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Music-reading deficiencies and the brain

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ABSTRACT

This paper reviews the literature on brain damage and music reading for the past 25 years. Acquired patterns of selective loss and sparing are described, including both the association and dissociation of music and text reading, and association and dissociation among components of music reading. As well, we suggest that developmental music – reading deficiencies may be isolated in a form analogous to developmental dyslexia for text or congenital amusia for auditory music processing. Finally, we propose that the results of brain damage studies can contribute to the development of a model of normal music reading.

Music reading is a complex subskill of musical performance that is learned through explicit tutoring. It includes both the basic skill of deciphering musical notation and the advanced skill of reading and performing a score in a musical context.

Not all musicians are music readers; some popular musicians, for instance, may well sustain lifetime careers in music without being able to read music. However, scores are the universal means of communication between composers and performers of classical music. Performing in professional musical circles requires the mastering of music notation.

Music reading differs from text reading in a number of important ways. As characterized by Sloboda (1980), music differs from text reading both in spatial demands and constraints and in temporal demands and constraints. Whereas text reading proceeds sequentially (i.e., horizontally) music reading proceeds both sequentially and simultaneously (i.e., vertically). Unlike text reading, music reading involves the decoding of single elements in sequence (notes) and elements in combination (chords). Moreover, unlike text reading, music reading involves decoding the vertical dimension over time. Changes in vertical distance and direction of the elements indicate pitch changes; there is no parallel involvement of vertical direction and distance in text reading. Another critical difference concerns pace. Unlike text reading, the notation of a musical score contains information about duration that must be decoded to realize the music as the composer intended; text reading has no such information or constraints on pace to derive the meaning intended by the author. In sum, according to Sloboda (1980), space and time play different roles in music and text reading.

Thus, given the importance of music reading to music performance and given its distinct nature, music reading deserves study in its own right. Yet, Sloboda (1978) noted with regret the neglect of the topic among scientists and educators despite its status as an integral aspect of music perception and performance (Sloboda, 1984). Since that time, music reading has still not enjoyed the attention paid to other areas of music research (for exceptions, see a review by Lehmann & McArthur, 2002). We know relatively little about how music reading is acquired and implemented and we know relatively little about its brain organization.

In this paper, we focus on one aspect that has in particular escaped scientific analysis – music-reading defi-

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ciencies. We acknowledge this is but one aspect of music reading and that there are many alternative methods of uncovering brain organization for music reading. However, the mandate for this special issue is that we present the particular focus of our ongoing research; we feel that the neuropsychological focus of our research will contribute to the larger picture that will emerge from converging and complementary research.

We first summarize case reports of professional musicians who have sustained brain damage are the primary source of evidence for music-reading deficiencies. Following basic principles of cognitive neuropsychology applied to music (see for example Peretz, Gagnon, Hébert & Macoir, 2004; Peretz & Zatorre, 2005) we consider the evidence for association versus dissociation between music-reading deficiencies and text-reading deficiencies. As well, we consider the evidence for association versus dissociation between the components of music reading. Next, we consider the possibility that a developmental form of music-reading deficiency may be uncovered. Such a deficiency would be revealed if, during music training, a student with otherwise normal progress experienced exceptional difficulties learning to read music. Finally, we propose that the findings may inform a model of normal music reading.

MUSIC-READING DEFICIENCIES AND BRAIN DAMAGE

Music and text reading

Table 1 presents 16 representative cases of music-reading deficiencies – all single case studies – that were published in the last 25 years (for earlier reports, see Judd, Gardner & Geschwind, 1983). The number is not great and reports may be scarce for several reasons. First, there are no standard tests of music reading with control data from healthy professional musicians. In other words, there is no available routine battery for assessment. Second, patients may rarely mention musical difficulties as the first complaint. More attention is likely paid to other difficulties, with music being a point of concern only if the difficulties interfere with resumption of professional activities. Finally, evidence of a full-blown pre-morbid skill, against which to assess possible damage, may be difficult to obtain. Thus only a small proportion of brain-damaged musicians may be represented in the literature. In any case, all these possibilities suggest why there are few published cases of musicians with music reading difficulties and why these cases are usually descriptive.

Table 1 also shows whether the reported music reading difficulties were accompanied by text-reading difficulties. The neurological terms alexia and agraphia designate, respectively, the separate acquired difficulties of reading and writing text after brain injury. Acquired dyslexia designates joint reading and writing difficulties after brain damage. In all cases the terms reflect subdeficits of aphasia. Parallel terms for the acquired difficulties of reading and writing music after brain injury are music alexia and music agraphia, respectively, as subdeficits of amusia. To our knowledge, the term acquired music dyslexia, designating joint reading and writing difficulties after brain damage, has never been used.

