

## Short Communication

## Amusics can imitate what they cannot discriminate

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## ABSTRACT

A longstanding issue in psychology is the relationship between how we perceive the world and how we act upon it. Pitch deafness provides an interesting opportunity to test for the independence of perception and production abilities in the speech domain. We tested eight amusics and eight matched controls for their ability to perceive pitch shifts in sentences and to imitate those same sentences. Congenital amusics were impaired in their ability to discriminate, but not to imitate different intonations in speech. These findings support the idea that, when we hear a vocally-imitatable sound, our brains encode it in two distinct ways- an abstract code, which allows us to identify it and compare it to other sounds, and a vocal-motor code, which allows us to imitate it.

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## 1. Introduction

Humans are natural mimics, and one of the things we are best at imitating is speech. Speech imitation is the basis for all sorts of behaviors, including clarification questions, sarcasm, and Monty Python recitations, and it is often considered to be the basis for children's language development. However, speech is an incredibly complex act; it seems unlikely that our ease at imitating speech arises from our conscious perception of all of the different components of the speech signal. One explanation for our ease of speech imitation is that it relies on our motor system. In this study, we test whether speech information can be recognized and acted upon by the motor system in cases of impaired conscious perception; in essence, a dissociation between speech perception and imitation.

One aspect of speech that we can test for such a dissociation is pitch, and congenital amusia provides a useful test case. Most congenital amusics are pitch deaf (Ayotte, Peretz, & Hyde, 2002; Hyde & Peretz, 2004); they have severe problems identifying pitch changes, discriminating rising from falling pitch, and identifying subtle pitch differences between statements and questions in speech (Foxton, Dean, Gee, Peretz, & Griffiths, 2004; Hyde & Peretz, 2004; Liu, Patel, Fourcin, & Stewart, 2010; Loui, Guenther, Mathys, & Schlaug, 2008). However, pitch production abilities may outstrip pitch perception abilities among some amusics (Dalla Bella, Giguère, & Peretz, 2009; Hutchins, Zarate, Zatorre, & Peretz, 2010; Liu et al., 2010; Loui et al., 2008; Tremblay-Champoux, Dalla Bella, Phillips-Silver,

Lebrun, & Peretz, 2010). Loui et al. (2008), for example, demonstrated that congenital amusics were better at imitating the direction (although not the magnitude) of a pitch interval than at naming the direction of those same intervals. In speech, a similar finding was obtained by Liu and colleagues (Liu et al., 2010), who showed the same effects of pitch direction in speech, using statement-question pairs. In both of these studies, though, imitation ability was still significantly impaired compared to controls. These findings were explained by a dual-route theory, which posits that different neural processing pathways are used to support different types of responses. According to this theory, pitch can be encoded different ways in different neural pathways, with one representation supporting vocal production, and another supporting conscious perceptual tasks such as identification and discrimination. Williamson and colleagues (Williamson, Liu, Peryer, Greierson, & Stewart, 2012) failed to replicate Loui et al. (2008), and attempted to measure pitch perception and production with equivalent task designs. They found no difference between the two response modes, and claimed that differences in task demands between discrimination and imitation tasks can account for the better production than perception abilities among amusics, due to amusics' bias to be conservative in discrimination tasks. However, their results, which failed to show pitch discrimination threshold differences between amusics and controls (a hallmark of amusia, see above) and found several individuals with pitch identification and production thresholds near two octaves, may not be representative of amusics' true pitch perception and production abilities.

Although amusics' pitch problems are most easily identifiable in the domain of music, speech may be a more useful domain to test pitch perception and production. Unlike music, we can manipulate

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the pitch in speech without confounding it with changes in the underlying meaning of the sequence (see [Supplementary material](#) for a discussion and analysis of stress in sentences). In the present study, pitch deaf individuals (referred to hereafter as amusics) and matched controls were tested on their abilities to imitate sentences with local pitch variations and to perceive the same pitch differences between pairs of sentences. Amusics were expected to perform poorly on the discrimination task, due to their impaired pitch discrimination abilities. However, if we see preserved ability to imitate pitch in speech, this demonstrates that amusics still have access to a motor representation of pitch, which would in turn provide evidence that pitch in speech is represented both as a vocal-motor code, supporting imitation, and as an abstract, generalizable perceptual code, supporting identification and comparison.

