TONE DEAFNESS: FAILURES Of MUSICAL ANTICIPATION AND SELF-REFERENCE

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Abstract

"Tone deafness" is a term that tends to be applied indiscriminately to a constellation of musical processing, perceptual, and production deficits. It has been estimated that 3 - 10% of the population are tone deaf (Cox, 1947; Joyner, 1968). Tone deafness can result from organic trauma (in which case the term "amusia" is often applied) or from some as-yet-unknown combination of genetic, neurochemical and environmental (i.e., learning) factors. Although the medical term "amusia" was first applied over a century ago (Edgren, 1895) the various forms of the syndrome have not been systematically classified. Preliminary research suggests that at least some of those individuals who are labeled as tone deaf lack the cognitive structures necessary to anticipate musical tonality and harmony; or lack internal self-referencing tonal schema within which to understand, process, and remember musical material.

In this paper, I propose a taxonomic system for classifying the various forms of tone-deafness, as a precís to new empirical research. First, I propose that tone deafness can be grouped according to four different deficits: production deficits, perceptual deficits, memory deficits, and deficits in symbolic manipulation (either music reading or writing). Among the medically documented deficits is a condition that parallels "pure word deafness" in which the subject can perceive sound, but is unable to recognize any musical or melodic qualities.

Within each of these deficit families, I propose a number of specific deficits with varying causes, and describe tests that can determine the nature of a given individual's deficits. The present work, in addition to providing a formal theoretical structure within which to think about musical processing, also has relevance for artificial intelligence researchers attempting to model human cognition and music processing. Specifically, the study of individuals with tone deafness presents us with a window into the neural mechanisms of musical processing, revealing evidence for which sub-processes might be modular, and which might be interlinked.

keywords: tone deafness; self-referencing; human memory; mental codes; taxonomies

International Journal of Computing Anticipatory Systems, Volume 4, 1999
Edited by D. M. Dubois, CHAOS, Liège, Belgium, ISSN 1373-5411 ISBN 2-9600179-5-1

1 Introduction and background on musical deficit research

The term tone-deafness and the associated medical term amusia have unfortunately been applied somewhat loosely by medical practitioners, educators, laypersons and psychologists to a broad range of evident and supposed musical deficits. At present, amusia research is in somewhat the same situation that aphasia research was thirty years ago, with different classes, etiologies, and symptoms of deficits all lumped together under one non-specific, catch-all term. It is likely that the amusias (like the aphasias) are easily separated and understood as unique phenomena, and that they can be productively studied through the administration of theoretically motivated, carefully designed cognitive probes and tests.

To begin with, the term amusia no doubt encompasses deficits in four conceptually distinct domains: musical perception, production, memory, and (less commonly) the loss of symbolic manipulation skills (that is, deficits in reading or writing music; see, for example, Fasanaro, Spitaleri & Valiani, 1990; Stanzione & Grossi, 1990). The etiology of these deficits is poorly understood, but it appears that they can result from organic trauma or some as-yet-unknown combination of genetic and environmental factors. Although the term "amusia" was first applied over a century ago (Edgren, 1895), the various amusias have not yet been systematically documented or classified, and no comprehensive study of musical deficits has been undertaken. Approximately 3% of the general population are believed to be amusic from childhood (Cox, 1947; Davies & Roberts, 1975; Joyner, 1968), with no estimates of the incidence within patient populations. Anecdotally, Shepard (1964) found that only 38% of subjects he recruited from the Bell Laboratories could not distinguish sine tones that differed by slightly more than a semitone. Along these lines, Seashore (1919) noted that the difference limen for frequency can vary as much as 200-fold among different listeners. If such large proportions of people cannot distinguish musical tones a semitone apart, what are these people hearing when they listen to music?

From a scientific standpoint, the study of amusia can potentially provide us with a better understanding of the neuropsychology of auditory pattern processing and pattern memory, and an understanding of how music is organized in the brain. By studying some of the estimated 1 in 30 individuals who suffer from a musical processing deficit, we can hope to derive a better understanding of how the auditory system works in all individuals. This knowledge might lead to ways of improving musical function in amusiacs, and would thus inform questions about auditory system plasticity in adults; there exists preliminary evidence that some forms of amusia are correctable (Apfelstadt, 1984; Cobes, 1972; Dennis, 1975; Jordan-DeCarbo, 1982).

