A Case Study of Music and Text Dyslexia

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In this article, we first report the data of normal music readers on a new music-reading battery developed in our laboratory. The battery was inspired by the brain damage literature on music-reading deficits and comprised visual and auditory tasks. Second, we report the battery data of IG, a university musician who was referred to us as potentially dyslexic for music, and also her data on text reading and neuropsychological tests. We compare IG's data with those of normal readers. We suggest that IG might represent a case of associated music and text developmental dyslexia. Her results also indicate a dissociation between her pitch and rhythm reading abilities not quite the same as normal readers, as well as an interesting dissociation between reading and repetition, opposite to normal readers.

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The ability to read music easily and quickly is a prerequisite for achieving both the academic and professional goals of anyone who aspires to work as a professional musician. In contrast to language reading where acquisition begins with the regular curriculum around six years of age, music-reading acquisition is often delayed until much later, often by the method of instruction itself. Several music teaching methods begin with a focus on instrument playing without music notation (the Suzuki method, for instance). Certainly, music reading does not have the same focal position within music training as text reading has in general education, including its role as a tool to learn other topics. Thus, when a text-reading deficit is suspected, formal assessments of text-reading abilities are readily carried out and help is provided to those with significant difficulties. In contrast, for those who experience music-reading difficulties, no such formal assessment or help is provided other than perhaps some ad hoc help from a zealous music teacher. Those who cannot attain high levels of music reading usually just fail or choose to drop out of a music program.

Little is known about the acquisition of music-reading abilities and there is no proposed model of how this ability is acquired. The term "music dyslexia" to designate a difficulty to learn to read music, despite normal intelligence and opportunities, has only appeared recently in the scientific literature (in an editorial, Gordon, 2000). Since no case has ever been reported, it is difficult to predict how music dyslexia would manifest itself. There are, however, a few anecdotal reports of musicians with text dyslexia who were experiencing difficulties in learning to read music (Ganschow, Lloyd-Jones, & Miles, 1994; Jaarsma, Ruijssenaars, & Van den Broeck, 1998). One important question is then whether a specific developmental difficulty in learning to read music exists similar to a developmental difficulty in learning to read text.

However, we do know that music reading can be selectively impaired by brain damage. Hébert and Cuddy (2006) recently reviewed the literature of the past 25 years on brain damage and music reading and described acquired patterns of selective loss and sparing. These patterns included both the association and dissociation of music and text reading, and association and dissociation among components of music reading. Evidence of dissociation between music and text reading is available, but rather weak. Indeed, music and text-reading deficits are more often seen jointly than not,

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much like amusia and aphasia are more often associated than dissociated (for a review, see Marin & Perry, 1999). However, these associations may be the result of anatomical proximity of distinct functions; a natural lesion might damage an anatomical territory sustaining networks indispensable to the processing of two cognitive functions. Some crucial components of music reading, as well as text reading, seem to rely heavily on the posterior part of the left hemisphere (see Hébert & Cuddy, 2006).

The brain damage literature also shows that music reading after brain damage is dissociable from other music abilities. For instance, certain musicians were still able to play familiar pieces on their instrument while being unable to read new ones, or were able to sing from memory or recognize music aurally. Furthermore, within music, reading, pitch, and rhythm decoding seem to enjoy functional autonomy in brain damage. This separability of pitch and rhythm in music reading is consistent both with the fact that their written codes are very different and also with evidence from studies in music perception and memory (e.g., Hébert & Peretz, 1998; Peretz & Kolinsky, 1993).

The first step of the present study was to develop an in-house battery of music tests that would be administered to advanced-level music students and later used to assess the reading abilities of potentially dyslexic musicians. The battery was inspired by the dissociations found in the brain damage literature. It comprises visual reading tests (separate pitch and rhythm reading tasks, familiar tune recognition, symbol identification and discrimination) and of auditory tests (familiar tune recognition, repetition of unfamiliar tunes). The auditory tests were included to collect data in a different modality, using, in part, the same stimuli as the visual tasks. Data of normal readers, defined here as "musicians who self-reported having no difficulty to read music," served as reference points to verify the intended complexity of stimuli and to query whether potential patterns of dissociations were due to task difficulty—that is, to check for inherently dissimilar levels of difficulty of the pitch and rhythm reading tasks (for a detailed discussion of these issues in neuropsychological research, please see Shallice, 1988).

The second step introduces the case of IG, who was referred to us as potentially dyslexic for music. IG was tested on the battery and her scores were compared to those of normal music readers. Her text-reading abilities were also assessed. The pattern of results for IG is suggestive of music dyslexia associated with text dyslexia; however, though she demonstrated some dysfunction in reading text, her performance was confounded by a strong indication of attentional difficulties as seen in a student with attention deficit disorder. Moreover, her music-reading results also indicate an interesting dissociation between her pitch and rhythm reading abilities that are neither typical of normal readers nor predictable from her text-reading abilities.

