

MUSIC AND LANGUAGE

MUSICAL ALEXIA AND AGRAPHIA

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INTRODUCTION

MUSIC, 'the art or science of arranging sounds in notes and rhythms to give a desired pattern or effect' (Jacobs, 1967), joins language differently in song, recitative, chant, sprechstimme, poetry, the inflection of everyday speech, and, of course, musical notation (Critchley, 1972; Henson, 1977*a, b*). Amusia and aphasia occur alone or together, and prosody, which includes the musical elements of pitch, rhythm and stress, and which gives both propositional and emotional meaning to speech, may be altered in aphasics who retain ability to sing and to appreciate music (Monrad-Krohn, 1947). There appears to be left hemispheric dominance for identifying words whose meaning depends upon pitch (Van Laucke and Fromkin, 1973), whereas identification of the emotional context of speech seems to require the right hemisphere (Tucker, Watson and Heilman, 1977). Musical stimuli have precipitated seizures in patients with either right or left hemispheric lesions (Scott, 1977), and seizures generated from either hemisphere may include musical hallucinations (Mulder and Daly, 1952). In epileptics (Penfield and Perot, 1963), hallucinated music or spoken voices followed stimulation of either temporal lobe, and there was no topographical difference between areas associated with voices and those associated with music.

Music is usually non-propositional, yet appreciation of music may be more intellectual than emotional. Although most people enjoy music, some lack the fundamental skill of either recognizing or reproducing simple melodies or even single intervals. A majority are musically illiterate, although they may be musically talented. Few have absolute pitch in the accepted sense of the term. The elements of music—pitch, timbre, duration, loudness and rhythm—are separable, and recognition of sounds in a chord is horizontally non-linear, in contrast to recognizing melody. Musical notation includes both verbal and non-verbal elements and indicates both simultaneous and serial events.

It is not surprising, therefore, that studies of music and language, and attempts to localize and to classify amusia, have been conflicting. Henschen (1920, 1925, 1926) considered amusia, like aphasia, to be either motor (vocal and instrumental amusia and musical agraphia) or sensory ('music deafness', 'amnestic amusia' and musical alexia). On the basis of autopsy studies he believed centres for particular musical functions existed in the language-dominant hemisphere, for example a 'singing centre' in the pars triangularis of the third frontal convolution, a receptive music centre at the temporal pole, a note-reading centre near the angular gyrus and an instrumental centre at the foot of the second frontal convolution (although there appeared to be a special centre for violinists). Despite this rigidly anatomical approach, Henschen (1926) observed 'Musical faculty is phylogenetically as well as ontogenetically older than speech, and its representation is more uniformly distributed over both hemispheres'. Preserved musical function in the presence of aphasia he attributed to right hemispheric takeover.

Kleist (1928) divided motor and sensory amusias into those affecting either tone or melody, and placed the responsible lesions in the left hemisphere. 'Tone muteness', for example, he attributed to destruction of the lower third of the left anterior central convolution, between centres for singing and for whistling. On the basis of a single autopsy case of normal musical function and destroyed temporal tips, Kleist discounted their importance in musical reception. Feuchtwanger (1930), more interested in the neuropsychology of music and speech than in anatomical localization, observed that language and music each had symbolic and non-symbolic aspects and predicted that bilateral cortical activity was involved in the production and understanding of each. Although aphasia was present in each of his 34 amusic patients, he acknowledged that phonemic and melodic perception could be lost independently. Ustvedt (1937), noting the heterogeneity of amusic patients and the frequent failure of investigators to determine premorbid musical capacity or to use standardized tests, stressed '. . . how slight the possibility of localization is in the majority of cases and how unjustifiable it is to draw conclusions regarding the normal localization of a given function from the localization of a lesion associated with a particular defect'. He also criticized the neuropsychological views of Feuchtwanger as 'theoretical and artificial'.

Hécaen (1962) believed right hemispheric lesions caused difficulty with sound recognition, whereas left-sided lesions resulted in 'a disorganization of musical understanding'. Wertheim (1969, 1977) believed receptive amusia was most often due to lesions of the language-dominant hemisphere, whereas expressive amusia followed non-dominant hemispheric damage, the second frontal convolution in the case of instrumental amusia and the pars triangularis with vocal amusia. Damasio and Damasio (1977) accepted right hemispheric dominance for 'musical execution' but believed musical perception shifted from the right to the left hemisphere as a person became increasingly sophisticated musically. Benton (1977) noted that expressive amusia was associated with anterior lesions and receptive amusia ('defects in the perception and recognition of tones and melodies . . . with or without

concomitant expressive impairment') was caused by temporal lobe disease, but that either kind of amusia could follow damage to either hemisphere.

The two present cases demonstrate the prematurity of broad generalizations regarding either music and language or hemispheric specialization for musical function. Each was a professional musician, able to read and write music, in whom aphasia was accompanied by disturbed musical function, but of very different kind and degree, including musical alexia and agraphia.

PATIENTS AND METHODS

To minimize fatigue both patients were examined in short sessions seldom exceeding an hour. For language testing the manual of Goodglass and Kaplan (1972) was used. For musical testing Wertheim's (1969) procedure was used, and additional tests of musical alexia and agraphia were added. These included playing written single notes; playing or singing written intervals; matching written intervals with what was heard; observing whether a written interval was upward or downward; tapping out written rhythms; drawing specific notes, clefs and rests; indicating pitch on a score; and writing heard intervals.

Case 1

In February 1976 a 22-year-old music student was admitted to hospital for partial complex, right focal motor, and generalized seizures. Neurological examination was normal, but carotid angiography revealed a lemon-sized meningioma beneath the left temporal lobe. During attempted total removal, unexplained massive left temporal swelling developed; emergency right craniotomy and dural incision failed to reveal hæmatoma or swelling on that side. To allow skin closure, left hemicraniectomy and anterior temporal lobectomy were performed. She left the operating room breathing spontaneously but with both pupils dilated and unreactive to light.

Within several hours pupillary reactivity returned, and a few days later she was awake, with right hemiplegia and sensory loss, right homonymous hemianopia and global aphasia. At re-operation the left cerebral convexity was still swollen and discoloured. No significant hæmatoma was apparent, and the dura was closed with a fascia lata graft. Over the next few weeks her strength improved, and speech gradually became fluent, consisting largely of paraphasic jargon; there was little evidence of language comprehension. Deterioration attributed to hydrocephalus led to placement of a right ventriculo-atrial shunt through the right frontal lobe, following which improvement resumed.

In November 1976 computerized tomography revealed a large low density area in the posterior temporo-parietal area, consistent with infarction, plus an inferior contrast-enhanced lesion which was believed to represent residual neoplasm (fig. 1). Following uncomplicated total removal of the meningioma she had several major motor, partial complex, and right sensory seizures, controlled with phenytoin and carbamazepine. During the next eighteen months, the aphasia gradually improved, and strength became normal. Alexia and agraphia remained severe, and her visual field defect and sensory loss persisted. Resuming her studies, she received a degree of Bachelor of Music in May 1978.

Always right-handed, she had learned how to read music with the guitar in early adolescence and had begun singing lessons at the age of 14 years and piano lessons at the age of 15 years. When she was first admitted, during her fourth year of professional study, she could sightread madrigals by voice and Chopin waltzes on the piano and often wrote out musical parts. She did not have absolute pitch.

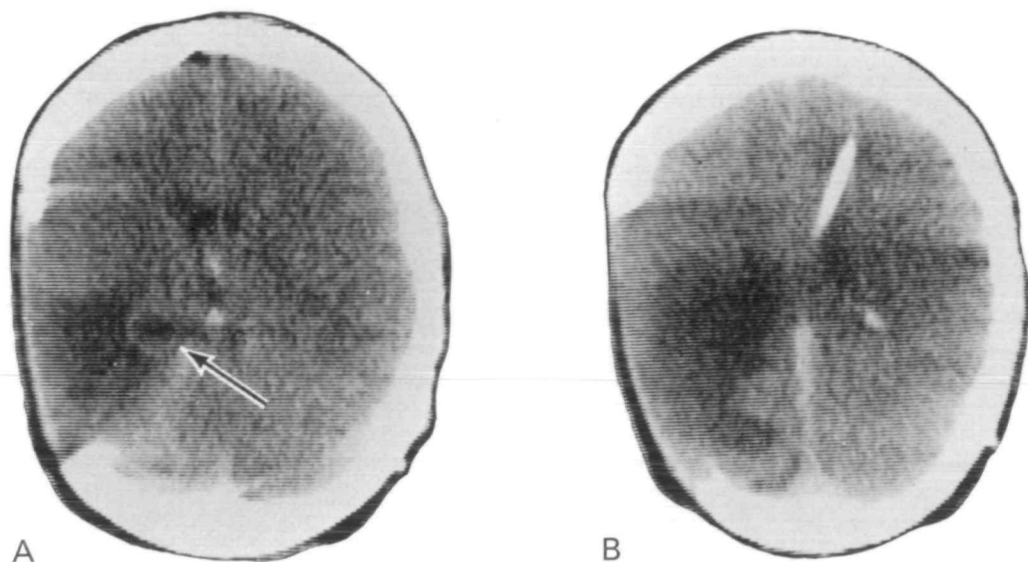


FIG. 1. *Case 1.* CT scan. A, left inferior temporal lobe lucency, consistent with infarction, plus contrast-enhancing residual meningioma (arrow). B, temporo-parietal lucency. Amputated left anterior temporal lobe is not demonstrated.

