Disorders of Music Cognition

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July 23, 2014

Abstract

Although music is ubiquitous across human cultures and from a very young age, a subset of the population possesses an unusual lack of musical ability, to the extent that may be disruptive to perceptual, cognitive, and socioemotional functioning in everyday life. These individuals may be construable as suffering from a constellation of musical disorders. This chapter reviews the current literature on musical disorders, with special emphasis on congenital amusia, also known as tone-deafness.

Keywords: music, disorders, amusia, tone-deafness, behavior, neuroimaging, speech, language, pitch, awareness

Overview and History

Human beings of all cultures and all ages perceive, produce, and enjoy music. Although music engages multiple systems of the human brain even in people without formal musical training, a subset of the normal population shows a seeming lack of musical ability that is thought to constitute a spectrum of musical disorders (Peretz, 2008). Tone-deafness, also known as congenital amusia, is a neurodevelopmental disorder that affects an individual's ability to perceive and produce musical pitch. Although the core deficit stems from fine-grained pitch perception (Peretz et al., 2002), the disorder affects multiple aspects of musical ability – including pitch production, awareness, learning, and memory – as well as other more general aspects of brain and cognitive function such as speech and language. Due to its widespread effects and its unusual cognitive and neural profile, tone deafness has become widely of interest to the researchers in music psychology and music neuroscience, as well as the cognitive science and cognitive neuroscience community and the general public in recent years. Here we review the literature on musical disorders, with special emphasis on tone-deafness. We will begin by defining the core deficits and their related network of auditory and auditory-motor deficits. Having defined the disorder, we turn to its behavioral effects in perception and cognition, with emphasis on its relationship with speech and language. After characterizing the behavioral aspects of the disorder, we will turn to its neural underpinnings in brain structure and function.

The historical understanding of distinct neural networks subserving music began with neurologist Paul Broca (1865) who reported the famous case on aphasic patient Tan who, despite being unable to speak as a result of stroke, could paradoxically sing normally.

This was followed by reports of more aphasic patients who had automatic and relatively intact musical functioning, such as the intriguing case reported by British neurologist John Hughlings Jackson (1871) of a boy who was mute but could sing normally. While aphasia without amusia was reported since the beginning of scientific attempts to localize language function in the brain, the first case of a severe musical handicap was reported in 1878 (Grant-Allen, 1878) in a patient who was unable to discriminate tones in pitch in the absence of neurological damage or generalized intelligence deficit. This condition was termed "note deafness". The term "amusia" (*amusie*) was coined in 1888 (Knoblauch, 1888) to designate an impairment in production of music after brain damage.

In the modern literature, impaired music production following brain damage is known as acquired amusia, in contrast to the naturally emergent condition known as congenital amusia. Congenital amusia is accepted as "a particular deficit in discriminating musical pitch variations and in recognizing familiar melodies" (Ayotte, Peretz, & Hyde, 2002).

Defining musical disorders

Congenital amusia

Congenital amusia was estimated to be present in 4% of the normal population (Kalmus & Fry, 1980), following a study that assessed the incidence of congenital amusia using the Distorted Tunes Test. The Distorted Tunes Test consists of popular melodies, and subjects' task was to detect note errors; performance below a cutoff of three or more errors categorizes a subject as tone-deaf. The Distorted Tunes Test bears similarities with the Montreal Battery for Evaluation of Amusia (Peretz, Champod, & Hyde, 2003), which has become the standard method of testing for tone-deafness in the literature. In the MBEA, pairs of melodies are presented and the subject's task is to determine whether the second melody is the same or different from the first. The melodies differ by melodic and rhythmic aspects of music processing (Peretz & Coltheart, 2003): the first three subtests assess the melodic properties of scale, contour, and interval, the fourth and fifth subtests assess the rhythmic properties of rhythm and meter, and the sixth subtests assesses incidental memory for the musical items encountered within the first five subtests. The threshold for failing the MBEA was originally determined as two standard deviations below the mean performance on a group of adults, which corresponds to a cutoff of 22 for each subtest when compared to the original relatively large sample of adults. However, as pointed out by a more recent report (Henry & McAuley, 2010), the cutoff of two standard deviations below the mean would misdiagnose an estimated 2.28 % of the population; furthermore the 4% cutoff is sensitive to skew in the distribution of scores within the sampled population. Thus, like many other disorders in neurology and psychiatry, the reported rate of amusia depends on the test used, as well as the cutoff chosen for the category of disorder. In addition to using the Montreal Battery, psychophysical measures such as staircase procedures in pitch can also be used to obtain a threshold, or a just noticeable difference in frequency. As the mean just noticeable difference of the population is well below one semitone, people whose pitch-discrimination thresholds are higher than one semitone (around 32 Hz around the center frequency of 500 Hz) are identified as tone-deaf. Those whose thresholds were between half a semitone (16 Hz) are identified as mildly tone-deaf.