## 2. Results

As expected, the amusics were significantly worse than matched controls in their ability to perceive pitch shifts in sentences as measured in hits minus false alarms,  $F(1,14) = 12.63$ ,  $p = .003$ ,  $\eta^2_{\text{partial}} = .47$  (Fig. 2; all degrees of freedom reflect Greenhouse–Geisser corrections). However, both groups responded to changes in the size of the pitch shift,  $F(1.54,21.58) = 34.34$ ,  $p < .001$ ,  $\eta^2_{\text{partial}} = .47$ ; there was no interaction between amusia and shift size. This indicates that amusics could discriminate the shifts to some extent, but were impaired across all shift sizes. The same pattern of significance was also obtained with d-prime measurements (see [Supplementary material](#)). In contrast, in imitation, amusics showed no difference from controls,  $F(1,14) = .003$ , *n.s.*,  $\eta^2_{\text{partial}} < .001$ , nor was there an interaction between amusia and shift size. Across both groups, there was a significant main effect of shift size,  $F(1.42,19.86) = 60.02$ ,  $p < .001$ ,  $\eta^2_{\text{partial}} = .81$ , indicating that participants were equally sensitive to the pitch differences in the imitation task. This same pattern of significance was also found using an interval measurement and global imitation indices (see [Supplementary material](#)). Non-parametric Mann–Whitney *U* tests confirmed the pattern of findings in both discrimination and imitation tasks. These findings indicate that congenital amusics are impaired in perception of pitch changes in speech, but have normal ability to imitate those same pitch changes.

Amusics showed practically no correlation between their performance on perception and imitation tasks,  $r(6) = .06$ , *n.s.*, whereas controls showed a strong correlation between these two measurements,  $r(6) = .90$ ,  $p = .002$ . These group differences were also shown in an items-based correlation (where the data points are averages of each stimulus across subjects, rather than vice versa), with,  $r(21) = .06$ , *n.s.* in amusics and  $r(21) = .422$ ,  $p = .05$  in controls.

## 3. Discussion

We found a clear dissociation between pitch perception and production. Amusics were impaired at discriminating between sentences with and without pitch shifts, but were unimpaired at imitating those same pitch shifts. Although neither group produced perfect imitations, both clearly approximated the pitch shifts of all sizes. Thus, there is some form of pitch information that amusics are able to use to inform their imitative responses. This is likely to reflect a motor-system based encoding of pitch; amusics seem able to create a pitch with their voice without being aware of what the pitch is or its relationship to other pitches. This disconnect between perception and production is further confirmed through the amusics' (but not controls') lack of correlation

between the perception and production tasks. Altogether, these results provide strong evidence for the dissociation of pitch perception and pitch production abilities. When both systems are fully functional, as in the controls, information from the two systems is coupled, and the two systems can interact, as is demonstrated by the perception–production correlation in the control group, indicating the possibility of cross-verification of information across encoding systems. However, when one system is compromised, as is the amusics' pitch perception system, the two systems are decoupled.

Some previous studies have also shown a dissociation between amusics' ability to perceive and imitate pitch direction (Loui et al., 2008; Liu et al., 2010; Nan, Sun, & Peretz, 2010); the current results demonstrate a dissociation of perception and production of pitch height, rather than direction, and are the first to show unimpaired imitation ability among congenital amusics who speak a non-tonal language. Williamson et al. (2012), however, failed to show such a dissociation, and has attributed this difference in results to differences in task demands. The current results use a new type of stimulus to support the dissociation framework, and argue against Williamson et al. (2012) by showing that these results are not due to a stronger conservative bias for amusics than controls in the discrimination task (see [Supplementary material](#)). Nor is it likely that these results could be accounted for by amusics' poorer pitch memory (Tillmann, Schulze, & Foxton, 2009; Williamson & Stewart, 2010), as the required retention interval in the discrimination task (less than 3 s) was the same as was required in the imitation task, and there was no effect of sentence length (in duration or number of syllables) on the performance of amusics or controls in either task, despite considerable variation in length across sentences (see [Supplementary material](#)).