Even while severely aphasic she enjoyed listening to music and later said that in contrast to her language difficulties, musical understanding never seemed impaired. Similarly, although she had often been aware of paraphasic errors when she spoke, she believed she had, from her first attempts at singing, sung the notes properly and with fewer paraphasic errors. Unable to read or write either words or music, she memorized new songs by listening to recordings. Right hand clumsiness prevented piano playing, and so she returned to the guitar, using her left hand for finely coordinated chord placement and her right hand for coarse but properly rhythmical strumming; individual string plucking was too difficult for her.

Language and music testing (July 1977). Despite paraphasic errors, her spontaneous speech was intelligible. Prosody was normal. Auditory comprehension was especially impaired for body parts, prepositions, passive subject-object discrimination, possessive relationships, and complex ideational material. Naming produced verbal paraphasic errors, and she named only six animals in one minute. Word and phrase repetition led to only occasional literal paraphasias, usually self-corrected, and she was able to repeat syntactically complex phrases (for example, 'no ifs, ands, or buts'). Reciting the days of the week and the months, she omitted Saturday and December. Literal and verbal paraphasias contaminated recitation of nursery rhymes and the words of familiar songs.

Reading single words and sentences aloud produced many literal and verbal paraphasias, for example, 'sammock' for 'hammock', and 'atomic' for 'explode'. Written language comprehension was more severely impaired than reading aloud. She mis-identified most written words after hearing them spoken and mis-named most words spelled orally. Selecting written words to complete written sentences or to answer questions about written paragraphs revealed severe disability. Word-picture

matching, on the other hand, was normal; she pointed to the correct pictured object, geometrical shape, number, colour, or action for the written word shown, including those she had read paraphasically or said she could neither read aloud nor understand.

She wrote her name correctly but not her address; 'Fair Hill Road' became 'Fa Ro'. Transcribing printed sentences into script was done clumsily but correctly. Writing the alphabet and numbers up to 21, she did the first few correctly and then made paragraphic errors, omissions and repetitions. She correctly wrote most dictated letters and numbers, but could write no more than the first letter of any dictated word or the name of something seen. Attempting to describe the cookie theft picture, she wrote, 'she m . . .', and then could write no more.

There was neither left-right confusion nor finger agnosia. Simple calculation, spoken and written, was poor, even when she understood the number involved. There was no apraxia. Copies of simple diagrams, including a Necker cube, and spontaneous drawings of a clock and a flower were normal, and there was no hemi-inattention.

Summary. She had moderately severe transcortical sensory aphasia. Repetition, though not normal, was much less impaired than auditory comprehension. Alexia and agraphia were marked, yet semantic understanding of written words appeared intact as far as matching them to pictures was concerned.

Non-lexic receptive musical appreciation was normal for tone, melody, and harmony. She correctly identified the higher or lower of two pitches, including half-tones. Single tones played on a piano were correctly sung. She identified a variety of well-known melodies either sung or played to her, and was aware of intentional errors. She correctly identified by naming or by imitation musical instruments from recordings. Identification of serially and simultaneously played intervals was correct within the limits of anomia. Major and minor chords, the number of notes in a chord (up to four), and intervals in chords (if arpeggio) were identified. She recognized 3/4 and 4/4 metre and correctly reproduced rhythms tapped, played on a single piano note, or bound to a melody. Fast vs slow, accelerando vs ritardando, and crescendo vs diminuendo were also identified.

Non-graphic musical expression was also intact. She correctly sang well-known melodies, accompanied and unaccompanied, and with upward and downward key transposition. She could learn new melodies. Ascending and descending scales, legato and staccato, were correctly imitated, and she could sing crescendo, decrescendo, accelerando, and ritardando. With her left hand she could play simple melodies on the piano and make proper chords on the guitar, and she correctly played named piano notes, guitar chords, and intervals. She believed her left-handed instrumental ability was as good as it was before her illness and, singing several current popular songs, correctly accompanied herself on the guitar. When she added words, there were paraphasic errors to the same degree as when she recited rhymes or lyrics, but the melody and rhythm remained correct.

She identified by naming or selection from a list all the notes on a piano keyboard. Naming written single notes was often incorrect, however, and playing written notes on the piano, especially in the bass clef, led to frequent errors. Written intervals and chords were played and sung badly, whether or not she played the first or lowest note correctly, and she could not match written intervals with what she heard. She

always recognized, however, whether an interval was upward or downward. Unsuccessfully attempting to sightread simple melodies, she usually heard her errors and attempted self-correction. She recognized whole, half, quarter and eighth notes, time signatures, accidentals and dynamic symbols, including letter abbreviations (*f*, *pp*, etc.). Rhythm was read better than pitch, with only occasional errors tapping simple written patterns, including sixteenth notes, dotted quarters and eighths, and easy syncopation. She figured out guitar chord fingering with her left hand from standard tabulature.

Several lines of a four-part score were correctly copied, including clefs, metre indication, key, measures, rests and notes, and she drew on command whole, half, quarter and sixteenth notes, a treble and a bass clef, and whole, half and quarter rests. She could not, however, indicate pitch on a score. Attempting to write intervals (sung or played), she made frequent errors, but always wrote upward or downward correctly. Writing well-known melodies (named or played) was done laboriously and with errors of note placement and rhythm (fig. 2), especially in the bass clef, and with no improvement when she wrote either element alone.



FIG. 2. Case 1. Attempt to write 'Happy Birthday', demonstrating errors of note placement and rhythm. (This and subsequent musical illustrations have been transcribed by an artist for clarity.)

In April 1978 she gave a singing recital, which included works in five languages ('Ah, Spietato', by Handel; 'Zwei Lieder', Op. 91, by Brahms; 'Le Bestaire', by Poulenc; 'Cancion De Duna Para Dormir A Un Negrito', by Montsalvatge; and 'Four Songs', based on the poetry of Thomas Campion, by Virgil Thomson). Several of these pieces she had learned since her illness. There were no apparent errors of either music and words, although she believed that there had been occasional paraphasias in the foreign languages, especially German.

Several weeks later aphasia was barely apparent on casual conversation. There were still, however, disturbances in auditory comprehension and naming; repetition was normal. Reading and writing were only mildly improved. She still made frequent verbal paralexias, had considerable difficulty naming words spelled aloud, and missed most of the tests of reading comprehension. Written words were again correctly matched with pictures even when she could neither read them aloud nor give other evidence of comprehending them. She wrote her address better than before ('Fail Hill Rd' for 'Fair Hill Rd'), as well as dictated words and names of

objects; but spontaneous written description of the cookie theft picture was limited to 'The gil + the bog'.

Except for reading and writing, musical abilities continued to be normal. She still made errors reading notes, especially in the bass clef, whether using her right or left hand. Written intervals were often incorrectly played or sung, and she tended to ignore sharps and flats, but as before, was correct on upward or downward movement. Although sightreading notes, intervals, and simple melodies was still very difficult, rhythm was now nearly normal. Single notes written to dictation were frequently wrong, especially in the bass clef, and dictated or played intervals or well-known melodies were written nearly as badly as before. Rhythmical elements, however, were much improved (fig. 3), and when she wrote a tune with all notes of the same pitch, rhythm was done correctly.

About this time she embarked on a career singing popular songs (in English) in New York nightclubs. Attending a performance, the author was unable to detect errors of either words or music.



FIG. 3. *Case 1*. Later attempt to write 'Happy Birthday'. There has been greater improvement with rhythm than with note placement; in fact, when she wrote the same tune with all notes of the same pitch, rhythm was correct.

Case 2

A 42-year-old hypertensive man was admitted October 3, 1978, following a major motor seizure. He was initially mute and did not appear to comprehend any speech. There was left gaze preference and right homonymous hemianopia, facial weakness and sensory loss, but he moved his limbs symmetrically, and reflexes were normal. Cerebrospinal fluid (CSF) was grossly bloody, with 52,000 red blood cells per high power field, xanthochromic supernatant, protein 320 mg/dl, and normal glucose content. At left carotid angiography there was an avascular mass in the posterior temporal lobe, plus an aneurysm at an early bifurcation of the middle cerebral artery. Computerized tomography, three weeks after admission, revealed lucency suggestive of infarction in the left posterior temporal and inferior parietal lobes (fig. 4). Recurrent seizures during the first week were effectively treated with phenytoin and phenobarbital, which he took for the remainder of his stay. Improving steadily, he refused operation or further studies and on November 8 signed out against medical advice.

