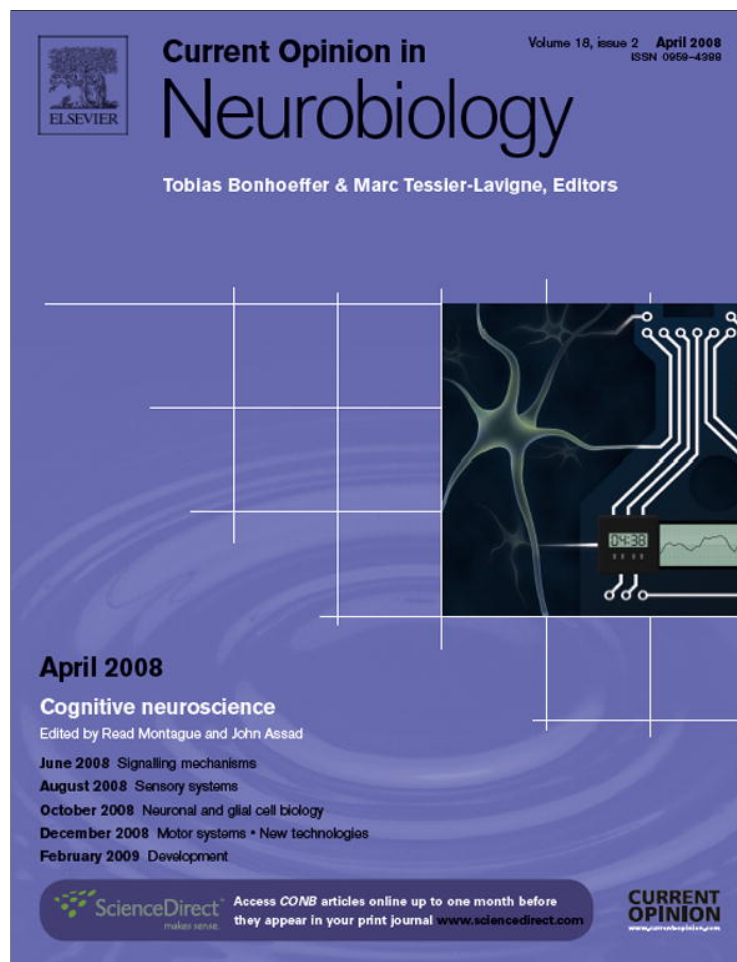


Provided for non-commercial research and education use.
Not for reproduction, distribution or commercial use.



This article appeared in a journal published by Elsevier. The attached copy is furnished to the author for internal non-commercial research and education use, including for instruction at the authors institution and sharing with colleagues.

Other uses, including reproduction and distribution, or selling or licensing copies, or posting to personal, institutional or third party websites are prohibited.

In most cases authors are permitted to post their version of the article (e.g. in Word or Tex form) to their personal website or institutional repository. Authors requiring further information regarding Elsevier's archiving and manuscript policies are encouraged to visit:

<http://www.elsevier.com/copyright>



ELSEVIER

Available online at www.sciencedirect.com
**Current Opinion in
Neurobiology**

Fractionating the musical mind: insights from congenital amusia

Lauren Stewart

Music, like language, is acquired effortlessly in early life and fulfils a multitude of social, cultural and emotional functions. However, those with a disorder recently termed 'congenital amusia' (CA) fail to recognise common tunes from their culture, do not hear when notes are 'out of tune' and sometimes report that music sounds like a 'din' or 'banging'. The core deficit appears to be a problem in discriminating pitch direction, a building block for the representation of melodic contour. Familial studies suggest the disorder is heritable and associated with structural differences in temporal and frontal cortices. The disorder provides a window onto the neuro-cognitive architecture of musical processing, and the possible etiologies of disordered development.

Address

Department of Psychology, Whitehead Building, Goldsmiths, University of London, New Cross, London SE14 6NW, United Kingdom

Corresponding author: Stewart, Lauren (l.stewart@gold.ac.uk)

Current Opinion in Neurobiology 2008, **18**:127–130

This review comes from a themed issue on
Cognitive neuroscience
Edited by Read Montague and John Assad

Available online 26th August 2008

0959-4388/\$ – see front matter

© 2008 Elsevier Ltd. All rights reserved.