Rather, our behavioral findings lend support to the characterization of congenital amusia as a disconnection syndrome. Amusics show reduced white matter and fiber tracts (Loui, Alsop, & Schlaug, 2009; Hyde, Zatorre, Griffiths, Lerch, & Peretz, 2006) and abnormal functional connectivity (Hyde, Zatorre, & Peretz, 2011) between the auditory cortex and the inferior frontal cortex (IFG) on the right side of the brain. Electrophysiological studies have also reinforced this view, showing evidence for early markers of auditory processing in amusics (MMN), but not later ones (P3; Peretz, Brattico, Järvenpää, & Tervaniemi, 2009). The dissociation between normal speech imitation and impaired discrimination among amusics is explainable in terms of impoverished communication in the auditory action–perception pathway; different neural pathways may support motor versus more consciously accessible encodings of pitch information. While the two systems can interact and are not likely not entirely separable, our results argue for multiple pathways for encoding pitch.

### 3.1. Theories of perception and production

This perception/production dissociation is in line with similar dissociations found in other domains. In vision, for example, dissociations have been shown between the abilities to perceive and to manipulate the orientations of objects (Goodale, Milner, Jakobson, & Carey, 1991; Perenin & Vighetto, 1983). In addition, studies of speech among aphasics have shown dissociations between the abilities to speak and to comprehend words. Such dissociations have also been explained using dual-route models (Goodale & Milner, 1992; Hickock & Poeppel, 2004; Rauschecker & Scott, 2009), in which information relative to perceptual judgments and to action are processed in separate neural pathways.

The current study supports a dual-route framework for pitch perception and production (Griffiths, 2008), and shows that this dual-route system is also a part of the larger system of speech

processing. This finding supports the case that dissociations between perception and production reflect the fundamental design of our neural architecture, rather than an oddity specific to individual domains. This domain generality may reflect independent evolutionary origins of the two neural functions— an organism's need to act within and upon the world is fundamental to all animals, whereas the need to categorize and compare sets of objects in the world may be only necessary in high-level cognition. Given this difference between the two systems, it may make sense to consider the action system the more basic of the two. Indeed, motion is the primary goal of brains (Wolpert, 2011) and may have provided an early evolutionary basis for the cortical action system.

### 3.2. Pitch in music and language

The present study presents a novel contribution to the debate on whether congenital amusia is specific to music (Ayotte et al., 2002), or whether it is music-relevant (Hutchins, Gosselin, & Peretz, 2010; Patel, Wong, Foxton, Lochy, & Peretz, 2008; Peretz & Hyde, 2003). While most amusics report no problem in everyday speech perception and production, there is evidence that approximately 30% of amusics show some problems with perception of pitch-related features of language, including statement/question discrimination (Patel et al., 2008) and lexical tones (Nan et al., 2010), especially when the relevant pitch cues are fine-grained (Liu et al., 2010, 2012). These studies have all investigated amusics' language problems with stimuli in which changes in pitch were confounded with changes in meaning; in contrast, the current study asked participants to imitate and discriminate pitch changes that did not evoke reliable changes in the meaning of the sentence. Our results show that, when meaning is not systematically manipulated along with pitch, amusics show a clear perceptual deficit in speech perception (see also Tillmann et al., 2011). This held across the entire sample—there was almost no overlap between the two groups in the discrimination task.

The dissociations shown by amusics in pitch perception and production in speech can provide explanations for similar patterns of behavior found in normal individuals in some situations. For instance, non-native speakers are often able to perceive a foreign language quite clearly, while still speaking with a strong accent. In contrast, trained vocalists may be able to sing in a foreign language without any accent, but not comprehend it at all. The dissociation between perception and production provides an explanation for why second language learners can have very different speech and comprehension abilities.