A professional jazz double-bassist, he could read and write music, more easily in the bass than the treble clef. He had been able to sing, but had never done so professionally and did not have absolute pitch. Though not a pianist, he had known where individual notes were on the keyboard.

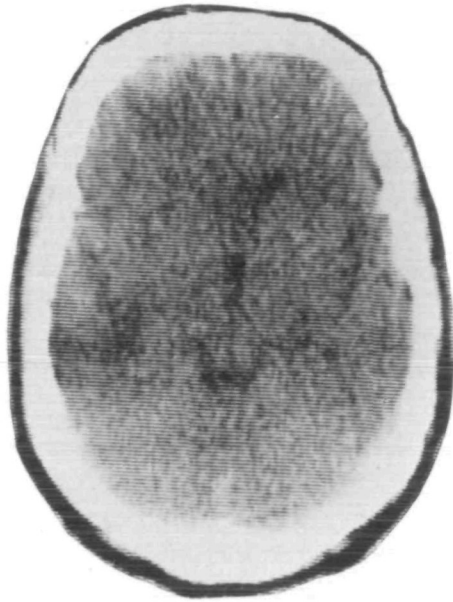


FIG. 4. *Case 2.* CT scan. Left parieto-temporal lucency consistent with infarction.

Language and music testing (October 16 and 17, 1978). He was alert, attentive, and co-operative, and had no neurological abnormalities other than aphasia, apraxia and amusia. Spontaneous speech was fluent with normal prosody and infrequent verbal paraphasias, but lacking in substantive content. Describing the cookie theft picture, he said, 'What I see . . . I see the woman . . . beginning to fall . . . I see the person . . . pressure . . . putting places all over the place . . . I see the mess all right.' He comprehended most spoken single words but had difficulty with more complex spoken material. He recited the days of the week and the months, but could count no higher than 12, and, reciting the alphabet, skipped several letters. He could neither recite nursery rhymes and well-known songs nor properly repeat phrases or more than one-syllable words. Grammatical phrases were no worse than non-grammatical. For example, he repeated 'The spy fled to Greece' as 'The spy fights flights', and 'One would have been enough' as 'One were as one'. Naming led to frequent verbal paraphasias.

Reading aloud produced literal and verbal paraphasias, for example, 'tinakel' for 'triangle' and 'How lo go home from worse' for 'I got home from work'. He correctly matched printed and script writing, but had great difficulty matching written and spoken words; there was neither semantic nor phonetic preference in his choices. He failed to identify orally most spelled words. Although there were frequent errors, he selected the correct written word for a picture more often than for a spoken word.

He wrote his name correctly but could write no more than the numerals of his address. He correctly wrote dictated letters and numbers. Transcribing a printed sentence into longhand led to several literal paraphasias, for example, 'bumps' for 'jumps', as did writing words of pictured items, for example, 'squain' for 'square'. He could write no dictated words, saying, 'I forgot my memory'. Shown the cookie theft picture, he wrote only 'fallin'.

Calculation, with the question spoken by the examiner and the answer spoken by the patient, was done poorly, but simple written calculation (addition of three numbers, subtraction, and multiplication) was nearly normal. There was neither left-right confusion nor finger agnosia. Despite his impaired comprehension, it was apparent that he had ideomotor apraxia for many transitive actions: he was

unable to imitate use of an object, but performed normally when given it. He was not apractic, however, in showing how to play his double-bass. He copied simple diagrams and put numbers correctly in a clock face, but he could not properly copy a Necker cube.

Summary. He had moderately severe conduction aphasia; repetition was significantly more impaired than auditory comprehension. Alexia and agraphia were marked. Although matching written words with pictures was superior to other reading tasks, he did make errors.

Music did not sound 'right' to him, but he could not elaborate. He was able to tell which of two tones was of higher pitch and to recognize well-known melodies. He identified intentional errors in these tunes and recognized instruments by timbre. He mis-identified most heard intervals, whether trying to name them or to select their names from a list. Similar difficulty occurred recognizing major and minor chords and the number of notes or the intervals in a chord. Attempts to imitate, by singing or whistling, single tones, intervals, or familiar melodies failed, with or without words and whether or not the examiner sang or played along. He would sometimes hit a note correctly but then fall off it; asked if he recognized what he was doing, he replied, 'I can't even hear my voice.' It was thus uncertain to what degree this difficulty was receptive as well as expressive. He appeared unable to recognize metre (e.g. 3/4 vs 4/4), and was unable to imitate either dynamic changes or rhythms tapped, played on a single piano note, or bound to a melody.

With written music he correctly named (or selected the name from a list) clefs, quarter, half, and whole notes, accidentals, rests, and time signatures, but not eighth or sixteenth notes or dynamic symbols (including *pp*, *ff*, and non-letter symbols for crescendo and decrescendo). He could neither name, identify, nor play on a piano keyboard written notes in bass or treble clef. He also had great difficulty, however, naming the notes of the piano keyboard, at a time when he had only mild difficulty naming objects, body parts, and colours. He was unable to sing or play simple written intervals, to match heard intervals with what was written, or to imitate written rhythm.

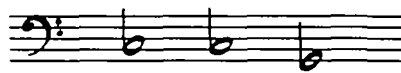


FIG. 5. Case 2. Attempt to write 'Happy Birthday' (which he recognized as it was played).

He correctly drew a treble and bass clef and quarter, half and eighth notes. On both treble and bass clef he wrote a C correctly when the name was dictated to him, but misplaced most other notes. He would occasionally write bass clef notes as if they were treble. Starting with C in bass or treble clef, he could not correctly write any intervals heard on the piano. Told to write 'Happy Birthday' (and recognizing it played), he produced only three half-notes with no resemblance to the initial intervals (fig. 5). Nor, using a single note, could he write the correct rhythm. Asked to write a C-sharp and shown it on the piano keyboard, he wrote first a treble clef,

then a backward note in the bass clef C position, then a misplaced sharp (fig. 6). Asked to copy a simple four-part hymn, he first incorrectly wrote a treble clef, spanning two staves. Starting again, he correctly copied the clefs, and then made frequent errors with note location, duration and bar placement.



FIG. 6. *Case 2.* Attempt to write a C-sharp.

On November 6 spontaneous speech, naming and auditory comprehension were nearly normal; repetition was still moderately impaired. He wrote well to dictation, and although he wrote few words to describe pictures, what he wrote was correct. He read well aloud and correctly matched written words with both pictures and spoken words.

Music now sounded nearly normal to him. He correctly sang single tones, intervals and well-known tunes, with or without words, after either hearing them or being told their titles. He continued, however, to imitate rhythm badly. Musical writing was still poor. Shown where to put the first note of a heard interval, he misplaced the second most of the time. He could not properly write well-known tunes after hearing them, choosing them himself, or correctly singing them (fig. 7).



FIG. 7. *Case 2.* A, later attempt to write 'Happy Birthday'. B, attempt to write 'Jingle Bells'.

He wrote simple heard rhythm poorly even when binding it to a single note; it made no difference whether the rhythm was tapped, played as a single note, or bound to a melody (fig. 8). Still error-ridden were his sightreading (singing) of two-note intervals and rhythm, matching of written intervals with what he heard, naming of written single notes, and identification of dynamic symbols, including letter abbreviations.



FIG. 8. *Case 2.* Attempt to write rhythm. A, rhythm played for patient on single piano note and then tapped. B, patient's written reproduction of same rhythm.

DISCUSSION

These two aphasic patients had musical dysfunction, yet to compare them with each other and with cases from the literature should discourage one from trying to predict what kind of amusia, if any, might follow a particular brain lesion. Case 1, with transcortical sensory aphasia, had entirely normal musical function except for musical alexia and agraphia, which in turn were greater for pitch than for rhythmic elements. Case 2, with conduction aphasia, had severe expressive (and probably mild receptive) amusia, which affected rhythm more than pitch, plus musical alexia and agraphia in which rhythm and pitch elements were affected with equal severity. Case 1's musical agraphia was less severe than her language agraphia; in Case 2, the reverse was true.

Previous reports cover a spectrum of aphasia without amusia, aphasia with amusia, and amusia without aphasia, and within each category the severity and type of aphasia or amusia varies widely. To appreciate the heterogeneity of each subgroup, including the presence or absence of musical alexia and agraphia, it is useful to review in detail some of these cases, none of whom, however, closely resembles either of the present patients.

Aphasia without Amusia

The first report of aphasia with relatively preserved musical ability was probably Dalin's (1745). A man with right hemiparesis and speech limited to the word 'yes' could sing hymns learned before his illness. To get started, however, he had to hear someone else singing the same song. He could also 'recite certain prayers without singing, but with a certain rhythm and in a high-pitched shouting tone'. Similar nineteenth-century reports were summarized by Edgren (1895), who found that aphasia and normal musical function were as common as aphasia plus amusia. Jackson (1871) described two children with non-fluent aphasia; one could sing with words; the other could sing only without them. Henschen (1925), citing 89 cases of aphasia and preserved musical function, found that appreciation of pitch might be intact with altered rhythmic sense, or *vice versa*. Critchley (1953/1966) described a patient with jargon aphasia, due to left parieto-temporal glioma, who was able to conduct his own orchestra.