A considerable literature has addressed the question of association between aphasia and amusia, with the underlying idea that if they can be dissociated, music and language must enjoy functional autonomy. Although associations are often found (for a review, see Marin & Perry, 1999), an increasing number of studies have found selective sparing of musical abilities in presence of aphasia (Godefroy, Leys, Furby et al., 1995; Laignel-Lavastine & Alajouanine, 1921; Mendez, 2001), and selective sparing of language abilities in amusia (Ayotte, Peretz, Rousseau, Bard & Bojanowski, 2000; Griffiths, Rees, Witton, Cross, Shakir & Green, 1997; Peretz, 1996; Peretz, Kolinsky, Tramo et al., 1994; Piccirilli, Sciarma & Luzzi, 2000; Steinke, Cuddy & Jakobson, 2001; Wilson & Pressing, 1999). Music and language are dissociated even in song production, an art form in which both language and music are naturally tied. For example, two patients who were severely aphasic, and could thus produce few words, could nevertheless produce melodies (Hébert, Racette, Gagnon & Peretz, 2003; Peretz et al., 2004). Word production was limited whether words were sung or spoken. The reverse pattern was found for a patient who could recognize the words of songs but was not able to sing them (Peretz, Belleville & Fontaine, 1997). The two patterns form a double dissociation which, as argued below, may be evidence for the independence of music and language. More than contributing to a theoretical issue, these results have led to questioning of the use of music as a means of speech rehabilitation (Hébert, Peretz & Racette, in press).

To what extent are music- and text-reading difficulties associated in the brain of professional (or semi-professional) musicians when there is brain damage? Music- and text-reading (or writing) difficulties were associated in at least 11 cases in Table 1 (Basso & Capitani, 1985; Brust, 1980, Cases #1 and #2; Fasanaro, Spitaleri, Valiani & Grossi, 1990; Hofman, Klein & Arlazoroff, 1993; Horikoshi, Asari, Watanabe et al., 1997; Judd et al., 1983; Levin & Rose, 1979;

Table 1.

Case descriptions of brain-injured musicians with alexia for music and text, or alexia for music only, published since 1979.

Authors	Text reading	Music reading			Lesion site
		Pitch reading	Rhythm reading	Symbol reading	
Levin & Rose (1979)	-	- ?	+ ?	+/-	Left splenio-occipital and left occipital pole
Brust (1980) Case #1	-	-	+	+	Left inferior temporal and temporo-parietal lobe, and left anterior temporal lobectomy
Brust (1980) Case #2	-	-	-	-	Left posterior temporal and inferior parietal lobes
Mavlov (1980)	+ Recovered	+ ?	-	+ ?	Left posterior parietal lobe
Judd, Gardner & Geschwind (1983)	-	-	+	+/-	Left occipito-temporal lobe
Basso & Capitani (1985)	-	+ Naming -	+	+	Left temporo-parieto-occipital lobe + posterior part of the right temporal lobe
Fasanaro, Spitaleri, Valiani & Grossi (1990)	-	-	+	+	Left temporoparieto-occipital lobe and thalamus
Stanzione, Grossi & Roberto (1990)	+/-	+/- ?	+/- ?	+	Left posterior temporo-parietal lobe
Hofman, Klein & Arlazoroff (1993)	-	-	-	-	Postero-lateral border of the left ventricle and hypodense left parieto-occipital area
Horikoshi, Asari, Watanabe et al. (1997)	-	-	+	N/A	Left occipital lobe and posterior part of tem-poro-parietal lobe
Beversdorf & Heilman (1998)	+/-	N/A	N/A	N/A	Bilateral posterior cortical, most prominent on the left side
Cappelletti et al. (2000)	+	-	-	+	Left posterior temporal lobe and small right occipito-temporal
Kawamura, Midorikawa & Kezuka (2000)	+ Recovered	+/- Recovered?	+	+	Left angular gyrus
Midorikawa & Kawamura (2000)[1]	+	+	-	+	Left upper parietal lobule
Schön, Semenza & Denes (2001)	+/-	+Naming - (*F clef only*)	-	+/-	Left temporo-parietal lobe
Midorikawa, Kawamura & Kezuka (2003)	-	+	-	+/-	From Left superior temporal gyrus to angular gyrus

Legend :

+	no deficit	N/A	information not available
-	deficit	?	unclear from the text
+/-	light deficit or incomplete information		

[1]This case presented with agraphia only, but is included under the term acquired dyslexia (see page 2).

