that have recently been shown to predict the perception of "groove" in real music: the density of events between beats, and beat salience (Madison et al., 2011).

The finding that amusics are capable of synchronizing their body movement to music raises the question of whether their relative impairment (in comparison with controls) might stem in part from a relative lack of deliberate practice in the amusic population. In a final exploratory study, we suggest that a modest amount of exposure, with the explicit intention of finding the beat, might bring an amusic's synchronization to a normal level.

EXPLORATORY STUDY: A CASE OF PRACTICE (ÉMILIE)

In a final exploration, we present the case of one amusic individual, Émilie, who shows a profile that is typical of pitch-deaf amusics. Émilie (A9 in Table 1) had a combined phase-locking score on the merengue music trials that was equivalent to the median score of the group, and she reported to dance "rarely", which is representative of her group. Also typical of her group was the fact that she showed a potential for improved

synchronization to music with repeated exposure: Eight out of the 10 amusics, including Émilie, showed improved performance (i.e., the circular variance, CV, of phase-locking decreased) from Experimental Trial 1 to Trial 2 in synchronizing to dance music (see Émilie's improvement in performance across experimental trials of the merengue music in Figure 8, upper two panels). Émilie gave informed consent for the use of videotaping from this exploratory study.

We retested Émilie a few months later on the same merengue stimulus. This was unexpected to her, and she had no exposure to the merengue music during those months in between her visits. On the two trials (both at the original tempo of 120 bpm, or 2.08 Hz) presented during this later visit, Émilie showed performance that reached the normal level (Figure 8, lower two panels).

As seen in the two postexperiment trials, Émilie's performance in proportion of power synchronized to the musical beat resembled that of the matched controls on the merengue music

(Figure 4). A sharp decrease in the circular variances of Émilie's phase-locking across all trials is consistent with the claim that she showed improvement with each instance of additional exposure, as follows: .8776 for Experimental Trial 1 (2.08 Hz); .3946 for Experimental Trial 2 (1.93 Hz); .1973 for Postexperiment Trial 1 (2.08 Hz); and .1581 for Postexperiment Trial 2 (2.08 Hz). Comparing these values with the median circular variance values of the amusic group (.3894 for the 1.93-Hz stimulus, .5876 for the 2.08-Hz stimulus) and control group (.1321 for the 1.93-Hz stimulus, .172 for the 2.08-Hz stimulus), we see that ultimately Émilie's performance on the merengue 2.08-Hz stimulus surpassed the average level of her matched controls (for a video of Émilie bouncing during her final trial see Supplementary Material 5).

Finally, a Rayleigh test on Émilie's data across trials shows that phase-locking was not significant ($p = .396$) for the Experimental Trial 1, but significant (all $p < .001$) for all subsequent trials
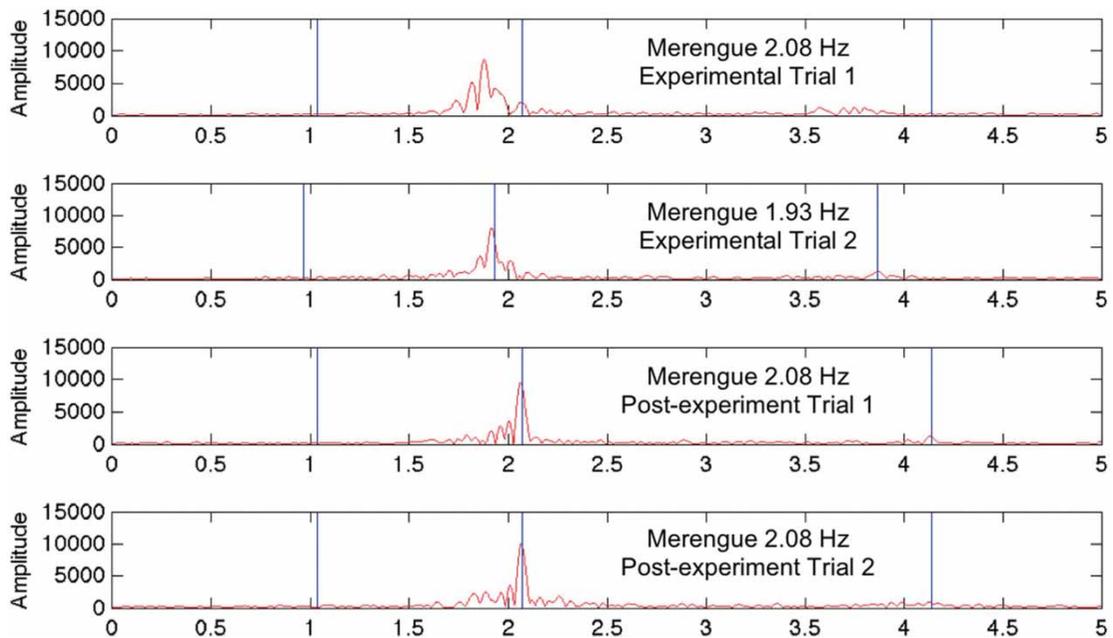