A more recent study has estimated that as many as 17% of adults self-identify as tone-deaf (Cuddy, Balkwill, Peretz, & Holden, 2005). However, most of these self-identified individuals are not truly tone-deaf as identified by perceptual testing, but self-assess as being poor singers or lacking in musical exposure. This tendency for self-assessment brings up an important pedagogical issue of stigma in self-labeling as tone-deaf. Compared to other communication or developmental disorders, such as dyslexia and dyscalculia, tone-deafness may not be as debilitating and may not affect educational outcomes in clear academic subjects outside of music education. Nevertheless, there are clear social benefits to belonging in a music making society, and the inability to participate in musical activities, especially from a young age, might be socially isolating. Furthermore, a rapidly increasing volume in research on tone-deafness ties the affected brain networks to other communication disorders, such as dyslexia and stuttering. While the arbitrary labeling of tone-deafness may result in unnecessary stigmatization in musical activities, accurate identification based on behavioral performance, and possibly biological markers (endophenotypes) in the future, may facilitate and inform the designs of future interventions that might not only have benefit for music education, but for related abilities such as language and reading as well.

Childhood amusia

Although amusia is thought to be a neurodevelopmental disorder, the majority of studies were exclusively on adults. While studies in music education have characterized the cognitive development of music – specifically of singing (Demorest, 1992) – few empirical investigations have assessed the pervasiveness and developmental trajectory of musical disorders in children. There is, however, one documented case of amusia in childhood (Lebrun, Moreau, McNally-Gagnon, Mignault Goulet, & Peretz, 2011). Using a shorter, more child-friendly version of the Montreal Battery for Evaluation of Amusia (MBEA-Ch), Lebrun et al identified a 10-year-old girl who showed profound difficulties with fine-grained pitch discrimination as well as increased error rates in interval production, contour production, and rhythm production as identified by acoustic analysis of recorded singing. These behavior patterns are very similar to adult amusics, suggesting that while the developmental trajectory of childhood tone-deafness is still uncharacterized, individual differences in musical ability, with extensions into musically disordered behavior, are present from a young age and possibly reflect one point along a delayed or diminished developmental trajectory of the neural pathways necessary for pitch awareness.

Poor pitch singing

In contrast to tone deafness, poor pitch singing (Pfordresher & Brown, 2007) is defined by inaccuracy in pith production rather than pitch perception. The affected network probably involves the perception action system: specifically, the forward and inverse models used in sensorimotor translation may be impaired in accuracy and/or precision (Pfordresher, 2011). Evidence for this inverse-modeling account of poor pitch singing comes from an improvement in pitch matching when the task is to imitate one's own voice (Pfordresher & Mantell, 2014). Although poor pitch singers share many characteristics with tone-deaf individuals, who principally complain that they cannot sing in tune, poor pitch singers show dissociable patterns of behavior from tone-deaf individuals specifically in their sparing of perceptual abilities such as in pitch discrimination (Pfordresher & Brown, 2007). Taken together with studies on self-report of tone-deafness (Cuddy, et al., 2005), it is likely that many self-reported tone-deaf individuals are not truly tone-deaf, but may be poor pitch singers instead. The differentiating criterion may be that poor pitch singers are able to perceive their own difficulties in pitch matching, whereas tone-deaf individuals are often unable to tell that they are out of tune, relying instead on those around them to provide feedback, thus constituting a potential source of social anxiety.

Beat deafness

While congenital amusia and poor pitch singing both specifically affect pitch, another subset of the population is not affected by pitch-related disorders, but have an abnormal inability to extract the beat from rhythmic stimuli. A case study was reported in 2011 of "Mathieu", an individual who, despite normal hearing, not failing the MBEA, and an almost-normal ability to synchronize to a metronome, had trouble matching the beat and synchronizing to rhythmic music such as meringue dance music (Phillips-Silver et al., 2011). This apparent dissociation between rhythmic sensitivity and pitch perception and production abilities provides evidence for the separation of pathways towards pitch and rhythm perception and production ability in the brain.