Amusia might also be a symptom of an underlying neurological disorder that in addition causes difficulties understanding spoken language, particularly when linguistic meaning is conveyed by prosody or pitched emphasis. Tallal, Miller & Fitch (1993) found that language-delayed children have trouble resolving the temporal order of phonemes. An important question is whether these children are also amusic (or arrhythmic), and thus whether language and music rely on the same brain mechanisms for temporal coding, as has suggested by Robinson & Solomon (1974) and others.

Research to fractionate the components of aphasia has yielded important insights for neuropsychologists. The evidence for a dissociation in the production and perception of intonation in sentences suggests the possibility for such dissociations in amusia as well. In drawing analogies between aphasia and amusia, we might note that in one key respect they are different: aphasia can have a huge impact on an individual's functioning, while at worst amusia is an inconvenience to most people who have it. Yet it is an inconvenience that can teach us a great deal about the neural underpinnings of auditory processing. The pattern of deficits, coincidences, and dissociations we find could have major implications for our understanding of auditory function.

2 What exactly is "amusic" behavior?

As mentioned above, a broad constellation of deficits have been labeled "tone deafness" or "amusia" by clinicians, educators and laypeople. Some individuals are exceedingly poor at singing well-known songs – either due to vocal quality or an apparent inability to match pitches. Are these failures of production, perception, or memory? Some individuals can not recognize well-known melodies when they hear them. Perhaps this constitutes the musical equivalent of "pure word deafness," a specific inability to process musical semantics. At what level do amusiacs not understand music? Are there deficits in melody, tonal sequence, isolated tones, rhythms? Do they suffer from impoverished schemas for melody, or poor auditory memory?

In the following section, I suggest fourteen specific areas of deficit, all easily testable, that could account for the experience and phenomenology of amusia. I suspect that these are present singly or in combination, and in varying degrees, in different individuals. Many of the types of deficits described have been reported anecdotally, such as an inability to understand "pitch direction" (subjects can't tell if one tone is higher or lower than another, presumably due to faulty mapping in pitch space); an inability to recognize gross distortions in melodies (perhaps an underdeveloped sense of melodic schema); and an inability to tap one's feet in time with even a simple 4/4 march beat. While various standardized tests of musical ability address many of the 14 proposed deficits described here, they have not been used before to classify deficits in any systematic fashion.

Many of us whose research focuses on the study of melody, rhythm and pitch perception have noticed that some subjects simply cannot perform simple auditory tasks that come easily to the majority of people. Most of the time, we tend to discard these subjects without further study (e.g., Deutsch, 1975 who rejected 75% of her subjects!) but in doing so, I believe we are ignoring a population that can yield important insights into the nature of auditory processes. Perhaps inadvertently, we have rejected some of the most interesting subjects.

By integrating findings from imaging studies and cognitive studies, we can add significantly to our understanding of the neuropsychology of music processing. Recent findings from a number of laboratories suggest that the type of fractionation and dissociations I expect to find have a neural basis. For example, right temporal lobe lesions tend to affect melodic perception, while left temporal lesions do not (Milner, 1962; Samson & Zatorre, 1988; Zatorre, 1985; Zatorre & Halpern, 1993); pitch memory appears to involve activation of the right inferior colliculus, and concepts of "pitch space" and "pitch distance" might involve parietal systems (Zatorre, Evans, Meyer & Gjedde, 1992). Thus, the same types of double-dissociations we have observed in speech aphasias will hopefully be found for the set of "musical aphasias."

Luria (1966) found patients with severe deficits in perception and reproduction of temporal patters (arrhythmia) when damage occurred to left auditory secondary association areas, with melodic and timbral processing remaining preserved. Milner (1962) found deficits in tone and timbre perception and reproduction following right temporal lobectomy, with relatively preserved rhythm.

Peretz and her colleagues have also studied musical function/dysfunction extensively using a variety of behavioral and neuroimaging techniques (Peretz, 1990; Peretz, 1993; Peretz, 1996; Peretz & Babaï, 1992; Peretz, Gagnon & Bouchard, 1997; Peretz & Hérbert, 1995; Peretz & Kolinsky, 1993; Peretz et al., 1994; Peretz & Morais, 1980; Peretz & Morais, 1988; Peretz & Morais, 1993; Peretz & Morias, 1979). While it is hazardous to draw broad generalizations from a relatively heterogeneous and small patient population, the emerging picture is that musical ability is composed of separable faculties (perhaps even independent faculties, or Fodorian modules as Peretz and others have proposed). This lends support to the current line of research that seeks to establish separable behavioral manifestations of musical disjunction.