Figure 8. *Power spectra for synchronization performance of amusic subject Émilie on merengue music, in two experimental testing trials and two postexperiment trials. Vertical lines indicate stimulus components at the half-beat, beat (quarter note; middle line), and twice-beat frequencies. To view this figure in colour, please visit the online issue of the Journal.*

(Experimental Trial 2, Postexperiment Trial 1, and Postexperiment Trial 2).

Results of Experiment 3 and the subsequent exploratory study thus suggest that even a modest amount of practice can potentially lead to improvement in synchronization to music in pitch-deaf amusics. What might differentiate this "practice" from the typical exposure that amusics have to dance music could be the repeated listening to a form of dedicated dance music with the explicit intention of finding the beat. This occurs naturally in the neurotypical population, while less so in the pitch-deaf population, and an experiment designed to measure practice effects, including the point at which participants begin bouncing at the start of a stimulus, could address this question in the future. Taken together with the results of Experiments 1 and 2, we offer the suggestion that given exposure to real dance music without complex pitch variations (as heard in drum circles or military marches), and the opportunity and encouragement to practice deliberately moving to the beat, we might find that this population is able to dance in time to music.

GENERAL DISCUSSION

The present set of experiments provides evidence for musical strengths in pitch deafness. In the context of music with reduced pitch variations (drum timbres), pitch-deaf amusics show normal metre discrimination. When listening to an ambiguous drum rhythm pattern, their body movement (bouncing on every second or third beat) can determine the auditory representation of the strong beat, just as is seen in normal adults and infants. And while the amusics' synchronization of body movement to popular music (with pitch variations) is not equivalent to that of their controls, we find preliminary evidence for their potential to improve to a normal level with some practice. Taken together, these findings suggest that we can predict in this population a particular proclivity towards synchronizing dance movement with real drum music.

The presence of pitch variations in typical dance music might help explain why pitch-deaf individuals tend to dance less frequently than the normal population. Pitch variations seem to interfere with beat and metre processing in music, as seen in Experiment 1 of this study (see also Foxton et al., 2006), which then might impede the ability to produce synchronized body motion. If such an impairment in synchronization ability is present from early in life, it might tend to reduce participation in dance activities as reported by many pitch-deaf individuals, and it might result in less enjoyment from dance. A lack of practice in dancing, and perhaps a lack of music that is most conducive to dancing for the pitch-impaired, can contribute to a reserved attitude towards synchronization and dance. It seems unlikely, however, that the synchronization impairment of the pitch-deaf is attributable solely to a lack of practice, because of the rapid improvement observed in the exploratory study with such a minimal amount of repeated exposure (a total of a couple of minutes across all trials) and the fact that the pitch-deaf population has shown impaired synchronization also in tapping to real music excerpts (Dalla Bella & Peretz, 2003)—a skill that is likely to be practiced more often than overt dancing because it can occur discretely and even covertly (Repp, 2007). What might differentiate the nature of the modest "practice" for Emilie in the exploratory study from amusics' typical experience is the repeated exposure to a form of dedicated dance music with the explicit intention to find the beat. This exercise, when continued over time, can be thought of as a form of deliberate practice and should be considered in addition to the nature of the music stimulus, in a prescription for improvement in beat finding and synchronization.