Significance of musical disorders in neuroscience

In recent years, neuroscientists have become increasingly aware that brain regions function as networks rather than in isolation. Musical disorders, of which amusia remains the most widely studied, serve as a useful vehicle to study the connectivity and interactions between brain regions for music and its associated neural functions.

Neural structure

The first studies on the affected neural network underlying tone deafness compared grey matter and white matter in the brains of tone-deaf and control individuals using Magnetic Resonance Imaging (MRI) (Hyde, Zatorre, Griffiths, Lerch, & Peretz, 2006). Comparing two groups of separately recruited amusics with matched controls, Hyde et al observed overlapping differences in voxel-based morphometry in the right inferior frontal gyrus (Brodmann Area 47). In addition to voxel-based morphometric measures, cortical thickness measures were compared in another study in which a group of amusics were recruited and then controls who matched the amusics in musical training, IQ, and handedness were identified and compared against the amusics (Hyde et al., 2007). Cortical thickness measures showed right hemisphere differences among amusics, with effects centering around the superior temporal gyrus and the inferior frontal gyrus.

Left hemisphere findings were also reported in a voxel-based morphometry study on congenital amusia (Mandell, Schulze, & Schlaug, 2007). This study differed in approach from the two previous reports in that the authors began with a large sample of individuals with different MBEA scores and applied a whole-brain regression to identify regions that were significantly associated in grey matter volume variations with overall performance on melodic and rhythmic subtests of the MBEA.

Results from voxel based morphometry and cortical thickness findings showed amusia-related differences in opposite hemispheres; however both lines of work revealed simultaneous frontal and superior temporal lobe differences. The hemispheric differences may arise from the different approaches in subject selection, as well as inherent differences in the biological properties of grey matter that are assessed by voxel based morphometry versus cortical thickness measures. While cortical thickness may be more sensitive to *size* of neural dendrites and cell bodies, voxel based morphometry is sensitive to *density* of neural dendrites and cell bodies. This methodological difference may suggest an imbalance between size and density of cortical areas in the frontal and temporal regions among tone-deaf individuals. In both cases, the coincidence of structural findings in frontal and temporal lobe regions offers a logical hypothesis that a common connection between the temporal and frontal areas is disrupted among people who are tone-deaf. Thus it was the white matter pathways that connect grey matter endpoints in the superior temporal and inferior frontal gyri that might offer a parsimonious account for simultaneously observed but anatomically distinct islands of grey matter deficits observed in the frontal and temporal regions of the brain.

Diffusion tensor imaging (DTI) is a relatively novel neuroimaging technique that offers a window into white matter connectivity in the brain. DTI is a variation of Magnetic Resonance Imaging (MRI) that makes use of the diffusion properties of water in biological matter to infer the characteristics of structural connectivity (coherence and myelination) across regions of the human brain. The idea is that if two regions of the brain are well connected, then water diffuses more efficiently between the well-connected regions than towards other, less connected regions. Directions of preferential diffusion can be reconstructed from images that are acquired for sensitivity to water diffusion in many different directions. Then, using the process of diffusion tensor tractography, the user can define regions of interest within the brain and identify measures of volume, Fractional Anisotropy (an index of white matter integrity), and other diffusion properties that bear relevance to white matter connectivity, and compare them between individuals and between groups. Using DTI and diffusion tensor tractography, tone-deaf individuals were identified to possess less volume and structural connectivity in the arcuate fasciculus, a major white matter pathway that connects the superior temporal and inferior frontal regions (Loui, Alsop, & Schlaug, 2009). Results were observed in both hemispheres, but the right hemispheric superior arcuate fasciculus, connecting the right superior temporal gyrus and the right inferior frontal gyrus, was most affected in the tone-deaf individuals, and furthermore showed negative correlations with the size of individual subjects' pitch discrimination threshold (i.e. more tone-deaf individuals had larger pitch discrimination thresholds and less identified volume in the right superior arcuate fasciculus). These results were robust to different neuroimaging parameters (Loui & Schlaug, 2009) and provide strong support for the conceptualization of tone-deafness as a fronto-temporal disconnection syndrome.