Interestingly, our results show that even normal participants were less than perfect at discriminating pitch shifts of even five semitones. This magnitude of shift would be easily noticed in music, where changes of one semitone are easily noticed by most listeners (Hutchins, Roquet, & Peretz, 2012; Peretz, Champod, & Hyde, 2003). There are several possible explanations for this difference between pitch change detection abilities in music and language. One explanation is that, in language, the pitch within a syllable is generally not as stable as it is within a musical note (although fluctuations in pitch associated with vocal vibrato can be very large, over two semitones in width; see Prame, 1997). Another possible explanation is that, as these are immediately recognized as examples of speech, the brain primarily processes them with the left, rather than the right auditory cortex, which is known to be recruited in examples requiring more temporal, rather than frequency, precision (Zatorre & Belin, 2001). The lower frequency precision of this type of spectral analysis would make pitch changes relatively more difficult to identify in speech, rather than in music, and normal participants have been shown to be more

accurate at recognizing very small  $\frac{1}{4}$  semitone shifts in repeated musical tones than syllables (interestingly, congenital amusics tend to show the opposite effect; Tillmann et al., 2011). Finally, this effect may be a function of our using non-meaningful pitch changes, which may not draw attention to themselves as much as would an equivalent pitch change in music. These potential causes are not exclusive, though, and our results provide experimental support for the notion that pitch changes in speech are not as easily identified as those in music.

### 3.3. Conclusion

Our results show a clear dissociation between pitch perception and production in speech. Congenital amusics were impaired in their ability to discriminate, but not to imitate the intonational patterns in speech prosody. These findings support the idea that, when we hear a vocally-imitatable sound, our brains encode it in two distinct ways— one way which allows us to identify it and compare it to other sounds, and another way which allows us to imitate it. The former encoding is consciously accessible, and supports the ability to make comparative judgments such as same or different, or higher or lower. In the case of pitch, this representation is likely to be akin to a mental pitch line. The motor-based encoding is not consciously accessible, and can be thought of as representing the way in which we would have to move and position our respiratory system, larynx, and vocal tract to create that sound. This is a similar concept to the motor theory of speech (see Galantucci, Fowler, and Turvey (2006), for a review), but does not posit the primacy or exclusivity of that encoding system. This motor representation contains much the same information about pitch as does a mental pitch line, but is not efficient to support pitch comparison judgments. The dissociation of these two abilities provides support for separate neural pathways regulating pitch production and perceptual judgments, and suggests that the latter ability may not be required for imitative behaviors.

## 4. Methods

### 4.1. Participants

Participants were eight congenital amusics and eight controls; the groups were matched for age and education level. All participants were female, so that we could use a unified set of stimuli. Amusics were determined by their scores on the Montreal Battery of Evaluation of Amusia (MBEA; Peretz et al., 2003), which assesses music processing with six tests concerning melody, rhythm, meter, and memory. Amusics obtained a global score more than two standard deviations below that of controls but had normal hearing for their age. Table 1 shows participant characteristics of the amusics and controls. All participants were native Québécoise francophones, and all participants gave informed consent for their participation.

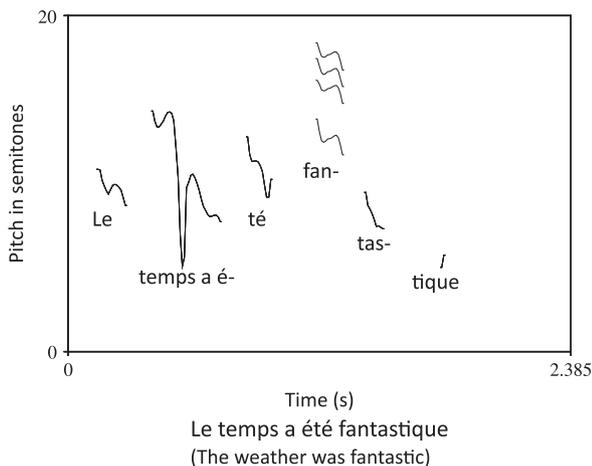
### 4.2. Stimuli

The stimuli were 23 original French sentences (see Supplementary material for full stimulus list). The sentences were read and recorded by a female native francophone in a neutral Québec accent, who was instructed to avoid monotone interpretations. The speaker recorded 100 sentences, and the best 23 were selected by the experimenter to use. All recordings were made using a Neumann TLM 103 microphone (Georg Neumann GmbH, Berlin, Germany) and saved as .wav files. For each of the examples, we selected a one to three syllable section to shift,

**Table 1**

Age, years of musical training, global MBEA percentage, and accuracy rates in the discrimination and imitation task, measured in hits minus false alarms and percentage of imitations following the shift direction, shown for each amusic and control participant.