An additional feature that should be explored in creating deliberate practice opportunities for beat finding and synchronization in amusics is the presence of a model. In the current study, the role of the experimenter was simply to observe the amusics and focus their attention on finding the beat. However, imitation of a dedicated model has previously been shown to improve singing in

this pitch-deaf population (Tremblay-Champoux et al., 2011). This may differ from the typical life experience in which models may be numerous, unreliable, or simply not dedicated to an intentional improvement of the specific musical skill under optimal conditions. The benefits of imitation of a dedicated model might extend to the tasks of beat finding and dancing in pitch-deaf amusics.

The present evidence that the pitch-deaf have musical strengths in beat finding, and potentially in dance, is consistent with the idea that there exists a double dissociation between pitch deafness and the newly documented form of congenital amusia called beat deafness. In the first reported case of beat deafness, Mathieu, the reverse profile is seen. That is, Mathieu's perception of musical pitch is intact while his perception of the musical beat (as in the MBEA metre test) and synchronization of body movement to the merengue music, as well as to an array of pieces from diverse musical genres, is severely impaired (Phillips-Silver et al., 2011).

Studies of pitch deafness and beat deafness point to distinct neurogenetic origins for musical pitch and time. In pitch deafness, a right-hemispheric neural network reveals abnormal connectivity (Hyde et al., 2007, 2011; Loui et al., 2009), which probably has a genetic origin (Drayna et al., 2001; Peretz et al., 2007). The neural networks underlying beat and metre processing are less well identified and likely to be more widespread in the brain. Potential candidate regions involved in the generation and perception of a periodic beat include right temporal parietal cortex (Fries & Swihart, 1990; Wilson, Pressing, & Wales, 2002), basal ganglia (Grahn & Brett, 2007, 2009), and connections between auditory and motor cortices (Chen, Penhune, & Zatorre, 2008). We predict that these musical time-based networks are normally functioning in pitch deafness based on the results of the present study (see also Foxton et al., 2006; Hyde & Peretz, 2004), although these networks may require more training or more optimal stimulation in the pitch-deaf population than in the normal population.

Future research should continue to address the extent of the abilities for beat perception and synchronization in the pitch-deaf amusic population and the circumstances that can support such behaviours. We suggest that investigations aim to determine whether the pitch deaf have a higher threshold for beat salience, irrespective of pitch variation. Future studies could also examine whether beat processing is normal in this population as indexed by neural resonance to beat and meter (Nozaradan, Peretz, Missal, & Mouraux, 2011) and by motor cortex excitability (Stupacher, Hove, Novembre, Schutz-Bosbach, & Keller, 2013), as well as whether optimal beat salience and synchronization ability can be enhanced in this population by modality processing affinities, such as moving visual signals (e.g., Grahn, 2012; Hove, Fairhurst, Kotz, & Keller, 2012). Following on the results of the present set of experiments, we also suggest that this group be evaluated for synchronization of body movement to real drum music, such as that heard in drum circles or military marches.

Not much is known about amusics' appraisal of the danceability of music. Recent work has suggested that the general population can judge whether pieces of music "groove", or make them want to move (Janata et al., 2012). This work also takes into consideration the degree of groove subjectively experienced when synchronizing movement (and in turn, the effect of groove on the manifestation of movement), as well as the positive affect and difficulty of the task (i.e., error correction mechanisms underlying performance) associated with synchronization (Janata et al., 2012).

Subjective ratings of emotional arousal and valence can provide an additional index of the positive affect associated with groove (Grewe, Nagel, Kopiez, & Altenmüller, 2007). Other recent work has attributed the perception of groove to physical characteristics in music, including beat salience and event density (Madison et al., 2011). Such features facilitate entrainment and synchronization: for example, musical genres such as West African music and Brazilian Samba have high levels of groove according to Western

listeners, the latter of which draws on multiple and redundant means to yield beat salience, as a dedicated dance music (Madison et al., 2011).

Such work in characterizing perceived groove opens up myriad possibilities for testing amusics' perception of those features in real music, as well as the judgement of gradations in such features in the context of controlled experimental stimuli. Questions for future research include whether the pitch-deaf population show a normal sensitivity in their appraisal of the groove factor, and whether their synchronization ability is affected by their subjective judgements, as is the case in the normal population. Could a failure of a pitch-deaf individual to reach normal levels of synchronization reflect not only a pitch deficit, but also a dampened sense of affect in groove? To address this we might measure whether pitch-deaf individuals experience reduced positive affect with synchronization and groove relative to controls, as it has been shown that the quality of sensorimotor synchronization predicts affect and feelings of affiliation (Hove & Risen, 2009), and that synchronized movement fosters cooperation and prosocial behaviour (Kirschner & Tomasello, 2010; Wiltermuth & Heath, 2009).