Functional networks

Functional MRI also showed an abnormal deactivation of the right inferior frontal gyrus in the amusic group, as well as reduced connectivity with the auditory cortex in amusics compared with controls (Hyde, Zatorre, & Peretz, 2011). These fMRI results converge with the structural findings in the auditory and inferior frontal cortices, as well as reduced white matter connections between these regions. Magnetoencephalography (MEG) combined with VBM converged with the right fronto-temporal account, but were able to combine the structural neuroimaging data with functional results with high spatiotemporal acuity (Albouy et al., 2013). In-depth analyses of magnetic components from the auditory cortex showed increased latency of sequential processing of tones emerging at an early point in the auditory cortex. This is possibly suggestive of compensatory mechanisms that involve increased recruitment of early cortical regions for auditory perception.

Theories of musical disorders

Several theories of amusia emerge from recent literature. Generally and perhaps the most widely accepted, is that amusia is a disorder of high-level pitch processing.

Pitch perception

Amusia is thought to be a disorder of fine-grained pitch perception (Peretz, et al., 2002) and pitch contour perception (Foxton, Dean, Gee, Peretz, & Griffiths, 2004). While rhythm perception is also impaired in some amusics as assessed by the rhythmic subtests of the MBEA, beat-deafness and tone-deafness appear to be different subpopulations, possibly because of distinct hemispheric specialization for spectral and temporal processing (Zatorre, Belin, & Penhune, 2002). While the perception of harmony is also impaired in amusics (Cousineau, McDermott, & Peretz, 2012), this impairment may be an emergent property of difficulties in fine-grained pitch perception. Amusics report disliking listening to music because "everything sounds dissonant" (Ayotte, et al., 2002), suggesting that the disorder may also extend to the emergent property of how pitches combine to form harmony.

Pitch awareness

Results from event-related potential studies show that the N1 component, generally thought to originate from the primary auditory cortex, is mostly normal in amusics. This confirms the earlier assumption that tone-deafness does not originate from primary cortical auditory areas. However, later components of auditory event-related potentials in amusics, in particular the N2-P3 complex, do not reflect the gradient of fine-grained perception of pitch differences that are characteristic of non-tone-deaf controls, but show an all-or-none effect: undetected, smaller pitch differences do not cause an N2-P3 effect, while the larger, detected pitch differences show a paradoxically larger N2-P3 waveform. This pattern of results suggests that compensatory mechanisms are voluntarily over-recruited when more automatic detection of pitch differences is not available to conscious access (Peretz, Brattico, & Tervaniemi, 2005). These results suggest that the amusic brain lacks awareness for pitch, suggesting that tone-deafness may be fundamentally an awareness issue rather than a perceptual issue (Peretz, Brattico, Jarvenpaa, & Tervaniemi, 2009). Further studies on pitch deviance using event-related potentials also suggest that early markers of pitch processing are spared in amusics, but later markers of decision-making processes are abnormal or absent in amusics (Moreau, Jolicoeur, & Peretz, 2013), providing additional support for the hypothesis of a deficit in awareness towards pitch information in congenital amusia.

If pitch awareness is the primary issue in tone-deafness, then one might predict that tone-deaf individuals might exhibit some of the same paradoxical behavioral patterns observed in other special populations with deficits of awareness to specific types of information. In that regard, blindsight is an unusual but informative neurological disorder of the visual system, where cortically blind individuals, who lack conscious awareness of objects in their visual field, are nevertheless able to catch objects that are thrown at them and are able to scale their hand grip to the size of the object to be grasped. The existence of this dissociation between perception and action provides a neural distinction between pathways involved in perception and action within the visual system (Goodale & Milner, 1992). Evidence for an auditory analog of this perception-action mismatch came from tone-deaf individuals upon being asked to perform pitch perception and production tasks on the same stimuli (Loui, Guenther, Mathys, & Schlaug, 2008). Given small intervals in pitch, the tone-deaf individuals correctly reproduced the directions of pitch intervals, but incorrectly reported their perceptions of the same intervals. This striking dissociation between pitch perception and production suggests multiple pathways towards conscious access of pitch information in the brain: dissociable pathways may exist to subserve fine-grained perceptual identification of auditory stimuli, and coarse-grained, action-based coding of directional information. The preservation of the coarse-grained pathways of pitch direction might be used in speech prosody, for instance, to enable tone-deaf individuals to produce the pitch intonations inherent in their speech patterns with normal accuracy during natural speech.