Participant	Age	Music training	Global MBEA percentage (%)	Discrimination (H-FA) (%)	Imitation (%)
<i>Amusics</i>					
FA	70	2	69	49	82
MA	68	0	63	23	71
MB	69	4	74	49	83
GC	64	1	73	46	89
EL	60	3	61	49	66
ML	70	0	60	04	83
DM	61	1	74	43	90
AS	69	2	63	58	81
<i>Controls</i>					
FB	62	2	92	78	91
GBD	66	2	91	65	83
LF	65	0	93	67	83
AJ	70	1	91	65	80
LL	60	0	85	45	75
LO	58	0	98	78	96
MP	67	3	91	68	84
RSP	67	2	93	62	84
<i>Amusic mean</i>	66.4	1.6	67	40	81
<i>Control mean</i>	64.4	1.3	92	66	84



**Fig. 1.** The fundamental frequency trace of a sample sentence is shown, overlaid with the traces of shifted versions of the same sentence. Note that the traces are identical for all syllables except the shifted one, “fan”, which shows four different heights (one for each version).

using the stretch function of Adobe Audition v2.0 (Adobe Systems Inc., San Jose, California, USA), set to preserve the timing and formant structure of the voice. Shifted sections generally started and ended on non-vocalic phonemes (e.g. /s/, /p/), which do not have a pitch and thus mask the abruptness of the shift. The same sections were shifted by three, four, and five semitones to create three shifted version of each original sentence. All sentences and each of their shifted versions were subsequently verified by native speakers to be natural sounding, and not contain any noticeable artefacts of the shifting. These sentences had a mean length of 2.16 s (range = 1.29–2.98 s), comprising 6.48 words (8.91 syllables; see Fig. 1 for an example of an original sentence and shifted versions).

### 4.3. Procedure and design

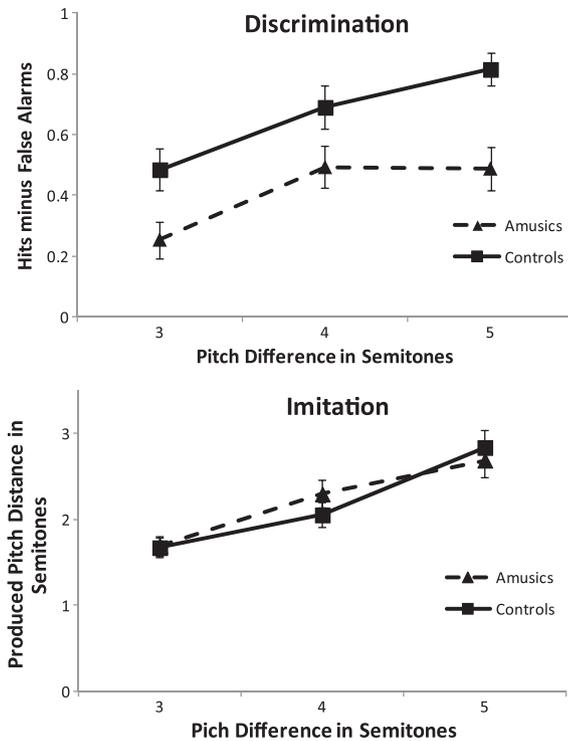
In the imitation task, participants heard the sentences individually and imitated them as closely as they could. The 92 stimuli, including 23 original recordings and 69 shifted versions, were presented in a pseudo-random order, such that a sentence was never presented within three trials of another version of the same sentence. Participants were instructed to imitate “the duration, the intonation, and the emotion” of each sentence after listening to it. The presentation of the stimuli was self-paced. Participants were not informed or given explicit instructions about the repetitions or variations in sentences.