The near-intact ability to synchronize movement to music and its associated social aspects, including positive affect and cooperation, are important topics of investigation in congenital amusia for understanding the neural networks underlying music and dance, as well as the potential to tap into relative musical strengths for the sake of practice and even remediation of specific musical impairments. For example, if beat finding and social entrainment are preserved in pitch deafness then a music intervention tailored to these strengths, such as practice with an adaptive virtual partner (Fairhurst, Janata, & Keller, 2013), could provide a road to remediation of pitch processing, perhaps especially when the disorder is identified early in life (cf. Lebrun, Moreau, McNally-Gagnon, Goulet, & Peretz, 2011) when cortical plasticity might be maximal for musical stimuli (e.g., Trainor, Lee, & Bosnyak, 2011).

A music intervention tailored to the pitch-deaf population might take up two aims. The first aim might be to tap into musical strengths (i.e., rhythm) to the benefit of impaired capacities (i.e., pitch discrimination). An empirical question is whether detection of fine-grained pitch changes could be improved by relying on temporal expectations. For example, the coupling of internal timekeepers with musical periodicities can affect allocation of attention (Jones, 2009) and might facilitate memorization of musical features (Keller & Burnham, 2005). Attention, timing, and sequencing in music often recruit areas involved in the intimate coupling of perception and action—including premotor, parietal, cerebellar, and basal ganglia structures—and also support skills such as tracking the individual parts in polyphonic music (Janata & Grafton, 2003). However, since the current study indicates a mild impairment in the pitch-deaf subjects' ability to synchronize movement to an isochronous beat, a primary area of investigation might be the neural representation of isochronous sequences in the absence of intent to move, as manifest across auditory and motor areas in neuromagnetic beta-band oscillations (Fujioka, Trainor, Large, & Ross, 2012). If predictive timing is intact in the pitch-deaf population, this technique could provide an indication of whether it can be used for bootstrapping of pitch discrimination abilities.

A second aim of tailored music intervention might involve an early music education programme that focuses on the relative musical strengths present early in life in the pitch deaf population—that is, rhythm perception and beat-finding—by teaching percussion and dance skills. These skills would be in keeping with the literature supporting the benefits of synchronization for positive affect, affiliation, and cooperation (Hove & Risen, 2009; Janata et al., 2012; Kirschner & Tomasello, 2010; Wiltermuth & Heath, 2009). The target of such a musical education programme could be drawn from some classical Western music pedagogies, such as Dalcroze Eurythmics, Kodály Concept and Orff Schulwerk, but it could just as well be developed out of non-Western or non-European music traditions that center around movement and percussion.

A musical approach that embraces non-pitch-centric skills is musical nonetheless and ecologically valid. It is worth considering that an amusic disorder such as pitch deafness might be a somewhat culturally specific impediment—one that is particular to the features of a particular tonal music system. Pitch deafness might not even be diagnosed in the context of an archaic music society that implements a wide zone of intonation, as in Lithuanian song (Ambrazevičius & Wiśniewska, 2008), or a much larger tolerance for pitch variation in particular steps of the scale than in traditions that base the musical scale on a fixed pitch of 440 vibrations per second for A, such as in traditional African vocal music (Nketia, 1974). Likewise, there are musical cultures that feature sensory roughness and very narrow pitch ranges, such as the harmonic intervals that are no larger than a major second in Bosnian ganga song (Vassilakis, 2005). In such musical traditions, "good performance" showcases different features of musical expression from those in Western music—including the sonic effects of roughness, steady spectral envelopes, and nuanced rhythmic and amplitude fluctuations—and thus may not require the same degree or type of pitch intonation (Vassilakis, 2005). In these contexts, intonation is important, but it is an open question whether the demands on intonation might fall within the range of ability of the individuals that are characterized as pitch-deaf by Western criteria. Certainly the demands of distinct musical systems exercise various skills in musical expression, with some placing higher demands on execution of pitch (e.g., Western music), and others placing higher demands on execution of temporal (e.g., African music) or timbral features (e.g., Balkan music). In the latter, a diagnosis of pitch deafness may not be likely to occur, or may simply not matter, if it is not at the core of musicality in those systems. On the other hand, such musical cultures might be quick to discover cases of beat deafness. Musicality has many facets, and it helps us to remember this as we explore selective musical deficits and move towards unearthing the neurobiological origins of musical pitch and time.