Spatial processing

An alternative theory of amusia states that the inability to perceive and recognize melodic contour arises from a deficit in spatial processing. Visual tasks indicated that the mental rotation task, a distinctly spatial process, was selectively impaired in amusic subjects, suggesting that amusia might originate from an inability to carry out mental representations of space (Douglas & Bilkey, 2007). While this idea is attractive, amusics in the study have a somewhat lower IQ than normals, and the control task of animal matching was so easy that a ceiling effect was observed. These results, as such, do not readily distinguish between normal and amusic performance in other, more demanding tasks. Furthermore, several failed attempts to replicate the deficits of spatial processing (line bisection and mental rotation) in amusics (Tillmann et al., 2010; Williamson, Cocchini, & Stewart, 2011) suggest that when control subjects are matched for general cognitive function, amusia emerges as a more specific neurocognitive disorder and does not generalize to the processing of space.

Auditory feedback

The principal complaint of amusics is that they cannot sing in tune, suggesting a possible deficit in production as well as a perception. In addition to being unable to hear pitch differences, amusics may be unable to receive feedback from their own vocal output. The hypothesis of disrupted auditory feedback is in line with numerous studies in delayed auditory feedback in speech, showing radically altered speech output as a result of slight changes in auditory feedback following speaking (Fairbanks & Guttman, 1958; Tiffany & Hanley, 1952). These results led researchers to posit that learning the mapping between auditory and motor pathways were essential for successful speech. Unsuccessful auditory-motor mapping may lead to difficulties in speech such as stuttering (Neelley, 1961; Soderberg, 1968). In addition, the acquisition of this sound-motor mapping occurs relatively quickly and flexibly, as demonstrated by prolonged delay in auditory feedback resulting in adaptation and the relearning of motor mappings (Goldiamond, 1962). Based on this literature on auditory feedback, as well as studies that disrupt somatosensory feedback instead of auditory feedback by implementing jaw-perturbation during speech (Tourville, Guenther, Ghosh, & Bohland, 2004), the acquisition and computation of auditory feedback and sound-motor maps are incorporated into the Directions Into Velocities of Articulators (DIVA) model of neural networks of speech acquisition and production (Guenther, 2006). In domains other than speech, analogous disruptions were found following delayed auditory feedback in the tapping of rhythmic sequences (Chase, Harvey, Standfast, Rapin, & Sutton, 1959) and in combined speech and music (Bradshaw, Nettleton, & Geffen, 1971). A 250ms delay in auditory feedback was found to lead to disrupted whistling and playing of musical instruments, and hand clapping (Kalmus, Denes, & Fry, 1955). More recently, the disruption in performance due to delayed auditory feedback in pianists was found to be attenuated when pianists mentally subdivided their sequences of productions (Pfordresher & Palmer, 2002), suggesting that cognitive strategies employed to sequence motor movements in music performance may play a role in sequence planning. Thus, effects of delayed auditory feedback may be disruptive for speech and music performance both as a direct result of disrupting the contingent mapping between motor actions and their target sounds (sound-motor mapping), or by disrupting the memory trace of the sequence of motor plans at a more cognitive level (Keele, Ivry, Mayr, Hazeltine, & Heuer, 2003; Pfordresher & Palmer, 2002). This is in line with the hypothesis of amusia as a pitch awareness problem, as well as the hypothesis of inverse mapping underlying poor pitch singing, but makes specific predictions on behavior: the inability to sing in tune may arise from insensitivity to auditory feedback, the disruption of direct mappings between sound and motor plans, or the functional integration of auditory and motor networks that enable the acquisition of sound-dependent motor plans.

Working memory

In addition to the hypotheses of pitch perception, pitch awareness, and auditory-motor feedback models of amusia, which generally couch the disorder as a perception-action decoupling or disconnect, other theories of the disorder have more cognitive bases. Williamson et al. showed that amusics had a faster decline in memory for pitch information over time compared to controls (Williamson, McDonald, Deutsch, Griffiths, & Stewart, 2010), suggesting that congenital amusia may extend beyond a fine-grained pitch discrimination problem in that pitch specific memory, rather than pure perception or production, is impaired (Williamson & Stewart, 2010). Amusics were also shown to have a smaller working memory capacity for pitch, and their memory for pitch was more easily disrupted by auditory distractors compared to controls (Gosselin, Jolicoeur, &

Peretz, 2009). However, follow-up studies have shown that difficulties with pitch discrimination can influence pitch memory as an emergent property or default mechanism, rather than memory being affected as a separate component of the disorder (Jiang, Lim, Wang, & Hamm, 2013). The best experimental approach probably involves matching for pitch discrimination difficulties (e.g. using stimuli that are matched for number of just noticeable differences) as well as matching for pitch stimulus differences themselves.