DOI [10.1016/j.conb.2008.07.008](https://doi.org/10.1016/j.conb.2008.07.008)

Introduction

The ability to make sense of musical sound has been observed in every culture since the beginning of recorded history. In early infancy, music allows us to respond to the sing–song interactions from a primary caregiver and to engage in musical play; in later life it shapes our social and cultural identities and modulates our affective and emotional states. This ability does not require formal training: individuals are born with the capacity to internalise the musical structure of their own culture [1]. But a few per cent of the population lack this ability and are unable to make sense of or engage with music. This cannot be ascribed to brain insult, peripheral hearing problems, lack of environmental exposure or to intellectual impairment [2]. Individuals with congenital amusia (CA) cannot recognise familiar tunes or tell one tune from another, may complain that music sounds like a 'din' and tend to avoid the many social situations in which music plays a role [3]. Although the first case study of such a disorder was described more than a century ago [4],

systematic investigation into the cognitive and neural basis of this disorder has been a relatively recent endeavour. Characterisation of the disorder at a cognitive and neurobiological level sheds light on the neuro-cognitive architecture of musical processing and highlights possible etiologies of disordered brain development.

Phenomenology

Individuals with CA are often identified via advertisements in the media that invite those who have experienced lifelong difficulties with music to participate in laboratory-based research. The Montreal Battery for the Evaluation of Amusia [3] subsequently confirms the presence or absence of a musical receptive disorder. Recently, screening of large numbers of potential CA individuals has been possible via an online version of two subtests of the MBEA (<http://www.delosis.com/listening/home.html>). Seventy per cent of individuals who score below cut-off on the online score also fulfil criteria for CA after laboratory testing with the MBEA battery [5]. Counter-intuitively, individuals who self-label as 'tone-deaf' rarely fall into the CA category: the general use of this term has been shown to relate to a perceived inability to sing in tune, while perceptual abilities are generally normal [6–8].

CA has been described as a deficit of fine-grained pitch processing on the basis of psychophysical testing revealing elevated pitch thresholds in these individuals [9,10]. Thresholds are particularly high when there is a requirement to discriminate a change in pitch direction, as opposed to simply detecting a simple pitch change amidst monotonies [9]. At the group level, thresholds for the pitch direction task exceed a semitone: the smallest step size in Western music and one of the most commonly used intervals [11]. The implications of elevated thresholds for pitch direction are clear: CA individuals may register pitch changes in a melody but will be unable to discern the melodic contour, something which is crucial for the perception and storage of melodies [12].

CA may involve a deficit of fine-grained pitch perception, but elevated pitch thresholds are not a universal finding across all individuals who score in the amusic range of the MBEA. Deficits in the discrimination of two melodies are observed even when the constituent intervals of both melodies can be easily discerned [9]. Failure to discriminate between pairs of tunes despite normal perceptual thresholds invites an explanation in terms of failure to retain pitch information in memory. The perception of music, by definition, depends upon the integration of events as they unfold in time. Impaired retention of pitch

information may lead to music being perceived as a series of auditory 'snapshots' rather than as an integrated stream of related events. Preliminary data provide support for this hypothesis. In a task that required individuals to discriminate two tones separated by a variable time interval, CA individuals performed worse than matched controls [13]. Crucially, the pitch difference used always exceeded discrimination thresholds, so poor discrimination cannot explain these findings. Strikingly, these individuals were not impaired on a short-term verbal memory task, refuting the idea that these individuals have general short-term memory deficits and supporting the notion of an independent store for verbal and musical information [14]. The extent to which a pitch-memory deficit is independent or interacts with elevated pitch thresholds is yet to be explored. Nevertheless, it is congruent with the comments of one CA individual (Stewart, unpublished) who described her attempts to repeat a short musical phrase:

"When the music finished the sound was always gone - as though it had never happened. And this bewildered me with a sense of failure, of failure to hold on to what I had just heard. Others told me that if I tried to remember I would. But I never did. I have no idea what people mean when they say: "I have a tune going round in my head." I have never had a tune tell out its music in my head let alone repeat itself!"

Specificity of CA: links to space?