A 47-year-old right-handed man (Smith, 1966), globally aphasic following left hemispherectomy, gradually recovered considerable auditory comprehension, although his speech remained severely limited. He was able to sing familiar songs 'with little hesitation and few errors in articulation'. Similarly preserved singing followed left hemispherectomy (Gott, 1973) in a right-handed 14-year-old whose spontaneous speech was 'limited as a rule to single words or short phrases'.

A woman who survived carbon monoxide poisoning (Segarra and Quadfasel, 1961; Geschwind, Quadfasel and Segarra, 1968) had spontaneous speech limited to a few recurrent utterances (e.g. 'Hi, Daddy'), echolalia, palilalia and no apparent language comprehension. She could sing the words and music of familiar songs and

of new material taught to her. Serial speech was adequate for a few digits and months, and she could say rhymes but not random words in unison with the examiner. At autopsy there was widespread destruction of frontal, parietal and temporal lobes (including both temporal tips), but preservation of peri-opercular regions. The authors considered the case an example of mixed transcortical aphasia (Goldstein, 1917), due to 'isolation of the speech area', and correlated the pathology with her ability to repeat rather than with musical function *per se*.

Yamadori, Osumi, Masuhara and Okubo (1977) found that 21 of 24 Broca's aphasics sang satisfactorily, six excellently. Two produced poor melody and one was unable to form a melody at all. Six of the 21 who sang well could not produce words with the melody and 3 contaminated the words with literal paraphasias. Eight who could sing required a few notes by the examiner to get started. Ability to sing, with or without words, did not correlate with severity of aphasia.

Preserved musical function in aphasics has included musical reading and writing. Jackson (1871) cited a patient of Trousseau's, 'completely aphasic', including alexia and agraphia, who 'could note down a musical phrase sung in his presence'.

The Russian composer Shebalin, despite severe Wernicke's aphasia, with alexia and agraphia (Luria, Tsvetkova and Futer, 1965), continued musical composition '... which other musicians considered to be up to standard', including songs, quartets, choruses and a symphony. At autopsy there was 'massive red softening of the left hemisphere of the brain in the temporal and inferior parietal regions'. Luria *et al.* concluded that '... phonematic and musical (prosodic) organization of acoustic perception and memory are included in different systems, and have as their basis different cortical structures.' A similar patient (Blau and Henson, 1977) had severely impaired comprehension of spoken and written speech, yet could read music and play the piano properly with his left hand.

A professional pianist (Assal, 1973) with Wernicke's aphasia, including moderately severe alexia and agraphia, continued to play the piano publicly. Not only could he play melodies sung to him, whether or not he had heard them before, reproduce heard chords, and recognize dynamics, instruments and intentional errors, but he could read a score nearly correctly and could write and compose music.

Aphasia plus Amusia

A number of nineteenth-century workers reported amusia in aphasics (Edgren, 1895). Although usually neither language nor musical dysfunction were described in detail, it was apparent that amusia could be expressive, receptive, or mixed, and that it was sometimes of uncertain type. A left-handed aphasic with a right hemispheric lesion (Finkelnburg, 1870) could play heard melodies on the violin but not on the piano.

A patient with mild anomia (Pötzl and Uiberall, 1937) heard music as dissonant and voices, including his own, as too high-pitched; he could neither sing nor reproduce rhythmic patterns. At autopsy the auditory cortices were bilaterally

damaged. A professional singer with absolute pitch (Jellineck, 1956) had anomic aphasia with mild alexia and agraphia. Her major musical disability consisted of difficulty recognizing melodies she had once sung unless the words were added. A patient with Wernicke's aphasia (Kleist, 1962) was unable to recognize or play familiar melodies although he could still appreciate pitches and intervals, tuning his zither precisely and reproducing chords properly. At autopsy there was infarction of the left anterior second and posterior first temporal convolutions, extending into the supramarginal gyrus. Two aphasic patients (Dorgeuille, 1966) following left anterior temporal lobe surgery had difficulty discriminating tone and, in one, timbre. A third patient, with a more posterior left temporal lobe lesion, had difficulty recognizing tonal sequences.

Receptive amusia has accompanied both auditory agnosia and pure word deafness. A woman unable to distinguish speech from music following a lesion in the left superior temporal transverse gyri (Heschl's and adjacent) could, however, sing songs after reading their titles (Schuster and Taterka, 1926). A man with word deafness but nearly normal speech (Ziegler, 1952) could not recognize melodies, and although able to tell which of two or three notes was higher, could not reproduce intervals. He imitated heard rhythms but not dynamics. A patient who heard speech, including his own, as an 'undifferentiated mass of sounds without structure or rhythm' and could not repeat spoken words (Klein and Harper, 1956) could none the less recognize people's voices and regional accents and identify other sounds and melodies. He could not, however, reproduce melodies correctly.

After excision of a right frontal glioma, a right-handed man (Botez and Wertheim, 1959) had left hemiparesis and aphasia consisting of dysarthria and altered prosody on spontaneous speech and repetition, mildly impaired speech comprehension, paraphasias on reading aloud and paraphasias. Although lacking musical training, he had played the accordion and sung in a dance band. A year after operation language function was nearly normal except for dysprosody and tachyphemy, yet he still sang 'wrong' and could not play his instrument. On formal testing he correctly sang notes sung to him, but hearing them played on his accordion, he sang them a fourth too high or too low. He was aware of his errors but could not correct them. Imitation of rhythm was poor, improving when it was 'bound' to a melody. He sang well-known tunes poorly with wrong tones, poor stress, inappropriate staccato and tremulo, and inability to do *accelerando* vs *ritardando* or *crescendo* vs *decrecendo*. Attempts to learn new songs failed; rhythm was especially poor. He could not play his accordion, although he held his hands correctly. As the authors conceded, cerebral language dominance was uncertain in this patient. If bihemispheric language representation is likely in dextrals with 'crossed aphasia' (Brown and Hécaen, 1976), the question of 'musical dominance' in such patients becomes even more problematical than in conventional right-handers. Predominantly motor amusia was described in another dextral with crossed aphasia by Barraquer-Bordas, Mendilaharsu, Peres-Serra, Acevedo de Mendilaharsu and Grau-Veciana (1963).

In cases of aphasia plus amusia, musical reading and writing may be either spared or affected. Proust (1866) reported an aphasic patient who could recognize, sing, play and write music, but could not read it. An aphasic music teacher (Fischer, 1867) recognized melodies and rhythmic patterns and could play tunes on the violin but could neither read nor write music, nor play or sing tunes sung to him. A woman (Proust, 1872) with 'a smattering' of musical knowledge had conduction aphasia with agraphia but normal reading comprehension; she could read notes, play scales, and recognize tunes, but could not hum them. A 'completely aphasic' musician (Proust, 1872), unable to speak or write, was also unable to hum, yet she recognized melodies, read music and composed. Dejerine's (1892) patient with pure alexia also lost the ability to read music; speech, writing and singing were normal.

A piano teacher (Souques and Baruk, 1926, 1930) sustained infarction of the left superior posterior temporal lobe, causing jargon aphasia with severely impaired speech comprehension, reading and writing. She could play, spontaneously, a simple 'air de danse' on the piano, but no other piece. Scales were played properly after demonstration by the examiner, and she imitated rhythm well but although she could play scales in thirds, she could not play them in sixths or ninths. She could not play, copying the examiner, simple tunes, although she sometimes reproduced the correct rhythm with wrong notes. She recognized deliberate errors in scales. In contrast to her inability to play what she heard, she played from score perfectly a Clementi sonatina. A prelude from Bach's *Well-tempered Klavier* was performed slowly, as by a novice. She copied music well, although transposing with difficulty, and she wrote correctly music she heard.

Each of Ustvedt's (1937) 19 patients with left hemispheric stroke, most of whom were aphasic, noted less emotional involvement with music afterward. Uniformly impaired were appreciation of measure and recognition of short melodic-rhythmic figures; appreciation of pitch, volume, and timbre was intact. Some had difficulty singing; others sang well, with or without words. In the few who had been able to read music pre-morbidly, musical alexia paralleled or was worse than language alexia.

Maurice Ravel had Wernicke's aphasia, alexia, agraphia and ideomotor apraxia (Alajouanine, 1948); a definite aetiology was never established. 'Memory, judgement, affectivity, (and) aesthetic taste' were said to be intact, as was 'musical thinking': he recognized melodies and errors of rhythm and pitch, including a badly tuned piano. He could not, however, play the piano or sing properly, either spontaneously, by imitation, or from score, nor could he name, play, or sing written notes. He wrote music poorly, although better than he wrote words; copying music was 'almost impossible'. Alajouanine did not determine to what degree Ravel's difficulties with musical expression, reading and writing involved rhythm, pitch, interval, or melody, but simply observed that, although he could 'still listen to music, attend a concert, and express criticism on it or describe the musical pleasure he felt', he never again was able to compose the pieces he heard 'in his head'.