Learning deficit

If memory for pitch information is impaired in amusics, a related question becomes whether learning might be affected in amusics as well. A harmonic priming paradigm has shown at least some presence of harmonic knowledge in amusics (Tillmann, Gosselin, Bigand, & Peretz, 2012), suggesting that some aspects of pitch learning may be intact. Several studies have investigated rapid statistical learning of pitch information based on probabilistic input. Using a statistical learning paradigm that tested for familiarity with patterns of tones that co-occurred with certain transitional probabilities, Omigie et al observed no difficulty in learning tonal and linguistic material in amusics (Omigie & Stewart, 2011). However, as this study only investigated the transitional probability, it was possible that other types of learning might be affected. Contrasting results were observed by Peretz et al (Peretz, Saffran, Schon, & Gosselin, 2012), who showed statistical learning of speech but not music in congenital amusia. However, control subjects in this study also failed to learn the music, which contradicts previously published results showing successful learning of musical pitch patterns based on transitional probabilities alone among adult and children listeners (Saffran, Johnson, Aslin, & Newport, 1999). Using a non-Western musical scale to ensure that *de novo* learning in an approach that could tease apart different forms of statistical learning, Loui and Schlaug showed that tone-deaf individuals had impaired learning of event frequencies (the raw probability of occurrence of events over time) but not transitional probabilities (the probability that certain events follow each other) (Loui & Schlaug, 2012). Taken together, results from these studies suggest that tone deafness is characterized by an impaired ability to acquire frequency information from pitched materials in the sound environment.

Generalization of musical disorders to speech and language

Speech perception

Given the combination of statistical learning deficits, perceptual, productive, and memory deficits, and structural and functional deficits in the frontotemporal networks known to be important for speech and language, one would expect that processing of language would also be impaired in people with musical disorders. Interestingly, most tone-deaf individuals do not report any difficulties with speech and language processing. However, when the pitch patterns in speech sounds were extracted to create gliding-pitch analogs of speech, amusics' discrimination in a same-different judgment task was impaired (Patel, Foxton, & Griffiths, 2005), suggesting that amusia may affect speech processing in subtle ways that may be compensated for in normal, everyday speech. Strikingly, amusics also show difficulties in identifying the emotional content from speech (Thompson, Marin, & Stewart, 2012). When speech samples of neutral emotional content were spoken with differing prosodic information (patterns of stress, pitch changes, and rhythmic inflections) to convey several different emotions, amusics showed some impairments in select categories of emotion identification. Specifically, amusics were worse than controls at identifying happy, sad, tender, and irritated speech samples (Thompson, et al., 2012). The selective nature of some emotional categories being impaired in recognition among amusics may suggest that different types of emotion are conveyed differently within speech, or amusics may have developed compensatory mechanisms to aid them in processing select categories of emotion, such as fear. These interesting asymmetries in emotional processing lend themselves to theories on the evolutionary bases of different emotions, and how they are conveyed in speech and music across different cultures.

Tone language processing

Many cultures in the world, although not including English, convey meaning in their languages using tones, i.e. they are tonal languages that rely on pitch and pitch inflections to convey meaning. As tone-deafness primarily affects pitch perception and production, populations of tonal language speaking cultures may be expected to have a different incidence, behavioral consequence, and/or developmental trajectory when compared to cultures that do not use tones in their languages. Liu et al compared speakers of Mandarin Chinese (a tone language) with and without amusia in tasks of pitch discrimination and word discrimination using natural words and their gliding tone analogs (as in (Liu et al., 2012; Patel, et al., 2005)) and found that Mandarin Chinese speaking amusics performed worse on discriminating gliding tone speech. Nan et al (Nan, Sun, & Peretz, 2010) conducted tests of lexical tone identification as well as pitch discrimination in Mandarin Chinese speakers relative to a large sample of controls. Results showed the same patterns among Mandarin-speaking amusics as in non-tone language speaking amusics, in that the melodic subtests of the MBEA were more impaired than the rhythmic subtests. The general performance levels on the MBEA also appeared to be comparable across the tone language and non-tone language speakers. However, a subset of the identified amusics showed some impairments in their ability to identify lexical tones in Mandarin Chinese. Results from this study suggest that there may be an association between amusia and lexical tone agnosia. Furthermore, the results suggest that there are subcategories of amusics, some of whom show deficits that more readily extend to speech and language difficulties. Despite their perception deficits in lexical tones, however, the amusics with lexical tone agnosia were able to produce lexical tone contrasts at a similar level of accuracy as non-amusics. This sparing of production accuracy, in contrast with perceptual accuracy, supports the model of a multiply connected perception-and-action network with multiple pathways that might be selectively impaired in different subpopulations of amusics.