3 Probing amusic behaviors - a proposal for new empirical research

This section describes the taxonomic structure of musical deficits upon which I propose further empirical research be based. This conceptual underpinning to the scientific study of amusia provides a starting point for a formal and systematic study of musical deficits, either acquired (due to lesion or organic trauma) or genetic in origin.

Subjects could be recruited based on self-report, report of acquaintances, and (in the case of organic trauma) physician referrals. Control subjects, unselected for musical ability but matched for age, sex, handedness, and overall IQ should be tested.

The subjects would participate in a testing session that lasts one to two hours, and involves tests of musical perception, production, and memory, as well as other standard tests to be elaborated below. All the sub-tests detailed below exist as part of larger published "test banks" of musical aptitude or ability, but they simply haven't previously been brought together to address questions of amusia; they tend to be used for musical placement in school curriculums, rather than for clinical or psychological evaluation of a pattern of deficits. Again, a core assumption of the following is that amusia can be divided into three broad classes of deficits: perception, production and memory. The fourth class described above, that of deficits in symbolic manipulation, is an acquired syndrome by definition, and only affects musicians; because of its comparatively limited occurrence in the general population, I will not pursue it further in this paper.

3.1 Procedure

On arrival at the experimental session, all subjects in the experimental group should be asked why they believe they are "tone deaf," that is, what behavior has caused them to believe (or caused others to believe) they are tone deaf. It is possible that some subjects are not in fact tone deaf, and have been mislabeled. Control subjects should be asked to describe, in open response format, their musical abilities. Patients should be asked to describe (in open response format) how their musical processing has changed since the injury. Responses to these questions should be recorded on audio tape, and transcribed later for inclusion as background information and possible qualitative analysis. Where possible, preliminary assignments to one or more of the 14 deficit categories (described below) are made based on the subject's self-report. It is important to note also that there is a strong possibility that some people acquire the label "tone deaf" if, even though they are capable of processing musical information in a normal way, other people simply don't like the sound of their voices, and hence some subjects may not be "tone deaf" by any conventional meaning of the term. (It is possible that popular singers with "unconventional" voices, such as Bob Dylan or Neil Young, might have been so described as schoolchildren.)

Subjects should complete a questionnaire for background information including age, years of musical training, handedness, childhood diseases; age of onset of tone deafness; and other pertinent information.

The subjects will be administered fourteen tests (see Table 1). These tests fractionate musical (dis)ability into logical components. There is a priori reason to believe that dissociations exist between some of these components, based on neurological evidence.

3.2 Evaluation and coding of results

Subjects whose performance falls more than 2 standard deviations below the (published normed) mean for that item will be considered grossly deficient in that particular area; subjects whose performance falls more than 1 standard deviation below the (published normed) mean will be considered mildly deficient. Most test items have objective "right and wrong" answers as provided in the Gordon or Gardner test kits. Other items (such as vocal range) will require coding by the PI. Vocal productions should be recorded on digital audio tape and pitch extracted by an FFT program.

Perception: 1) Hearing test (for standard audiological thresholds)
2) Same/different pitch discrimination
3) Same/different rhythmic discrimination
4) Same/different timbre discrimination
5) High/Low pitch "directionality"
6) Tonal schema: Krumhansl tonal hierarchies
Memory: 7) Working memory, assessed with word span, digit span
8) Same/different tonal sequence
9) Tests of melodic schema (recognition of distorted melodies; White, 1960)
Production: 10) Range Test: Ss sing in semitone steps up and down from ç A220 (Murry, 1990).
11) Pitch matching of single tones with tone generator
12) Pitch matching of single tones with voice, humming, whistling
13) Pitch matching of tonal sequence with voice
    Questions: Do they preserve contour? Are there "erratic transposers?"
14) Rhythmic sequence matching - tapping tests

TABLE 1: List of deficit tests, by deficit "family"

3.3 Testing Amusia

3.3.1 Perceptual Deficit Tests (1-6)
Amusia may result from one or several perceptual deficits:

(1) Standard audiological threshold hearing tests will be administered to test for hearing loss. Some subjects who thought they were tone deaf may actually suffer from hearing loss. Published norms (e.g., Gardner) will be used to establish z-scores for each subject as a function of age and sex.