Midorikawa, Kawamura & Kezuka, 2003; Schön, Semenza & Denes, 2001; Stanzione, Grossi & Roberto, 1990). Some cases are particularly clear. Schön and colleagues (2001) reported scores on reading tests (regular words, irregular words, and non-words), extensive data of general music abilities (e.g., improvisation, playing by memory, harmonic identification, etc.), of music reading and writing (e.g., oral reading, copying, playing, naming, etc.), as well as control data from three professional musicians on all music tests. The pattern of results implicated both text and music-reading difficulties. Schön and colleagues found that the patient had a letter-by-letter alexia, and a selective difficulty in naming notes in the F clef (not in the G clef). Moreover, her difficulty was confined to naming notes aloud, since she was able to play them.

Other cases also suggest an association between music and text reading difficulties, but are less clear. Indeed, because of different methodologies across studies, and different forms of reporting (six out of the 16 cases presented in Table 1 do not report any data at all), it is sometimes extremely difficult to evaluate the extent of difficulties in either music or text reading. The case of Beversdorf and Heilman (1998) is an example: The patient was a professional musician and music-reading difficulties were the first symptom to be reported by the patient, followed by text-reading difficulties. However, beyond self-report there were no formal tests assessing difficulties. In another case reported by Kawamura, Midorikawa and Kezuka (2000), a professional trombonist following stroke was reported impaired in both reading and writing musical scores and sentences. No language impairment was found, as assessed by a standardized battery. After 52 weeks post-stroke, the authors concluded that the patient had recovered his text-reading abilities, and most music-reading abilities. However, it is not clear whether Kawamura and colleagues uncovered an associated transient case of text and music alexia. The reported difficulties were obtained shortly after the infarct, when it is likely that the patient had not yet reached a stable medical state.

On the other hand, three of the 16 cases suggest dissociation between music- and text-reading difficulties. Only one is a clear case of dissociation—the case reported by Cappelletti, Waley-Cohen, Butterworth and Kopelman (2000). Both music and text reading were assessed. Music reading was significantly impaired in many tasks (e.g., transcribing musical notes from spoken note names, reading musical scores the patient had herself written, etc.). In contrast, text reading was normal, again as assessed by performance on many tasks (e.g., spelling words, reading words and non-words, letters, and so on).

In other cases, music difficulties were reported as remaining while text reading difficulties had recovered. Mavlov (1980) tested a patient on several occasions, and at four years post-stroke; text reading recovered (on the basis of unspecified tests) while discrimination of musical rhythms, including the discrimination of notated rhythms, did not. Here again, the report is descriptive only and no data are provided. Another case involved music writing (but not reading) difficulties, which were not associated with either text reading or writing difficulties (Midorikawa & Kawamura, 2000).

In sum, only one study out of the 16 studies in Table 1, the study by Cappelletti et al. (2000), presents a clear dissociation between music and text reading where music reading was impaired. In studies where music reading was not impaired and the studies are thus not included in Table 1, dissociations have also been found. Musicians had text-reading difficulties while music reading was spared (Di Pietro, Laganaro, Leemann & Schnider, 2004; Signoret, Van Eeckhout, Poncet & Castaigne, 1987; Tzortzis, Goldblum, Dang, Forette & Boller, 2000).

The finding of two reverse forms of dissociation constitutes an instance of neuropsychological double dissociation. It suggests a functional autonomy of text and music reading as well as structural independence of their neurobiological substrates. The most striking instance of functional independence between text and music reading is probably the one described by Signoret and colleagues (1987). The authors describe the case of a blind organist who, following brain damage lost the ability to read the alphabet though he could still read music. In Braille, the same symbols are used in language or music. Nevertheless, the musician was able to read the music symbol but not the text symbol. Although touch is an atypical modality for reading, the complete independence between text and music in this case suggest that different brain areas are responsible for these two functions.

Evidence for a functional independence between text and music reading has an important theoretical aspect, because difficulty in music reading could be argued simply to be secondary to other deficits. For instance, note-naming deficits could be merely a consequence of aphasia, and note-playing deficits could merely be a consequence of apraxia. The double dissociations presented above suggest that an explanation invoking secondary deficits, while applicable on occasion, is insufficient.

Components of music reading

Music reading involves a number of operations or components that in principle may be separable at a neuropsychological level (Peretz & Zatorre, 2005). Here we discuss the music-reading components described as pitch, rhythm, and symbol reading (see Table 1). The term "symbol" is reserved here for those elements that are neither pitch nor rhythm indicators—elements such as dynamic markings (e.g., ff), articulation (e.g., staccato), and clefs (e.g., the G clef symbol).