Speech production

In addition to the speech perception, the production of speech among amusics has received some interest as well, partially because the congruence between perception and production may provide a window into the extent to which conscious awareness is involved in amusia (Griffiths, 2008). Acoustical analyses of pitch matching have shown decreased accuracy and increased variability among amusics (Hutchins & Peretz, 2012, 2013; Hutchins, Zarate, Zatorre, & Peretz, 2010). However, pitch perception is even more impaired than production in amusics (Hutchins & Peretz, 2012). This relative sparing of production provides further support for an action-perception mismatch in tone-deafness (Loui, et al., 2008), indicative of a deficit in awareness of pitch (Peretz, et al., 2009). This pitch awareness deficit may be related to phonemic awareness, a construct that is central to speech and language processing and is thought to underlie communication disorders such as dyslexia. In a group of seven- to nine-year-old children, Loui et al assessed pitch awareness (operationalized here as a linear correlation between pitch perception and pitch production) and phonemic awareness as assessed using standard psychometric tests of speech sound manipulation, and showed an association between pitch and phonemic awareness (Loui, Kroog, Zuk, Winner, & Schlaug, 2011). Results were independent of individual differences in musical training, socioeconomic status, and nonverbal IQ measures, suggesting that the association between speech and music processing centers around sound awareness, and may extend to an association between tone-deafness and dyslexia.

Liu et al compared speech production in amusics relative to controls (Liu, Patel, Fourcin, & Stewart, 2010) and showed impaired performance on discrimination, identification and imitation among amusics in statements and questions that differed pitch direction. Training amusics to recognize pitch direction might provide a viable pathway towards treating musical disorders, thus improving standards of music education as well as speech and language processing especially in tonal language speaking cultures.

Rehabilitation

Although training tone language speaking amusics to recognize pitch direction was posited as a pathway to recovery from musical disorders (Liu, Jiang, Francart, Chan, & Wong, 2013), full intervention studies in musical disorders are yet few and far between. In an intervention study, Anderson et al reported an attempt to rehabilitate congenital amusia by conducting an intensive musical intervention on a group of five amusics (Anderson, Himonides, Wise, Welch, & Stewart, 2012). Singing was recorded and pitch perception and production tasks were conducted before and after training. Results showed no significant improvement in perception, but some improvements in a subset of amusics in song production. Results were heterogeneous within the group of amusics and illustrated that while neurorehabilitation was possible, at least in a subset of amusics, it would require significant time and resources and would possibly have to be individually tailored to the needs of each amusic. The disproportional resources required to enable neurorehabilitation in amusics underlines the reality and severity of the musical disorder and further confirms that it is very much dissociated from a simple lack of formal musical training.

Conclusion

Taken together, the best currently available evidence suggests that musical disorders, including tone-deafness and poor pitch production, affect the perception and production of pitch. They are characterized by disconnection of the temporal to frontal pathway that is involved in auditory-motor interactions. This pathway is crucial for awareness of pitch information, and the lack of pitch awareness pervades to other aspects of perception, cognition, and production including speech and language perception and production. Musical disorders can affect speech perception and production, especially in tone language speaking cultures, and in emotional processing requiring the detection pitch changes such as in prosody. Future studies that focus on the rehabilitation of musical disorders may be informative not only as a targeted intervention for those who suffer from the possible social and emotional consequences of being non-musical in a musical society, but will have scientific value as they help characterize and potentially impact the individual differences in behavioral, cognitive, and neural structure and function that inform the overarching question of why humans experience music.

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