CA individuals do not report difficulties outside the musical domain but non-musical abilities have not been exhaustively tested in a formal situation, despite the potential for associated deficits to illuminate the cognitive endophenotype(s) of the disorder. However, a recent study suggests that the amusia may be related to a deficit in spatial perception. Douglas and Bilkey [15^{*}] found CA individuals to be impaired on a three-dimensional mental rotation task. Their spatial deficits were correlated with the degree of impairment shown on the melodic contour subtest of the MBEA, suggesting that the two deficits are functionally linked. It is possible only to speculate about the origins of the association between musical and spatial deficits, but one possibility would be that the processing of melodic contour depends upon the ability to represent patterns at a higher order level. A study by McDermott *et al.* [16^{**}] supports the view that representation of contour is not specific to pitch, but appears to be a general principle of the auditory system. Psychophysical testing demonstrated that contour representations could be formed from variations in brightness (an aspect of timbre) and intensity, as well as pitch. Discrimination of contours was possible both within and across these different stimulus dimensions. Most surprisingly, familiar melodies were recognisable when translated into brightness or intensity contours. These tasks have the potential to

elucidate the level of the cognitive deficit in CA. If the deficit in amusia is specific to pitch, CA individuals will show dissociation in performance between the pitch-based and non-pitch-based contour tasks. If CA derives from impairment at a more abstract level of pattern perception, these individuals will be impaired across all contour-discrimination tasks.

Specificity of CA: links to language?

A pitch-based deficit may be expected to impact upon the processing of language, particularly the intonational aspects of speech that are used to convey emotion, emphasis and to denote whether a spoken utterance is a statement or a question. CA individuals do not report deficits in their comprehension of spoken language. However, the pitch excursions involved in speech are typically in excess of the pitch thresholds displayed by CA individuals. Furthermore, given the presence of semantic, syntactic and contextual cues, deficits in intonation perception would rarely, if ever, limit the comprehension of speech. The absence of deficits in the everyday processing of language does not, however, preclude the existence of prosodic impairments that would be revealed in the context of carefully designed laboratory-based tasks. Ayotte *et al.* [2^{*}] asked CA individuals to report whether pairs of spoken phrases with the same lexical content were the same or different, based upon their pattern of intonation. When different, the final word had a different pitch trajectory in the two phrases, such that one phrase was a statement (downward pitch inflection) while the other phrase was a question (upward pitch inflection). In a different condition, focus shift pairs were used. These are phrases which, though lexically identical, differ in their emphasis depending upon the position of the pitch inflection (e.g. 'go in FRONT of the bank, I said' versus 'go in front of the BANK I said', with a salient up-down pitch inflection on each of the capitalised words). CA individuals performed as accurately as controls on these tasks. However, when the stimuli were delexicalised, such that the words were replaced by pitch-modulated tones, CA individuals performed worse than controls [2^{*}]. This finding was replicated even when pitch contours in the delexicalised pairs exactly mimicked the pitch changes present in the spoken sentences [17]. This dissociation in performance, between pitch-based discrimination in a linguistic versus a non-linguistic context, has been taken to suggest that there exists a separate mental module for the processing of contours in speech and in music [18]. However, Patel [19^{**}] cogently argues that this dissociation in contour processing between speech and music may be more apparent than real, based on the differential use of 'semantic recoding strategies' for the spoken versus delexicalised stimulus pairs. His 'melodic contour deafness hypothesis' holds that pitch-processing impairments are not exclusive to music but that impairments are seen only in music and not in language because the

discrimination of pitch direction is crucial only for music [19**].

Neurobiology of amusia

Studies into the neurobiology of amusia are in their infancy but structural MRI studies show morphological differences in inferior frontal cortex and superior temporal areas, variously in the left [20**,21**] or right [22**] hemisphere. Differences outside auditory cortex can be reconciled with the results from functional imaging studies showing the activation of inferior frontal cortex during integration [23–25] and discrimination [26] of sequential auditory events. Primate studies have revealed a major projection from temporal cortex to frontal areas [27] and future studies comparing structural and functional connectivity in CA individuals versus controls will be important to determine whether the structural differences observed in this group can be related to under-connectivity within this pathway.

Brain development is shaped by nurture, as well as nature thus anatomical differences in CA individuals do not rule out an interpretation in terms of a lack of exposure to music. However, infants display a level of musical sensitivity that is absent in CA individuals and the degree of exposure required to develop musically appears to be minimal. The most compelling support for a genetic etiology of amusia comes from a familial aggregation study [28*] in which amusia was ascertained in 39% of first-degree relatives of CA individuals, compared with only 3% of the relatives of controls. Investigation into pedigrees of amusia sets the stage for the elucidation of candidate genes that may underlie amusia. The anatomical findings make a tentative prediction that a putative candidate gene or set of genes will be involved in early neuronal migration processes underpinning fronto-temporal connectivity.