A singer-guitarist after left frontal lobe surgery (Jellineck, 1956) had mixed aphasia, including alexia and agraphia, as well as mixed amusia. Singing was wrong in pitch and rhythm, worsening if words were added, and scales and pure phrases were more difficult than extended tunes. He did not recognize his errors. He could immediately repeat melodies, but could not later recognize them and often did not recognize well-known melodies. Musical alexia was total, and worse than reading language; he could not even orientate himself on the page, tell if a note was higher or lower than another, or identify a chord.

A professional violinist with absolute pitch had mild Wernicke's aphasia and right hemiparesis following a stroke (Wertheim and Botez, 1961). There were paraphasias on spontaneous speech, naming and repetition, decreased comprehension for complex commands, paralexias on reading aloud and mild agraphia. Reading comprehension was intact. Amusia was said to be 'receptive' because of difficulty naming intervals, pitches, and rhythmic patterns and inability to name familiar melodies played on the piano after correctly identifying them when they were sung. Some of his other difficulties, however, could have been either receptive or expressive, for example, failure to imitate heard rhythm or to sing a melody previously unknown to him, and some were probably expressive, for instance, singing familiar songs with frequent intonational errors. He copied music correctly, but writing music both spontaneously and to dictation was poor; rhythm was better than placement of notes. He named most notes correctly in the treble clef but had great difficulty with the bass and viola clefs; he could not sing solfeggio simple tunes written on any clef. A problem with this case is that, in addition to the difficulty in defining many components of his amusia as either 'expressive' or 'receptive', it is not clear whether the anomia and decreased speech comprehension distorted the results of musical testing.

An orchestral conductor and composer (Critchley, 1970) was unable to play the piano or write music properly while aphasic, although he said '... I have the music in me'. Following removal of a left parietal meningioma, speech and ability to compose seemed to improve in parallel.

Amusia without Aphasia

Not surprisingly, cases of amusia without aphasia have been reported infrequently. Edgren (1895) collected 5 cases from the literature, in contrast to 23 with amusia plus aphasia. There have been several accounts of right hemispheric damage with inability to sing or to whistle but with preserved language function and melody recognition; such patients have had either frontal (Mann, 1898) or temporal (Brain, 1941) lobe injury, or even hemispherectomy (Damasio, Lima and Damasio, 1975). Gordon and Bogen (1974) found, following right carotid amobarbital injection to right-handed subjects, impaired singing ability; pitch was more affected than rhythm, but patients had a general tonal sense, tried to correct errors and could recognize songs sung to them. Speech was rather dysarthric, but had normal prosody and phonetic stress.

Difficulty with musical perception has been described. Kohl and Tschabitscher (1953) and Pittrich (1956) reported inability to recognize musical sounds following right hemispheric lesions, and Pötzl (1939) reported difficulty appreciating rhythm. Following right temporal lobe surgery, a man (Jellineck, 1956) reported that music sounded 'out of tune'. He found it easier to imitate melodies sung by male than by female voices; chords, however, were better recognized when high-pitched. Rhythm was normally appreciated, but rhythmic changes gave him a sense of tonal change as well. A woman with a right thalamic tumour (Roeser and Daly, 1974) experienced 'gross distortion of music perception in her left ear'. A man unable to recognize any non-verbal sounds (Spreen, Benton and Fincham, 1965) was poor at pitch identification, yet could comprehend speech. At autopsy there was infarction of the right frontal, parietal and temporal lobes and insula.

Milner (1962) gave the Seashore Test of musical abilities (which measures discrimination of pitch, loudness, rhythm, duration, timbre and tonal memory) to 27 left speech-dominant patients before and after either right or left temporal lobectomy. Whereas there was no loss of musical ability after left lobectomy, deterioration followed right lobectomy, slight for pitch and rhythm, marked for timbre and tonal memory. There was no difference whether or not Heschl's gyrus was removed. Shankweiler (1966) found that whereas melody recognition deteriorated after right temporal lobectomy, pure frequency discrimination did not.

Musical reading and writing have seldom been tested in patients with amusia but not aphasia. A professional trombonist and music copier, seen by Charcot (Souques and Baruk, 1930), suddenly lost the ability to copy music or to play his trombone properly, yet he appreciated music and could read it, singing it mentally. There was no weakness or other apraxia and language function, including reading and writing, was normal. The site of pathology was not determined. Jossmann's (1927) patient, following right carotid ligation and left hemiparesis without aphasia, could neither sing, whistle tunes, nor read music, but recognized pitch and his own errors. A trumpeter, after head injury (Dorgeuille, 1966), had difficulty writing heard rhythmic patterns; language and musical function were otherwise normal.

The Present Patients

The varieties of amusia, including musical alexia and agraphia, are thus not predicted by the presence or absence of aphasia, and there is considerable heterogeneity among those cases of aphasia with normal musical function, including musical reading and writing (Jackson, 1871; Luria, Tsvetkova and Futer, 1965; Assal, 1973; Blau and Henson, 1977), aphasia with amusia, including musical alexia and agraphia (Fischer, 1867; Ustvedt, 1937; Alajouanine, 1948; Jellineck, 1956; Wertheim and Botez, 1961), and aphasia with amusia but preserved musical reading and writing (Proust, 1872; Souques and Baruk, 1926, 1930).

The present Case 1, with transcortical sensory aphasia and normal musical function except for musical alexia and agraphia, appears to have no well-studied

counterpart in the literature. Proust's (1866) patient, while unable to read music, could write it. Dejerine's (1892) patient was unable to read music as part of a pure alexia syndrome. How much Case 2, with conduction aphasia, resembles previously reported patients is uncertain, as details of both language assessment and musical reading and writing have usually been absent. Proust's (1872) patient with conduction aphasia could not hum tunes, but could play scales and read notes; she apparently had never written music. Jellineck's (1956) patient had mixed aphasia and more severe musical alexia. Wertheim and Botez's (1961) patient had rather similar aphasia, although the relative severity of comprehension and repetition is unclear, and reading comprehension and writing were better preserved than in Case 1's earliest testing. As with Case 2, there were abnormalities of musical function which could have been either receptive or expressive. In contrast to our case, Wertheim and Botez's patient copied music well and wrote rhythm better than he designated pitch. Anomia and expressive (singing) amusia leave the degree of his musical alexia uncertain, and many components of musical reading and writing were not tested.

Musical Reading and Writing

Musical reading and writing involve 'skills commonly believed to be language-specific' (Henson, 1977*b*). Sloboda (1976), comparing musically literate and illiterate subjects, found that the musically sophisticated, when analysing written note sequences, appeared to use neither visual (that is, spatial), naming, nor pitch codes but rather to code 'relations between the notes rather than the notes themselves'. Similar processing has been suggested to underlie the reading of language (Kollers, 1972). Musical reading and writing, however, involve more heterogeneous symbols than ordinary reading and writing of words. There are real words, often abbreviated (*allegro*, *largo*, *DC*, *pp*, *f*, etc.); notes whose pitch is designated by letters (A, B, C, etc.) but represented spatially, and whose duration is indicated by appearance (*minim*, *crotchet*, *quaver*, etc.); metre, expressed as numerical fractions and dependent upon placement of bars; and purely musical symbols for pitch alteration and key signature (*sharps*, *flats*, *naturals*), pauses (*rest*), tonal prolongation (*fermata*), pitch calibration (*clef*), *crescendo* or *decrescendo*, *staccato*, *legato* and *repeat*. Both simultaneous and sequential events are indicated.

It was therefore of interest to determine whether those aspects of musical notation closest to verbal language or most dependent upon temporal (sequential) processing were maximally impaired in our aphasic patients. Such was not the case. In fact, the first patient suggested an opposite dissociation. Her maximal difficulty with reading music was with note placement (pitch designation); she could not read single notes, two note intervals or chords properly, but knew whether the second of two notes was higher or lower. That this difficulty did not reflect inability to read notes as letters is suggested by the fact that she named written notes and intervals better than she sang or played them. She was considerably more adept at reading the kind of note present, key and time signatures, accidentals, dynamic and agogical symbols,

word abbreviations and significantly, from the standpoint of sequential processing, pure rhythm. Writing music led to errors of both pitch and rhythm, whether done alone or together. Her greater difficulty reading and writing in the bass clef paralleled reports of others (Wertheim and Botez, 1961) as well as the experience of beginning musicians. At her second examination reading alexia and musical alexia-agraphia had all improved more than language agraphia, and there was particular improvement in writing rhythm.

Case 2 showed no dissociation between temporal and non-temporal or verbal and non-verbal elements in his musical alexia and agraphia (or, for that matter, early in his expressive and receptive amusia, although later he could imitate pitch and interval better than rhythm). Like Case 1 he named written notes better than he sang, played or wrote them. Unlike Case 1, his musical alexia and agraphia remained severe when his language alexia and agraphia had improved considerably, and he had more difficulty recognizing musical dynamic abbreviation (*p*, *pp*, *f*, *ff*) than in reading letters, words or sentences.