(2) Some subjects may have an inability to detect whether two pitches are the same or different. The JND for pitch for normals is roughly 5 - 50 cents. Subjects will hear pairs of pitches (from the Gordon test bank section for pitch discrimination) and respond "same" or "different" by typing an appropriate key on a computer keyboard. D.V. will be the number of correct responses (transformed to z-scores based on the Gordon norms). RTs will also be collected, and analyzed later for longer-than-normal decision latencies among amusiacs.

(3) Same/different rhythmic discrimination from the Gordon tests, analyses as for Item 2. The rhythm tests are administered immediately following the pitch tests in order to avoid subject fatigue.

(4) Same/different timbre discrimination from the Gordon tests, analyses as for Item 2. Typical discriminations include such close items as trumpet vs. trombone, and "far" items such as trumpet vs. clarinet.

[If an interesting pattern of deficits emerge relevant to timbre discrimination, and cannot be adequately captured by the Gordon measures, one could develop new timbre comparison test items (in a similar 2AFC paradigm) based on the timbre space/synthesis model of McAdams, Winsberg, Donnadieu & De Soete, 1995. Evidence for localized representation of timbre is provided by Pitt, 1995].

(5) High/Low pitch "directionality." There is no standard test for this, but anecdotal evidence indicates that some people may possess an ability to distinguish two tones as being different from one another, but an inability to tell which tone is higher or lower. This could result from a faulty directional sense in pitch space, analogous to a faulty directional sense in Euclidean space (e.g., people who can't tell "left" from "right"). Shepard (1964) found people who fit this description. (Some subjects might be able to tell that two tones are different, and which one is higher or lower, but not have a good sense for how much higher or how much lower one tone is from another. That is, they may not have a well-defined sense of distance in musical pitch space, and thus may not be able to accurately reproduce musical intervals.) This deficit could account for difficulty in producing and perceiving melodic patterns.

(6) Diatonic schema: Krumhansl tests of tonal hierarchy. Some amusiacs may lack a schema for diatonic harmony, that is, they may be unable to determine the tonal center of a piece of music. Subjects will be played excerpts of melodies as used by Krumhansl and asked to indicate how well each of the 12 chromatic tones "fits" with the excerpt just played. Failure to recover standard diatonic tonal hierarchies could indicate the absence of a schema for diatonic harmony that most non-musicians apparently share.

3.3.2 Memory Deficit Tests (7-9)

Amusia may result from memory deficits, either specific to musical stimuli or more general. Normal music cognition is assumed to depend on working memory (Miller, 1991; Sergeant, 1993).

(7) Working memory (WM), assessed by words span and digit span from Gardner's TAPS:UL., Gordon's tonal memory test. In Gardner's test, the subjects are given a string to rehearse and their performance is judged by how many they can accurately produce when asked. The D.V. is the number of items subject can keep active in WM. Score based on published norms.

Subjects with WM deficits might be unable to perform pitch comparisons because they cannot keep pitches active in memory long enough to effect the comparisons. Other subjects might have difficulty learning songs because they can't keep the tonal pattern active in memory.

(8) Same/different tonal sequence. From Gordon's test, subjects hear two tonal sequences (of varying lengths) and make a same/different judgment. This involves WM as in item 6, again assessed by maximum string length retained without error, but the subjects in this condition do not need to produce the contents of their WM, they need simply to recognize which of two alternatives is identical to the sequence they are rehearsing. I am not aware of any evidence in the speech or music literature that suggests an individual might perform differently in these two conditions, but for the sake of completeness, it seems worth testing.

(9) Tests of melodic schema (recognition of distorted melodies; White, 1960). White developed a system of seven melodic distortions of standard melodies (such as "Yankee Doodle," and "Jeannie with the light brown hair,") and found that most people can recognize familiar songs under certain melodic distortions. Some amusiacs may have poor long-term memory for melodic schemas, which I predict would reveal themselves in substandard performance on the White task. This could lead to difficulties learning and producing songs. An assumption of the White tests is that subjects can recognize the songs in the undistorted condition, and of course, there may be some subjects who are unable to do even that.

3.3.3 Production Deficit Tests (10 - 14)

Amusia may occur in subjects who lack normal production abilities, either due to lack of vocal control or some broader spectral/temporal production deficit.