In the discrimination task, participants heard two versions of the same sentence, and were asked to decide whether the two versions were exactly the same or had any difference. Participants were instructed to respond to any differences they might hear between the versions, and were informed that the sentences would differ in intonation. The perception task comprised 138 sentence pairs, in pseudo-random order, such that a sentence was never presented within three trials of another version of the same sentence. In each trial, participants heard one version of a sentence, followed by a 500 ms pause, then another example of the same sentence. After the second example, participants indicated whether the two sentences were identical or not by pressing ‘1’ or ‘0’ on the keyboard. No responses were accepted until the sentences were completely finished playing, and the onset of each trial was self-paced. Half of the sentence pairs were identical, and half were different (one shifted version, one original version). The different pairs were equally likely to contain a shift of three, four, or five semitones. The identical pairs could be two original versions or two shifted versions, making it a fully-balanced design.

The imitation task was always run before the discrimination task, so that participants would not be primed to recognize the intonation differences in the imitation section. The imitation section lasted about 15 min, and the discrimination section lasted about 30 min. In the imitation task, stimuli were presented and responses were recorded using Max/MSP (Cycling ’74, San Francisco, California, USA). The discrimination task was run using *ePrime* (Psychology Software Tools, Inc., Sharpsburg, Pennsylvania, USA). All stimuli were heard through open *BeyerDynamic* DT 990 Pro headphones (Beyerdynamic GmbH & Co. KG, Heilbronn, Germany), and imitations were recorded with *Neumann* TLM 103 microphone (Georg Neumann GmbH, Berlin, Germany).

### 4.4. Analysis

Performance on the perception task was measured in terms of proportion of hits minus false alarms, as well as *d-prime*, for each participant at each level of pitch shift. Data from the imitation section were analyzed for pitch using *Praat* (Boersma & Weenink, 2012) and converted into semitones (a logarithmic measurement which conserves octave equivalence; 12 semitones = 1 octave). We analyzed the data at the level of vocalic groups, which are sections of continuously pitched material. Vocalic groups are often individual syllables, but can include multiple syllables when phonated consonants, which have a pitch (such as /m/ or /l/) are included. This allows us to easily find units which have clear beginnings and endings and are stable across different speakers (assuming reasonably accurate imitations). For example, in the stimulus example of Fig. 1, both “Le” and “temps a é-” are vocalic groups, flanked by periods with no distinct pitch. Vocalic groups here are represented as continuous lines; breaks in the line represent divisions between vocalic groups. We measured the mean pitch of the vocalic group that was shifted in the original. In imitations of unshifted stimuli, the same vocalic groups were measured as in the imitations of shifted versions. Note that this method does



**Fig. 2.** Results of the discrimination task (top) are shown in terms of hits minus false alarms, and the means of this measurement are shown at each shift size compared, along with standard error bars. Results of the imitation task (bottom) are shown in terms of the vocalic group measurement, assessing the degree to which the shifted vocalic group was imitated, and also include standard error bars.

require the imitations to have the same durations as the original or each other. Imitations with errors, such as wrong words, stuttering, or restarts, were discarded; these made up 0.9% of the imitations among amusics, and 1.4% among controls. We measured the pitch of participants' imitations of the shifted vocalic groups and the pitch of the same vocalic groups in the unshifted version, and calculated the difference between the two to see how much the pitch shift affected the pitch of the imitation.

In order to measure correlations across tasks, individual imitations were deemed to be good imitations of the shift if there was more than one half semitone difference between the imitation of the shifted vocalic groups and the imitations of the unshifted versions (only differences in the correct direction were counted). One half semitone has been found to be an empirically-validated criterion for noticeably different tuning in vocal tones (Hutchins & Peretz, 2012; Hutchins et al., 2012). The average rate of good shift imitations was computed as the participant's Shift Imitation rate, which was correlated with their rate of Hits minus False Alarms in the discrimination task.

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### Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.bandl.2012.09.011>.

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