A Japanese patient with transcortical sensory aphasia (Sasanuma and Monei, 1975) could not comprehend written kanji (Chinese ideogrammatic) characters yet understood kana (phonetic) characters and wrote kanji with more difficulty than kana. Conversely, preservation of kanji relative to kana reading has been reported in anomic aphasia (Yamadori, 1975). No such dissociation between kinds of musical symbol occurred with either Case 1 or Case 2.

Like a patient with better repetition than auditory comprehension (Albert, Yamadori, Gardner and Howes, 1973), Case 1 had severe disability comprehending written words or sentences and spelled words, yet successfully matched written words with appropriate pictures, suggesting preservation of 'semantic understanding' of written words. There was no corresponding ability to match written musical notes or intervals with what she heard played or what was spoken to her. Non-pitch musical alexia was too mild for such dissociation to be testable.

As noted, it seems unlikely that letter coding was the main reason for these patients' difficulty reading and writing pitch; it cannot, however, be dismissed as a contributing factor. Experienced musicians do not usually name individual notes or chords as they read them (Henson, 1977*b*), but beginners do. Several reported patients with aphasia but preserved musical reading and writing were older or more musically experienced than our patients (Souques and Baruk, 1926; Luria, Tsvetkova and Futer, 1965; Assal, 1973). On the other hand, so were some with aphasia, amusia and musical alexia-agraphia (Alajouanine, 1948; Jellineck, 1956; Wertheim and Botez, 1961).

Singing and Repetition

When Case 1's aphasia was still moderately severe, she could sing nearly flawlessly, in five languages, songs learned since her illness. Reports of aphasics who sing better than they speak have been mostly concerned with Broca's or otherwise non-fluent speech (Yamadori *et al.*, 1977; Geschwind *et al.*, 1968) and have included

those who could sing with words (Jackson, 1871; Ustvedt, 1937; Smith, 1966; Gott, 1973; Geschwind *et al.*, 1968; Heilman, Tucker and Valentstein, 1976; Yamadori *et al.*, 1977) and those who could not (Jackson, 1871; Head, 1926/1963; Jellineck, 1956; Yamadori *et al.*, 1977). The ability to sing words which could not be spoken has been attributed to the factor of automaticity. Ustvedt (1937) cited the same phenomenon in parkinsonians and stutterers. Goldstein (1927) suggested that singing would be preserved in an aphasic to the degree that '... it is an activity closely connected to the patient's affective life. Under such conditions the song is not representative speech, but a "series speech" performance expressive of feeling, like a prayer.' More mechanistically, Bogen (1969) suggested that the addition of words to song might lead to transcallosal inhibition of the right hemisphere by the left.

Whether Case 1's ability to sing with words was related to her relatively preserved repetition, as with the cases of Geschwind *et al.* (1968) and of Heilman *et al.* (1976), and whether Case 2's inability to sing, with or without words, was related to his particular difficulty with repetition, is conjectural. Case 1 sang well in English and made infrequent paraphasic errors in foreign languages. Henson (1977c) stated 'There is no apparent record of any professional vocalist who was able to perform acceptably with permanent dysphasia'. This statement would apply to Case 1 as far as non-English singing is concerned, yet she has been able to pursue a singing career within the limits of popular songs in her own language.

It is also speculative whether Case 2's particular difficulty in repetition was related to his disability with written and imitated rhythm. Musical function was not discussed in a recent review of conduction aphasia (Benson, Sheremata, Bouchard, Segarra, Price and Geschwind, 1973). It is difficult to relate his repetition deficit to his greater difficulty, compared to Case 1, with non-pitch written symbols, either ideogrammatic, numerical or word abbreviations, but it is of interest that whereas his alexia-agraphia for language became much milder than Case 1's, his musical alexia-agraphia for these types of symbols was much more severe. Unlike Case 1 he had difficulty in matching written words with pictures; in addition, like her, he could not match heard intervals with a read score. His musical alexia-agraphia remained severe when music sounded normal to him and he could sing heard notes, intervals and songs, yet was still unable to imitate simple rhythms, whether bound to melody or not.

Experimental Studies

Attempts, using dichotic or reaction-time techniques, to determine hemispheric superiority for components of music have yielded conflicting results. Kimura (1964), playing fragments of different baroque and classical melodies simultaneously into the ears of normal subjects, found the left ear, and therefore presumably the right hemisphere, superior in melody recognition. King and Kimura (1972) demonstrated left ear superiority for non-verbal human voice sounds as well (for example, laughing, crying, coughing). Schuloff and Goodglass (1969) showed, in normals, left ear superiority for tonal sequences, right ear superiority for spoken digits, and no

difference for simple clicks. For pure tone recognition Kallman and Corballis (1975) found left ear superiority, Haydon and Spellacy (1973) right ear superiority, and Nachshon (1973) no difference. Kallman and Corballis (1975) found left ear superiority for timbre, and Robinson and Solomon (1974) right ear superiority for rhythm, but Spellacy (1970) detected no difference for either. Gordon (1970) found left ear superiority for chord recognition but no difference for melodies. Spellacy (1970) and Spreen, Spellacy and Reid (1970) believed that asymmetry for music recognition was influenced by duration of the interstimulus interval. Halperin, Nachshon and Carmon (1973), using dichotic sets of three tones, found that as the number of frequency or duration transitions increased from zero to two, ear superiority shifted from left to right.

As noted, musical understanding involves both sequential-analytic and simultaneous-gestalt processing and so, more than language, might be expected to require co-operation between the 'propositional' left hemisphere and the 'appositional' right. Speech itself is, of course, not wholly a left hemispheric activity (Larsen, Skinhøj and Lassen, 1978). It is hardly surprising, therefore, that those studies which have attempted to isolate temporal and non-temporal aspects of musical ability have not consistently placed them in either the left or right hemisphere (Wyke, 1977). Moreover, people listen to or perform music differently. Werner (1948) observed 'Musically experienced listeners have learned to perceive a melody as an articulated set of relations among components rather than as a whole'. Consistent with this idea, Bever and Chiarello (1974) found that, whereas musically naïve listeners recognized melodies better with the left ear, sophisticated listeners did better with the right. The authors noted that Gordon (1970) had used college students of probably intermediate sophistication, perhaps explaining their non-lateralization of melody recognition. On the other hand, Cook (1973) found left ear superiority for melody recognition in sophisticated listeners. Oscar-Berman, Blumstein and DeLuca (1974), using bilateral simultaneous tachistoscopes, demonstrated that musically sophisticated subjects were more likely than those musically naïve to use both hemispheres in the analysis of musical symbols.

If Case 1's musical sophistication had led, pre-operatively, to left hemispheric musical dominance, with post-operative return to right hemispheric musical processing, such a change was not reflected in her non-lexical musical ability, subjectively or objectively. Left hemispheric destruction was massive and the anterior temporal lobe was amputated. Musical sophistication, with prominent left hemispheric participation in analysing musical symbols, could have contributed to musical alexia and agraphia, but would be at variance with cases from the literature of preserved musical reading and writing in aphasic professional musicians and composers (Souques and Baruk, 1926; Luria *et al.*, 1965; Assal, 1973; Blau and Henson, 1977).

Case 2, although a musically literate professional musician, was less sophisticated than Case 1, and so his musical abilities might be expected to be less dependent upon the left hemisphere. Moreover, his lesion was far smaller than Case 1's and, by

computerized tomography, occupied an area shared by Case 1's lesion. Yet, in contrast to her, he did have expressive and probably receptive amusia, and, whereas his aphasia was milder than hers, his musical alexia-agraphia was more severe.

Conclusion

These two cases thus do not clarify the question of music's relation to speech, language and hemispheric function; rather, consistent with previous literature, they illustrate the complexity of the problem and the prematurity of defining as propositional or appositional either music, its components, or the kind of processing employed by each hemisphere. Chomsky (1972), stressing the inadequacy of present concepts of language and the need to study it in abstract, not physical, terms, stated 'We can only leave open for the future the question of how these abstract structures and processes are realized or accounted for in some concrete terms, conceivably in terms that are not within the range of physical processes as presently understood—a conclusion that, if correct, should surprise no one.' The same can be said about music.

SUMMARY

Two aphasic right-handed professional musicians with left hemispheric lesions had disturbed musical function, especially musical alexia and agraphia. In Case 1 aphasia was of transcortical sensory type, with severe agraphia and decreased comprehension of written words, although she could match them with pictures. Except for reading and writing, musical ability was normal; she could sing in five languages. Musical alexia and agraphia affected pitch symbols more than rhythm. Case 2 had conduction aphasia and severe expressive amusia, especially for rhythm. Although his language alexia and agraphia were milder than Case 1's, his musical alexia and agraphia were more severe, affecting rhythm as much as pitch. In neither patient were those aspects of musical notation either closest to verbal language or most dependent upon temporal (sequential) processing maximally impaired.