Fine-grained dissociations exist within these music-reading abilities. According to the table, some patients have difficulty with only one of these components. Again, the logic of double dissociation may be applied. For example, patients who could not read rhythm very well could still read pitch (in the G clef, Midorikawa et al., 2003; Schön et al., 2001). In another case, the patient could not write rhythm alone but could still write pitch and rhythm (Midorikawa & Kawamura, 2000). More often, however, the reverse pattern was reported. Patients who could not read pitch could still read rhythm (Brust, 1980, Case #1; Fasanaro et al., 1990; Horikoshi et al., 1997; Judd et al., 1983; Kawamura et al., 2000).

Two further studies reported note-naming difficulties of a different nature. In the first, the patient, a conductor with expressive aphasia, could not name notes, but was still able to play them (Basso & Capitani, 1985). As he was also able to conduct from the score, it is likely that his naming difficulties represented a secondary consequence of his aphasia rather than a pitch-naming problem per se. In the second case, a pitch-reading problem revealed a peculiar difficulty in taking into account the clef rule in the F clef only. Although the patient systematically switched the F clef notes to G clef notes during naming, she was able to play notes in the F clef, and was able to name notes in the G clef (Schön et al., 2001).

Music symbol identification, when evaluated, was sometimes found disrupted (Brust, 1980, Case #2; Judd et al., 1983; Levin & Rose, 1979; Midorikawa et al., 2003; Schön et al., 2001) but was not tied to either pitch- or rhythm- reading problems in particular (Basso & Capitani, 1985; Brust, 1980, Case #1; Cappelletti et al., 2000; Fasanaro et al., 1990; Kawamura et al., 2000; Midorikawa & Kawamura, 2000; Stanzione et al., 1990). These findings suggest that reading music symbols is dissociable from pitch and rhythm reading.

Difficulties in reading music have been found in association, or not, with other music abilities such as playing, enjoying, recognizing, or learning new music by ear. Some musicians with music-reading deficiencies had other music disturbances (Judd et al., 1983; Levin & Rose, 1979) while others did not (Basso & Capitani, 1985; Brust, 1980, Case #1).

Anatomical correlates

Perhaps one of the most consistent and precise data are the anatomical correlates of music-reading difficulties in brain-damaged musicians. It is evident from Table 1 that music reading relies heavily on the left hemisphere. Although the precise lesion sites vary somewhat, all the patients with music-reading difficulties had posterior left hemisphere damage. Either the posterior part of the left hemisphere is responsible for music-reading processing or (more likely) is a mandatory step within a network of involved regions. Patients with text-reading difficulties but no music-reading difficulties also had a left-sided lesion (temporo-parietal in the case of Signoret et al., 1987; temporo-occipital in the case of Judd et al., 1983) or bilateral temporal damage (Tzortzis et al., 2000). Thus both music and text reading seem to rely on adjacent areas in the left hemisphere. A natural lesion might thus easily damage an anatomical territory that encompasses crucial components of these two cognitive functions.

MUSIC-READING DEFICIENCIES DURING LEARNING

Consideration of the brain-damage findings leads to the following hypothesis: Developmental music dyslexia, defined as difficulty with learning to read music despite normal intelligence and opportunities, should be identifiable and should exist as an entity separate from text dyslexia. Moreover, deficits in music reading should be viewed within a framework that allows any component to be disturbed, with the possibility that the immaturity or lack of development of any of these components is a potential locus of deficit. Thus, a further hypothesis is that difficulties with learning to read music may be related either to pitch, rhythm, or symbol reading, or any combination thereof.

Text dyslexia, similarly defined as a difficulty with learning to read despite normal intelligence and opportunities, is a well recognized problem and has stimulated much research in past decades. Music dyslexia has been mentioned as worthy of notice only recently in a scientific editorial (Gordon, 2000). Gordon (2000) proposed that although the inability to read a musical score may result from a cerebral lesion it may also occur as a developmental disorder. He relates two short anecdotes involving children (aged 10 and 12, respectively) who, despite excellent progress with piano lessons in most respects, still had exceptional difficulties reading a musical score. Gordon urged readers to provide further reports of such individuals and to suggest how they may be helped.

Recently, a specific learning deficit has been linked to the observation of music perception failures that cannot be explained by obvious sensory or brain anomalies, low intelligence nor lack of environmental stimulation to music. This deficit is revealed, for instance, in an inability to recognize one's own national anthem, or an inability to tap in time with music (Ayotte, Peretz & Hyde, 2002; Peretz, Ayotte, Zatorre et al., 2002). Following brain damage studies on amusia, this musical learning deficit has been termed congenital amusia, to acknowledge the possibility that there exist as many forms of congenital amusias as they are forms of acquired amusias. We suggest the work on brain damage and music reading should be viewed in much the same way.