Method

Participants

Nineteen musicians (6 men and 13 women, mean age = 23.6, range = 19-36) were tested on the battery. All were enrolled in an advanced music program and all reported no difficulty with music reading. They all had completed at least four semesters of post high school music education and were enrolled either at the college ($n = 5$) or at the university ($n = 14$) level. All had started reading music before or at 10 years old in a Western music setting. They had an average of 14.3 years of music-reading experience (range = 9-30, $SD = 4.9$), and 13.3 years of main instrument lessons (range = 1.5-30, $SD = 7.5$). Four reported having absolute pitch. All but one had a second instrument, and six had a third instrument. Instruments played were varied and included keyboard, wind, voice, and strings. Drummers were excluded because they are mainly exposed to rhythm notation.

Materials and Apparatus

All stimuli were constructed with the Sibelius software (version 3) controlled by E-prime (1.1) and presented centrally on a computer screen. Stimuli were black and white. Tasks were self-paced; participants controlled the presentation by pressing the space bar key. All production tasks were recorded online by the Cool Edit (2.0) software.

Procedure

Participants were tested individually in a quiet testing booth. They were paid $10/hr for their participation.

Analyses of Productions

In-house software, programmed with Matlab, was developed to analyze the sung productions of participants in the Pitch and Rhythm reading tasks and the unfamiliar tune repetition task. For the pitch dimension, the program used the PRAAT pitch tracking function to calculate the mean frequency of sung tones. Any interval between two notes (rather than the absolute pitches) that was discrepant of one or more semitone than the theoretical pitch of the written target interval was considered an error. For the rhythm dimension, the program calculated inter-onset intervals and any interval greater than 25% of the written interval was considered an error. Each additional event in a sequence was considered an error.

Description of the Battery

In order to facilitate reading of this section, each presented task will be immediately followed by the results.

1. Music Tasks with Visual Input

PITCH READING TASK

A composer (CB) constructed 18 stimulus melodies of three different lengths (3, 8, and 12 notes) crossed with three levels of difficulty (easy, medium, difficult). As difficulty level increased, there were more contour changes, more difficult intervals, accidentals, and so forth. The stimulus melodies appeared on the computer screen as isochronous black dots on a staff—that is, without duration cues. All started on "C4." When the stimulus appeared, two "C4" notes on the beat were presented along with a pulse of 60 beats/s and participants had to sight read the stimuli by singing the note names or on a neutral syllable "la," whichever they found more comfortable. They all used note names. Each stimulus length was presented at each of the difficulty levels in succession before the stimuli length was increased. Participants were encouraged to complete the series of difficulty levels at a given stimulus length but could quit a series if they felt the task was becoming too difficult. They were then presented with the first (easy) difficulty level of the next stimulus length.

Performances were evaluated as percent correct for each sequence for each participant and averaged across all items. Unattempted items were given the score "0." Overall, performance was at 77.05% (with a rather large *SD* of 28.57), with 16 items performed on average (range = 4-18). When absolute pitch possessors ($n = 4$) were not considered, the global score decreased to 71.91% ($SD = 31.11$). Also, singers were advantaged compared to non-singers, with means of 93.92 and 72.55, respectively, $t(14.2) = -2.68, p < .05$.

RHYTHM READING TASK

The composer constructed 18 stimuli of three different lengths (3, 8, and 12 notes) crossed with three levels of difficulty (easy, medium, difficult). As difficulty level increased there were more duration values, tied notes, syncopations, and so forth. The visual appearance was black dots with duration cues in binary or ternary meter. When the stimulus appeared, a pulse of 60 beats/s (quarter note for binary meters, eighth note for ternary meters) was presented and participants had to sight read the rhythm on the neutral syllable "ta." Each stimulus length was presented at each of the difficulty levels in succession before the stimuli length was increased. Participants were encouraged to complete the series of difficulty levels at a given stimulus length but could quit a series if they felt the task was becoming too difficult. They were then presented with the first (easy) difficulty level of the next stimulus length.

Performances were evaluated as percent correct for each sequence for each participant and averaged across all items. Performance was very high at 96.65% ($SD = 4.34$), and all items were performed and did not change when absolute pitch possessors were removed ($M = 95.85\%$; $SD = 4.57$). A comparison between the Pitch and Rhythm tasks confirmed the advantage of the Rhythm task over the Pitch task, $t(18) = -3.00, p < .01$ (for a paired *t*-test).

SYMBOL IDENTIFICATION

One hundred and fifty music symbols were presented in the center of the screen. They related to pitch, silence and note duration, meter, and dynamics. They were divided in three blocks of increasing difficulty (i.e., decreasing familiarity). For instance, the third block included symbols specific to Baroque music. Participants were asked to name each symbol.

Percentages of correct responses for increasing levels of difficulty were 96.63%, 91.16%, and 79.34%. An ANOVA with Level of difficulty as a within-subject factor yielded a significant effect of Level of difficulty, $F(2, 36) = 48.90, p < .001$. Level 1 was better than Level 2, which was better than Level 3 ($p < .05$ by Tukey post hoc comparisons). Participants were therefore sensitive to the intended difficulty of the task.