In sum, the present findings are encouraging for the pitch-deaf amusic population, who have historically been shunned from many music or dance activities. If feeling the beat—and the dance-related skills that might develop out of listening and practicing to legitimate percussion music—is enough, then we might just consider that amusic does *not* mean "unmusical".

Supplementary material

Supplementary content is available via the 'Supplementary' tab on the article's online page (http://dx.doi.org/10.1080/02643294.2013.863183).

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APPENDIX

Accuracy of Individual Phase-Locking for Amusic Subjects

The Appendix shows the accuracy of individual phase-locking for each amusic subject, expressed as the circular variance (CV), and the Rayleigh's Z-statistic (Z-value). The CV indicates the variance in phase-locking: the higher the CV, the lower the degree of phase-locking and, thus, the worse the performance. The Rayleigh's score indicates whether the subject synchronized to the tempo of the music (against chance level).

Subject	Stimulus	Tempo	CV	r	Z
A1	Drum	112	.077	.923	56.68
A1	Drum	120	.286	.714	28.13
A1	Merengue	112	.122	.878	41.13
A1	Merengue	120	.126	.874	44.45
A1	Metronome	112	.083	.917	60.97
A1	Metronome	120	.120	.880	44.47
A2	Drum	112	.703	.297	4.87
A2	Drum	120	.406	.594	21.32
A2	Merengue	112	.160	.840	37.17
A2	Merengue	120	.640	.360	7.79
A2	Metronome	112	.088	.912	66.69
A2	Metronome	120	.152	.848	41.14
A3	Drum	112	.249	.751	29.23
A3	Drum	120	.637	.363	7.28
A3	Merengue	112	.377	.623	21.85
A3	Merengue	120	.337	.663	25.50
A3	Metronome	112	.099	.901	42.49
A3	Metronome	120	.202	.798	36.80
A4	Drum	112	.343	.657	22.96
A4	Drum	120	.591	.409	4.25
A4	Merengue	112	.851	.149	0.52
A4	Merengue	120	.861	.139	0.57
A4	Metronome	112	.092	.908	59.70
A4	Metronome	120	.171	.829	56.84
A5	Drum	112	.735	.265	3.37
A5	Drum	120	.519	.481	8.50
A5	Merengue	112	.423	.577	16.54
A5	Merengue	120	.549	.451	11.31
A5	Metronome	112	.251	.749	24.26
A5	Metronome	120	.569	.431	10.57
A6	Drum	112	.447	.553	7.46
A6	Drum	120	.725	.275	2.08
A6	Merengue	112	.400	.600	13.80
A6	Merengue	120	.626	.374	8.49
A6	Metronome	112	.102	.898	19.74
A6	Metronome	120	.433	.567	13.91
A7	Drum	112	.698	.302	4.57
A7	Drum	120	.698	.302	2.34
A7	Merengue	112	.527	.473	6.18
A7	Merengue	120	.788	.212	1.83
A7	Metronome	112	.598	.402	3.74
A7	Metronome	120	.765	.235	1.24

(Continued)

Subject	Stimulus	Tempo	CV	r	Z
A8	Drum	112	.104	.896	52.55
A8	Drum	120	.106	.894	44.63
A8	Merengue	112	.105	.895	57.15
A8	Merengue	120	.109	.891	46.16
A8	Metronome	112	.114	.886	40.60
A8	Metronome	120	.104	.896	46.18
A9	Drum	112	.287	.713	27.11
A9	Drum	120	.624	.376	13.82
A9	Merengue	112	.282	.718	35.11
A9	Merengue	120	.667	.333	2.66
A9	Metronome	112	.179	.821	34.98
A9	Metronome	120	.133	.867	43.62
A10	Drum	112	.140	.860	38.51
A10	Drum	120	.147	.853	46.97
A10	Merengue	112	.384	.616	21.41
A10	Merengue	120	.173	.827	46.27
A10	Metronome	112	.067	.933	71.43
A10	Metronome	120	.093	.907	61.40