(10) Range Test: Subjects sing in semitone steps up and down from A220 (after Murry, 1990). Some subjects may not be "tone deaf" by other measures, but may simply have such a restricted vocal range that they cannot produce learned songs with their vocal instrument (Welch, 1979a, b). The experimenter will guide the subjects by playing

notes on a piano keyboard, to establish a range. Subject responses will be recorded on DAT for later F0 analysis by an FFT program.

(11) Pitch matching of single tones with tone generator. Items taken from Gardner, the subject is presented with a sine tone signal and asked to match its pitch with a tone generator. DV is percent correct. The analysis will employ published norms for this test and between group means (controls vs. amusiacs). To limit the confound of memory load, the subject will have the ability to flip a switch back and forth to alternately hear the sine tone they control and the target tone. We might expect to find some subjects who have intact "receptive" pitch matching (as evidenced by Item 2) but lack "productive" pitch matching, even when the vocal organ is not required. Such subjects would have a difficult time singing songs or playing instruments.

(12) Pitch matching of single tones with voice, humming, whistling. Some subjects may have a sufficiently developed mental representation for pitch to successfully complete a pitch matching experiment with an oscillator (previous item, #10) but these subjects may have an inability to produce precise pitches. The procedure for this test will parallel Item 11, except that subjects will be asked to match pitches by singing, humming, or whistling (production methods randomly assigned within a block). The testing sessions will be recorded on DAT tape, and the cents deviation from correct pitch determined by an FFT program.

(13) Pitch matching of tonal sequence with voice. This condition, taken again from Gordon, is essentially equivalent to asking the subject to learn a new song. When subjects fail to produce a tonal pattern or sequence, the ways in which they fail are instructive. For example, do they preserve contour? In pilot work I have encountered people who might best be described as "erratic transposers," people who might start singing a song in the right key and with the right pitches, but transpose the melody at various places after they've begun. This could result from not having a single, well-defined pitch anchor in their representation of the melody, or from having an overactive "transposition" schema.

(14) Rhythmic sequence matching – tapping tests. Similar to item 12, subjects are presented with a rhythmic sequence (from Gordon) and asked to tap or clap it back identically. This could be considered a specific disruption of <u>musical pattern perception</u>. Some of these subjects might have difficulty with determining the exact sequence of pitches in a melody. Shepard (1964) reported that subjects who were unpracticed in Morse Code were accurate in reporting the number of dots and dashes in a signal, but often mixed up the order. So too some subjects might know what tones constitute a melodic fragment, but have difficulty with the order of the tones. This could be related to temporal order deficits in the perception of phonemes (Tallal et al., 1993).

3.4 Qualitative assessments

There are many ways in which subjects can perform poorly in these tests apart from the strict quantitative analyses. Some subjects may have "shaky voices," or unpleasant "gritty" voices. Some subjects may need more time to complete the items than others. To provide as complete a profile as possible of the various amusiacs and their amusias, all of these factors – including qualitative impressions of the experimenter – will be documented as part of the procedures, in medical "case study" style. Among patients who have undergone a change in musical processing following brain injury, their subjective reports of how their musical experience has changed are also important. For example, some chromesthetes have reported changes in their internal pitch template with aging, and there is at least one known report of a change in the internal pitch template for an absolute pitch possessor as a result of drug use.

3.5 "Top-Level" analyses of data

A matrix of Pearson correlations should be analyzed to determine if some deficits correlate with others; and a factor analysis will be carried out on the group results to see if musical deficits can be decomposed into n orthogonal factors. These findings will form the basis for further studies of musical deficit using fMRI. One prediction is that three orthogonal factors (based on the superordinate categories of production, memory, and perception) will capture a significant amount of the variance, along with a fourth factor that distinguishes rhythm from pitch. The factor analysis may also reveal additional (or different) factors that can help to inform models of the underlying processes.

4 Conclusion

In this paper I have proposed ways in which existing methods and tests can be brought to bear on the problem of tone deafness (or amusia), in an effort to fractionate this deficit into component disabilities. Three logically distinct deficit families, those of production, perception, and memory, are discussed and mapped onto existing tests of musical function. (A fourth logically distinct deficit, of symbolic manipulation, was not described herein and is left for further research).

Amusia research is still in its infancy. An increase focus in this area holds great promise for explaining underlying processes of perception and memory, and the mental codes that are used to categorize and process perceptual experience.

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