Music dyslexia should be viewed as a potentially serious impediment in the acquisition of music reading. Although criteria, specificity, origin, and even its very existence are still to discover, it is highly probable that cases of music dyslexics can be found within the musician community. The assessment of these persons should be viewed within a theoretical framework that incorporates the knowledge gained from brain-damage studies.

TOWARD A MODEL OF MUSIC READING

Given the current state of knowledge of brain organization and music reading, a detailed model of music reading would be premature and certainly incomplete. However, brain studies urge the development of a model consistent with the basic assumptions of cognitive neuropsychology, two of which are functional modularity and anatomical modularity (Coltheart, 2001). The reports of brain-damage studies suggest that music and text reading, though often associated, may rely on distinct processes that share adjacent anatomical correlates. Moreover, the selective nature of music-reading deficiencies following brain damage suggests a model with multiple components.

Pitch and rhythm in music reading, for example, may be decoded independently, a profile reminiscent of the proposed independence of pitch and time perception based on brain-damage studies (Peretz & Kolinsky, 1993). If so, it is also plausible that pitch and rhythm may involve several subcomponents similar to those subsumed under pitch and time in perception and production (Peretz & Coltheart, 2003). If so, pitch modularity would subsume contour, interval, and tonality. Rhythm, a term used in the above studies to encompass the overall notation of time in music, would be further delineated as duration/tempo, grouping, and meter under the general rubric of temporal organization.

As well as incorporating the studies reported above, the model must include output considerations. Schön, Anton, Roth and Besson (2002) have suggested that at least three types of outputs may be involved when reading music: Playing on an instrument (transforming the visual symbol into a motor code), singing (transforming a visual symbol into a vocal code), and naming notes (transforming a visual symbol into a verbal code). Following this analysis, the model should have three pathways, and a possible fourth.

The three proposed pathways are visual-to-motor, visual-to singing, and visual-to-verbal. Evidence suggests the independence of the visual-to-motor route from both the visual-to-singing and from the visual-to-naming route. Certain musicians were reported to be able to play from a visual score, while unable to sight-sing or name notes (Basso & Capitani, 1985; Levin & Rose, 1979; Schön et al., 2001). Others, the opposite pattern, were unable to play but were able to note name and sing (Stanzione et al., 1990).

In another case, a musician was unable to play and to produce note names, on visual presentation; he was however, able to sing familiar (but not unfamiliar) songs from a score, and was able to point to notes when notes were named (Judd et al., 1983). This case suggests an impaired visual-to-motor route, but partly intact visual-to-singing and visual-to-verbal routes. The case reported by Fasanaro and colleagues (1990) was that of a musician who was unable to play or sing, but was able to name the notes. This case suggests an impaired visual-to-motor and impaired visual-to-singing routes but an intact visual-to-verbal route. So far, then, there is some evidence of independence among the visual-to-motor, visual-to-verbal, and visual-to-singing pathways.

A possible fourth pathway may link written note names to the motor code even if the link between the written symbols and note names is impaired. A musician who had difficulties playing of naming notes when music symbols were written was nevertheless able to play when written note names were given (Horikoshi et al., 1997). Another case was reported by Cappelletti and colleagues (2000): A musician was unable to play, sing, or name notes when they were presented as symbols but was able to play when note names were written. It is unclear at this point, however, whether written note names are uniquely related to visual music notation, so the status of the verbal-to-motor route is tentative.

Much remains to be discovered in order to develop the model. We do not have sufficient information about the role of music expertise following brain damage, the possible role played by absolute-pitch possession, or the consequences of the notation system employed (fixed vs movable do). How to fit in the status of different symbol types (expressive vs dynamics)? What about "audiation", the auditory image of written music (Brodsky, Henik, Rubenstein & Zorman, 2003)? Most importantly, we have yet to work out how to relate the components of the model to the cognitive aspects of musical knowledge, expectancy meaning, and context, as aptly described by Sloboda (1984).

All in all, many components are involved in music reading, and similarly as for music perception and production, music reading cannot be viewed as a monolithic entity. Each one of these components may be a locus of impairment that would lead to a music-reading deficit. These deficits should be observable both in the context of acquired brain damage and in the context of music learning. New techniques such as eye tracking and brain imaging should provide evidence for the model about how and which components are dysfunctional. We have offered here some ideas how the study of music reading deficiencies may contribute to the overall modeling of music reading.

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