These cases are consistent with the literature in suggesting that the presence or absence of aphasia or of right or left hemispheric damage fails to predict the presence, type, or severity of amusia, including musical alexia and agraphia. The popular notion that receptive amusia follows lesions of the language-dominant temporal lobe, whereas expressive amusia follows non-dominant frontal lobe damage, is an over-simplification, as is the view that increasing musical sophistication causes a shift of musical processing from the right hemisphere to the left.

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REFERENCES

- ALAJOUANINE, T. (1948) Aphasia and artistic realization. *Brain*, **71**, 229–241.
- ALBERT, M. L., YAMADORI, A., GARDNER, H. and HOWES, D. (1973) Comprehension in alexia. *Brain*, **96**, 317–328.
- ASSAL, G. (1973) Aphasie de Wernicke sans amusie chez un pianiste. *Revue Neurologique*, **129**, 251–255.
- BARRAQUER-BORDAS, L., MENDILAHARSU, C., PERES-SERRA, J., ACEVEDO DE MENDILAHARSU, S. and GRAU-VECIANA, J. M. (1963) Estudio de dos casos de afasia cruzada en pacientes manidextros. *Acta Neurologica Latinoamerica*, **9**, 140–148.
- BENSON, D. F., SHEREMATA, W. A., BOUCHARD, R., SEGARRA, J. M., PRICE, D. and GESCHWIND, N. (1973) Conduction aphasia. A clinicopathological study. *Archives of Neurology, Chicago*, **28**, 339–346.
- BENTON, A. L. (1977) The amusias. In: *Music and the Brain*. Edited by M. Critchley and R. A. Henson. London: Heinemann Medical Books; Springfield, Illinois: Charles C. Thomas, pp. 378–397.
- and JOYNT, R. J. (1960) Early descriptions of aphasia. *Archives of Neurology, Chicago*, **3**, 205–222.
- BEVER, T. G. and CHIARELLO, R. J. (1974) Cerebral dominance in musicians and non-musicians. *Science*, **185**, 537–539.
- BLAU, J. N. and HENSON, R. A. (1977) Neurological disorders in performing musicians. In: *Music and the Brain*. Edited by M. Critchley and R. A. Henson. London: Heinemann Medical Books; Springfield, Illinois: Charles C. Thomas, pp. 301–322.
- BOGEN, J. E. (1969) The other side of the brain. II. An appositional mind. *Bulletin of the Los Angeles Neurological Society*, **34**, 135–162.
- BOTEZ, M. I. and WERTHEIM, N. (1959) Expressive aphasia and amusia following right frontal lesion in a right-handed man. *Brain*, **82**, 186–202.
- BRAIN, W. R. (1941) Visual disorientation with special reference to lesions of the right cerebral hemisphere. *Brain*, **64**, 244–272.
- BROWN, J. W. and HÉCAEN, H. (1976) Lateralization and language representation: observations on aphasia in children, left-handers, and ‘anomalous’ dextrals. *Neurology, Minneapolis*, **26**, 183–189.
- CHOMSKY, N. (1972) *Language and Mind*. New York: Harcourt Brace Jovanovich, p. 14.
- COOK, R. B. (1973) Left-right differences in the perception of dichotically presented musical stimuli. *Journal of Music Therapy*, **10**, 59–63.
- CRITCHLEY, M. (1953, reprinted 1966) *The Parietal Lobes*. New York: Hafner Publishing, p. 375.
- (1970) *Aphasiology and Other Aspects of Language*. London: Edward Arnold, pp. 256–257.
- (1972) Inter-hemispheric partnership and inter-hemispheric rivalry. In: *Scientific Foundations of Neurology*. Edited by M. Critchley, J. L. O’Leary and B. Jennett. London: William Heinemann Medical Books, pp. 216–221.
- DALIN, O. (1745) Berättelse om en dumbe, som kan siumga. *Kungliga Svenska Vetenskaps Academi Handlingar. Uppsala and Stockholm*, **6**, 114–115. Cited by Benton and Joynt (1960).

- DAMASIO, A. R. and DAMASIO, H. (1977) Musical faculty and cerebral dominance. In: *Music and the Brain*. Edited by M. Critchley and R. A. Henson. London: Heinemann Medical Books; Springfield, Illinois: Charles C. Thomas, pp. 141-155.
- LIMA, A. and DAMASIO, H. (1975) Nervous function after right hemispherectomy. *Neurology, Minneapolis*, **25**, 89-93.
- DEJERINE, J. (1892) Des différentes variétés de cécité verbale. *Compte-Rendu des Séances et Mémoires de la Société de Biologie*, **27**, 1-30.
- DORGEUILLE, C. (1966) Introduction à l'étude des amusies. Thèse, Paris. Cited by Benton (1977).
- EDGREN, J. G. (1895) Amusie (musicalische Aphasie). *Deutsche Zeitschrift für Nervenheilkunde*, **6**, 1-64.
- FEUCHTWANGER, E. (1930) *Amusie. Studien zur pathologischen Psychologie der akustischen Wahrnehmung und Vorstellung und ihrer Strukturgebiete, besonders in Musik und Sprache*. Berlin: Julius Springer.
- FINKELNBURG, F. C. (1870) Verhandlungen ärztlicher Gesellschaften. Niederrheinische Gesellschaft in Bonn. *Berliner Klinische Wochenschrift*, **7**, 449-450.
- FISCHER, A. (1867) Ueber zentrale Sprachstörungen mit besonderer Berücksichtigung der Aphasie. Dissertation, Berlin. Cited by Benton (1977).
- GESCHWIND, N., QUADFASEL, F. A. and SEGARRA, J. M. (1968) Isolation of the speech area. *Neuropsychologia*, **6**, 327-340.
- GOLDSTEIN, K. (1917) *Die transkortikalen Aphasien*. Jena: Fischer.
- (1927) Die Lokalisation in der Grosshirnrinde. *Handbüch der normalen und pathologischen Physiologie*, **10**, 796-797.
- GOODGLASS, H. and KAPLAN, E. (1972) *The Assessment of Aphasia and Related Disorders*. Philadelphia: Lea and Febiger.
- GORDON, H. W. (1970) Hemispheric asymmetries in the perception of musical chords. *Cortex*, **6**, 387-398.
- and BOGEN, J. E. (1974) Hemispheric lateralization of singing after intracarotid sodium amylobarbitone. *Journal of Neurology, Neurosurgery and Psychiatry*, **37**, 727-738.
- GOTT, P. S. (1973) Language after dominant hemispherectomy. *Journal of Neurology, Neurosurgery and Psychiatry*, **36**, 1082-1088.
- HALPERIN, Y., NACHSHON, I. and CARMON, A. (1973) Shift of ear superiority in dichotic listening to temporally patterned nonverbal stimuli. *Journal of the Acoustical Society of America*, **53**, 46-50.
- HAYDON, S. P. and SPELLACY, F. J. (1973) Monoaural reaction time asymmetries for speech and non-speech sounds. *Cortex*, **9**, 288-294.
- HEAD, H. (1926) *Aphasia and Kindred Disorders of Speech*. Oxford University Press. Reprinted 1963, New York: Hafner, Volume 2, pp. 89-107.
- HÉCAEN, H. (1962) Clinical symptomatology in right and left hemispheric lesions. In: *Interhemispheric Relations and Cerebral Dominance*. Edited by V. B. Mountcastle. Baltimore: Johns Hopkins University Press, pp. 215-243.
- HEILMAN, K. M., TUCKER, D. M. and VALENSTEIN, E. (1976) A case of mixed transcortical aphasia with intact naming. *Brain*, **99**, 415-426.