Future directions

Studies to date have characterised CA as a deficit of tune, rather than time [29]. This may reflect a recruitment bias since many of these studies have sought participants with tune-based deficits. Developmental deficits in timbre and timing are also logically possible; indeed there have been anecdotal reports from individuals who cannot keep time or who complain that music sounds like ‘banging’ or ‘noise’ (personal observations). Exploring these potential subtypes of amusia will reveal the extent to which these aspects of musical perception dissociate from each other; whether they differentially impact upon higher order perceptual and cognitive abilities and whether they are underpinned by distinct neuro-developmental trajectories. The study of disordered musical development sets in sharp relief the perceptual and cognitive abilities which most of us take for granted and allow us a unique chance to investigate how musical perceptual ability develops, from the level of the gene to the brain development and

the emergence of a complex and fundamental human behaviour.

Acknowledgements

The author is supported by a grant from the Economic and Social Research Council (ESRC). The authors thanks Ani Patel and Josh McDermott for their comments on an earlier version and Tim Griffiths, for discussions and collaboration that have contributed to the writing of this paper.

References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- of special interest
- of outstanding interest

1. Hannon EE, Trehub SE: **Tuning in to musical rhythms: infants learn more readily than adults.** *Proc Natl Acad Sci U S A* 2005, **102**:12639-12643.

2. Ayotte J, Peretz I, Hyde K: **Congenital amusia. A group study of adults afflicted with a music-specific disorder.** *Brain* 2002, **125**:238-251.

The first group study of congenital amusia. The performance of amusic individuals and matched controls was compared across a range of tests involving the reception/recognition/learning of musical and non-musical stimuli. Those with amusia performed worse on tests involving musical stimuli but performed comparably to controls on similar tests involving non-musical material. Particularly striking was the demonstration that amusic individuals could discriminate statement/question pairs, but were performed poorly in a condition where the words were replaced by tones at the mean fundamental frequency of each syllable.

3. Peretz I, Champod A-S, Hyde KL: **Varieties of musical disorders. The Montreal battery of evaluation of amusia.** *Ann N Y Acad Sci* 2003, **999**:58-75.

4. Grant-Allen X: **Note-deafness.** *Mind* 1878, **10**:157-167.

5. McDonald C, Stewart L: **Uses and functions of music in congenital amusia.** *Music Percept* 2008, **25**:345-355.

6. Cuddy LL, Balkwill LL, Peretz I, Holden RR: **Musical difficulties are rare: a study of “tone deafness” among university students.** *Ann N Y Acad Sci* 2005, **1060**:311-324.

7. Pfordresher PQ, Brown S: **Poor-pitch singing in the absence of “tone-deafness”.** *Music Percept* 2008, **25**:95-115.

8. Wise KJ, Sloboda JA: **Establishing an empirical profile of self-defined “tone-deafness”: perception, singing performance and self-assessment.** *Musicae Scientiae* 2008, **12**:3-26.

9. Foxton JM, Dean JL, Gee R, Peretz I, Griffiths TD: **Characterization of deficits in pitch perception underlying ‘tone deafness’.** *Brain* 2004, **127**:801-810.

A psychophysical study of pitch processing in congenital amusia. Compared with matched controls, individuals with amusia were found to have elevated thresholds on tasks involving the detection of a pitch change and the identification of pitch direction. For the latter, thresholds in the amusic group generally exceeded one semitone, which would be expected to impact upon the perception of western music.

10. Hyde KL, Peretz I: **Brains that are out of tune but in time.** *Psychol Sci* 2004, **15**:356-360.

A psychophysical study of pitch and temporal processing in congenital amusia. Individuals with amusia and matched controls were presented with monotonic and isochronous sequences of five tones and were required to detect when the fourth tone was displaced in pitch or time. All amusic participants were impaired in detecting the pitch changes, for pitch changes that were 1 semitone or less but they detected time changes as well as control adults.

11. Vos PG, Troost JM: **Ascending and descending melodic intervals: statistical findings and their perceptual relevance.** *Music Percept* 1989, **6**:383-396.

12. Dowling WJ, Fujitani DS: **Contour, interval and pitch recognition in memory for melodies.** *J Acoust Soc Am* 1970, **49**:524-531.