- HENSCHEN, S. E. (1920) *Klinische und anatomische Beiträge zur Pathologie des Gehirns*. Teil 5. *Ueber Aphasie, Amusie und Akalkulie*. Stockholm: Nordiska Bokhandeln.
- (1925) Clinical and anatomical contributions on brain pathology. *Archives of Neurology and Psychiatry, Chicago*, **13**, 226-249.
- (1926) On the function of the right hemisphere of the brain in relation to the left in speech, music and calculation. *Brain*, **49**, 110-123.
- HENSON, R. A. (1977a) The language of music. In: *Music and the Brain*. Edited by M. Critchley and R. A. Henson. London: Heinemann Medical Books; Springfield, Illinois: Charles C. Thomas, pp. 233-254.
- (1977b) Further observations on the neurology of music: musical notation and pitch discrimination. *British Medical Journal*, **1**, 1121-1125.
- (1977c) Neurological aspects of musical experience. In: *Music and the Brain*. Edited by M. Critchley and R. A. Henson. London: Heinemann Medical Books; Springfield, Illinois: Charles C. Thomas, pp. 3-21.
- JACKSON, J. H. (1871) Singing by speechless (aphasic) children. *Lancet*, **ii**, 430-431.
- JACOBS, A. (1967) *A New Dictionary of Music*. Harmondsworth, Middlesex: Penguin Books, p. 258.
- JELLINECK, A. (1956) Amusia. On the phenomenology and investigation of central disorders of the musical functions. *Folia Phoniatica*, **8**, 124-149.
- JOSSMANN, P. (1927) Die Beziehungen der motorischen Amusie zu den apraktischen Störungen. *Monatschrift für Psychiatrie und Neurologie*, **63**, 239-274.
- KALLMAN, H. J. and CORBALLIS, M. C. (1975) Ear asymmetry in reaction time to musical sounds. *Perception and Psychophysics*, **17**, 368-370.
- KIMURA, D. (1964) Left-right differences in the perception of melodies. *Quarterly Journal of Experimental Psychology*, **16**, 355-358.
- KING, F. L. and KIMURA, D. (1972) Left-ear superiority in dichotic perception of vocal nonverbal sounds. *Canadian Journal of Psychology*, **26**, 111-116.
- KLEIN, R. and HARPER, J. (1956) The problem of agnosia in the light of a case of pure word deafness. *Journal of Mental Science*, **102**, 112-120.
- KLEIST, K. (1928) Gehirnpathologie und localisatorische Ergebnisse über Horstorungen, Geräuschaubheiten und Amusien. *Monatschrift für Psychiatrie und Neurologie*, **68**, 853-860.
- (1962) *Sensory Aphasia and Amusia. The Myeloarchitectonic Basis*. Oxford and New York: Pergamon Press, pp. 67-87.
- KOHL, G. F. and TSCHABITSCHER, H. (1953) Über einen Fall von Amusie. *Wiener Zeitschrift für Nervenheilkunde, und deren Grenzgebiete*, **6**, 219-230.
- KOLERS, P. A. (1972) Experiments in reading. *Scientific American*, **227**, 84-91.
- LARSEN, B., SKINHØJ, E. and LASSEN, N. A. (1978) Variations in regional cortical blood flow in the right and left hemispheres during automatic speech. *Brain*, **101**, 193-209.
- LURIA, A. R., TSVETKOVA, L. S. and FUTER, D. S. (1965) Aphasia in a composer. *Journal of the Neurological Sciences*, **2**, 288-292.
- MANN, L. (1898) Casuistische Beiträge zur Hirnchirurgie und Hirnlocalization. *Monatschrift für Psychiatrie und Neurologie*, **4**, 369-378.

- MILNER, B. (1962) Laterality effects in audition. In: *Interhemispheric Relations and Cerebral Dominance*. Edited by V. B. Mountcastle. Baltimore: Johns Hopkins University Press, pp. 177-195.
- MONRAD-KROHN, G. H. (1947) Dysprosody or altered 'melody of language'. *Brain*, **70**, 405-415.
- MULDER, D. W. and DALY, D. (1952) Psychiatric symptoms associated with lesions of temporal lobe. *Journal of the American Medical Association*, **150**, 173-176.
- NACHSHON, I. (1973) Effects of cerebral dominance and attention on dichotic listening. *TIT Journal of Life Sciences*, **3**, 107-114.
- OSCAR-BERMAN, M., BLUMSTEIN, S. and DELUCA, D. (1974) Iconic recognition of musical symbols in lateral visual fields. Paper presented at the American Psychological Association, New Orleans, Louisiana, September 1974. Cited by Wyke (1977).
- PENFIELD, W. and PEROT, P. (1963) The brain's record of auditory and visual experience. *Brain*, **86**, 595-696.
- PITTRICH, H. (1956) Sensorische Amusie mit Paramusie nach rechtsseitiger Temporalverletzung. Goettingen Institute für den wissenschaften Film. Cited by Spreen *et al.* (1965).
- PÖTZL, O. (1939) Zur Pathologie der Amusie. *Zeitschrift für die gesamte Neurologie und Psychiatrie*, **165**, 187-195.
- and UIBERALL, H. (1937) Zur Pathologie der Amusie. *Wiener klinische Wochenschrift*, **50**, 770-775.
- PROUST, A. (1866) Cited by Henschen (1920).
- (1872) De l'aphasie. *Archives Générales de Médecine*, **1**, 147-166, 303-318, 653-685.
- ROBINSON, G. and SOLOMON, D. J. (1974) Rhythm is processed by the speech hemisphere. *Journal of Experimental Psychology*, **102**, 508-511.
- ROESER, R. J. and DALY, D. D. (1974) Auditory cortex disconnection associated with thalamic tumor: a case report. *Neurology, Minneapolis*, **24**, 555-559.
- SASANUMA, S. and MONEI, H. (1975) The syndrome of Gogi (word meaning) aphasia. Selective impairment of kanji processing. *Neurology, Minneapolis*, **25**, 627-632.
- SCHULOFF, C. and GOODGLASS, H. (1969) Dichotic listening, side of brain injury and cerebral dominance. *Neuropsychology*, **7**, 149-160.
- SCHUSTER, P. and TATERKA, H. (1926) Beitrag zur Anatomie und Klinik der reinen Worttaubheit. *Zeitschrift für die gesamte Neurologie und Psychiatrie*, **105**, 494-538.
- SCOTT, D. (1977) Musicogenic epilepsy. In: *Music and the Brain*. Edited by M. Critchley and R. A. Henson. London: Heinemann Medical Books; Springfield, Illinois: Charles C. Thomas, pp. 354-364.
- SEGARRA, J. M. and QUADFASEL, F. A. (1961) Destroyed temporal lobe tips-preserved ability to sing with total aphasia. A clinico-anatomical report. *Proceedings of the Seventh International Congress of Neurology, Rome*. Amsterdam: Elsevier; Rome: Societa Grapica, Volume 2, pp. 377-378.
- SHANKWEILER, D. (1966) Effects of temporal lobe damage on perception of dichotically presented melodies. *Journal of Comparative Physiology and Psychology*, **62**, 115-119.

- SLOBODA, J. A. (1976) Visual perception of musical notation: registering pitch symbols in memory. *Quarterly Journal of Experimental Psychology*, **28**, 1-16.
- SMITH, A. (1966) Speech and other functions after left (dominant) hemispherectomy. *Journal of Neurology, Neurosurgery and Psychiatry*, **29**, 467-471.
- SOUQUES, M. M. and BARUK, H. (1926) Un cas d'amusie chez un professeur de piano. *Revue Neurologique*, **33**, 179-184.
- — (1930) Autopsie d'un cas d'amusie (avec aphasie) chez un professeur de piano. *Revue Neurologique*, **37**, 545-556.
- SPELLACY, F. (1970) Lateral preferences in the identification of pattern stimuli. *Journal of the Acoustical Society of America*, **47**, 574-578.
- SPREEN, O., BENTON, A. L. and FINCHAM, R. W. (1965) Auditory agnosia without aphasia. *Archives of Neurology, Chicago*, **13**, 84-92.
- SPELLACY, F. J. and REID, J. (1970) The effect of interstimulus interval and intensity on ear asymmetry for non-verbal stimuli in dichotic listening. *Neuropsychologia*, **8**, 245-250.
- TUCKER, D. M., WATSON, R. T. and HEILMAN, K. M. (1977) Discrimination and evocation of affectively intoned speech in patients with right parietal disease. *Neurology, Minneapolis*, **27**, 947-950.
- USTVEDT, H. J. (1937) Ueber die untersuchung der musikalischen funktionen bei patienten mit gehirneiden, besonders bei patienten mit aphasie. *Acta Medica Scandinavica*, Supplement **86**, 1-737.
- VAN LAUCKER, D. and FROMKIN, V. A. (1973) Hemispheric specialization for pitch and 'tone': evidence from Thai. *Journal of Phonetics*, **1**, 101-109.
- WERNER, H. (1948) *Comparative Psychology of Mental Development*. New York: International Universities Press, p. 54.
- WERTHEIM, N. (1969) The amusias. In: *Handbook of Clinical Neurology*. Edited by P. J. Vinken and G. W. Bruyn. Volume 4. *Disorders of Speech, Perception and Symbolic Behaviour*. Amsterdam: North-Holland Publishing, pp. 195-206.
- (1977) Is there an anatomical localization for musical faculties? In: *Music and the Brain*. Edited by M. Critchley and R. A. Henson. London: Heinemann Medical Books; Springfield, Illinois: Charles C. Thomas, pp. 282-297.
- and BOTEZ, M. I. (1961) Receptive amusia: a clinical analysis. *Brain*, **84**, 19-30.
- WYKE, M. A. (1977) Musical ability: a neuropsychological interpretation. In: *Music and the Brain*. Edited by M. Critchley and R. A. Henson. London: Heinemann Medical Books; Springfield, Illinois: Charles C. Thomas, pp. 156-173.
- YAMADORI, A. (1975) Ideogram reading in alexia. *Brain*, **98**, 231-238.
- OSUMI, Y., MASUHARA, S. and OKUBO, M. (1977) Preservation of singing in Broca's aphasia. *Journal of Neurology, Neurosurgery and Psychiatry*, **40**, 221-224.
- ZIEGLER, D. K. (1952) Word deafness and Wernicke's aphasia. Report of cases and discussion of the syndrome. *Archives of Neurology and Psychiatry, Chicago*, **67**, 323-331.

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