13. Griffiths TD, McDonald C, Kumar S, Deutsch D, Chinnery P, Stewart L: **Could a congenital disorder of musical perception**

ever be explained by a single gene? *International Workshop on the Biology and Genetics of Music; Bologna, Italy: 2007.*

14. Deutsch D: **Tones and numbers: specificity of interference in immediate memory.** *Science* 1970, **168**:1604-1605.
15. Douglas KM, Bilkey DK: **Amusia is associated with deficits in spatial processing.** *Nat Neurosci* 2007, **10**:915-921.
A study of visuospatial processing in congenital amusia. Compared with matched controls, individuals with amusia (defined using the contour subtest of the MBEA) made more errors in a classic mental rotation task and performance correlated with score on the MBEA subtest.
16. McDermott JH, Lehr AJ, Oxenham AJ: **Is relative pitch specific to pitch?** *Psychol Sci* 2008.
The authors show that contour representations can be formed based on manipulations of spectral brightness and intensity, as well as pitch. This suggests that 'contour' is not specific to pitch but may be a general principle of the auditory system.
17. Patel AD, Foxton JM, Griffiths TD: **Musically tone-deaf individuals have difficulty discriminating intonation contours extracted from speech.** *Brain Cogn* 2005, **59**:310-313.
18. Peretz I, Coltheart M: **Modularity of music processing.** *Nat Neurosci* 2003, **6**:688-691.
19. Patel AD: **Music, Language and the Brain.** New York: Oxford University Press; 2008:228-238.
A review of studies investigating linguistic and non-linguistic processing of pitch patterns in congenital amusia. The review includes an exposition of the Melodic Contour Deafness Hypothesis.
20. Hyde K, Zatorre R, Griffiths TD, Lerch JP, Peretz I: **Morphometry of the amusic brain: a two-site study.** *Brain* 2006, **129**:2562-2570.
A structural MRI study. In two independent groups of amusic individuals, the authors found a region of reduced white matter density in right inferior frontal gyrus, in comparison to controls. White matter concentration correlated positively with performance on the scale and memory subtests of the MBEA. This was the first neuroimaging study of congenital amusia.
21. Hyde K, Lerch JP, Zatorre R, Griffiths TD, Evans AC, Peretz I: **Cortical thickness in congenital amusia: when less is better than more.** *J Neuroscience* 2007, **27**:13028-13032.
Using the data from [20**], the authors compared cortical thickness in congenital amusic individuals, compared with controls. Thicker cortex was found in the region of right inferior frontal gyrus and right superior temporal gyrus, as well as some areas that were not predicted *a priori*. There was a negative correlation with overall performance on the MBEA.
22. Mandell J, Schultz K, Schlaug G: **Congenital amusia: an auditory-motor feedback disorder?** *Restor Neural Neurosci* 2007, **25**:1-12.
A structural MRI study. The authors regressed MBEA scores of 51 individuals (including 13 congenital amusics) against gray matter density across the whole brain. Density of gray matter in left inferior frontal cortex and left superior temporal sulcus correlated positively with MBEA score (note similar regions but with opposite lateralisation compared to [20**,21**]).
23. Gaab N, Gaser C, Zaehle T, Jancke L, Schlaug G: **Functional anatomy of pitch memory – an fmri study with sparse temporal sampling.** *NeuroImage* 2003, **19**:1417-1426.
24. Levitin DJ, Menon V: **Musical structure is processed in "language" areas of the brain: a possible role for Brodmann area 47 in temporal coherence.** *NeuroImage* 2003, **20**:2142-2152.
25. Koelsch S, Siebel WA: **Towards a neural basis of music perception.** *Trends Cogn Sci* 2005, **9**:578-584.
26. Zatorre RJ, Evans AC, Meyer E: **Neural mechanisms underlying melodic perception and memory for pitch.** *J Neurosci* 1994, **14**:1908-1919.
27. Hackett TA, Stepniewska I, Kaas JH: **Prefrontal connections of the parabelt auditory cortex in macaque monkeys.** *Brain Res* 1999, **817**:45-58.
28. Peretz I, Cummings S, Dube MP: **The genetics of congenital amusia (or tone deafness): a family aggregation study.** *Am J Hum Genet* 2007, **81**:582-588.
A familial aggregation study of amusia. The first degree relatives of a group of amusic individuals and a group of matched controls took an online test similar to the MBEA, requiring them to detect musical anomalies. 39% of relatives of the amusia group were considered amusic versus 3% of relatives of the control group.
29. Hyde KL, Peretz I: **"Out-of-pitch" but still "in-time". An auditory psychophysical study in congenital amusic adults.** *Ann N Y Acad Sci* 2003, **999**:173-176.