SYMBOL DISCRIMINATION

The same stimuli as in symbol identification were presented in pairs. Half of the pairs were identical, half were different. They were presented in three blocks of increasing visual similarity. Participants were asked to judge whether the stimuli was the same or different by pressing the corresponding key. Response times were recorded.

Data of two participants were unavailable due to technical problems during the task. Performance was evaluated both in accuracy (hits minus false alarms) and median response times. For accuracy, performance was at ceiling for the first two levels of visual similarity, and somewhat lower at the most similar level, with average scores of 95.10% (*SD* = 6.58), 95.69% (*SD* = 4.53), and 88.43% (*SD* = 9.29), for Levels 1, 2, and 3, respectively. The ANOVA performed on these scores with Visual similarity as a within-subjects factor confirmed the effect of Visual similarity, $F(2, 32) = 9.21$, $p < .001$. Performances on Levels 1 and 2 did not differ from one another ($p > .05$) and were both significantly better than on Level 3 ($p < .05$ by Tukey post hoc comparisons).

For response times, two ANOVAs were conducted on same and different trials (on correct items only) with Visual similarity (1, 2, 3) as the within-subject factor. These analyses yielded no significant effect of Visual similarity either on the Same trials, $F(2, 36) = 1.28$, $p = .29$, or on the Different trials, $F(2, 36) = 1.50$, $p = .24$, confirming the easiness of the task.

VISUAL RECOGNITION OF FAMILIAR TUNES

Thirty-four familiar tunes were selected from the song literature. The first phrase served as stimuli for a visual and an auditory recognition tasks. Half the tunes were played correctly. Half were modified by exchanging the melody of one tune for the rhythm of another and vice versa. All phrases were presented in random order in the center of the computer screen. Participants had to decide whether the tune was a correct version, or a modified/incorrect version. Both accuracy and response times were collected.

Participants were better at rejecting a modified version than recognizing a correct version, with performances of 97.21% and 78.95%, respectively, $t(18) = -4.02$, $p < .01$ (paired *t*-test). Performances were next evaluated in both accuracy (hits minus false alarms) and in median response times for each type of item for each participant. A hit was defined as correct recognition of a familiar tune. Participants achieved an overall performance of 76.16% (*SD* = 15.12). Mean median response times were 11.27 s (*SD* = 8.73) and 14.51 s (*SD* = 9.06) for the familiar and modified versions, respectively.

2. Music Tasks with Auditory Input

REPETITION OF UNFAMILIAR TUNES

Eighteen stimuli arising from the combination of one pitch and one rhythm stimuli used in the previous reading tasks formed melodies of 3, 8, and 12 notes at various difficulty levels. They were played twice, separated by a 2-s interval by the Sibelius software set to a piano timbre and a tempo of 60 beats per minute, Participants were asked to repeat the tunes by singing.

Productions were analyzed separately for pitch and rhythm. On the pitch dimension, participants achieved 73.43% correct productions (range = 59.77% – 87.27%). Accuracy decreased as length of stimuli increased, with 97.95%, 75.26%, and 47.08% for the 3, 8, and 12-note sequences, respectively. An ANOVA on these percentages revealed a significant decrease in performance, $F(2, 36) = 147.38$, $p < .001$. Block 1 (3-note stimuli) was better performed than Block 2 (8-note stimuli), which was better performed than Block 3 (12-note stimuli, all *p*s < .05). When absolute pitch possessors were removed from the analyses, the global performance decreased slightly to 71.52%. In contrast with the pitch reading tasks, here singers were not advantaged compared to non-singers, with means of 74.19 and 73.23, respectively, $t < 1$.

On the rhythm dimension, participants achieved 78.10% (range = 56.28% – 89.25%). Accuracy decreased as length of stimuli increased, with 91.67%, 79.79%, and 62.85% for the 3, 8, and 12-note sequences, respectively. An ANOVA on these percentages here again revealed a significant decrease in performance with increasing melodies' length, $F(2,36) = 53.51$, $p < .001$. Block 1 was better performed than Block 2, which was better performed than Block 3 (all *p*s < .05). When absolute pitch possessors were removed from the analyses, the global performance did not change (79.11%).

In order to directly compare normal readers' performance on Visual and Auditory presentations on the Pitch and Rhythm components, a 2 × 2 ANOVA was run on their performances. This analysis revealed a significant main effect of Presentation (reading better than repetition), $F(1,18) = 11.42$, $p < .01$, as well as a significant main effect of Component (rhythm better than pitch), $F(1,18) = 9.72$, $p < .01$, plus an interaction between these two factors, $F(1,18) = 6.94$, $p < .05$. Simple effects revealed that the difference in performances between Pitch and Rhythm was greater in reading ($p < .01$) than in repetition ($p < .05$).

AUDITORY RECOGNITION OF FAMILIAR TUNES

Stimuli used in the visual recognition of the familiar tune task were presented auditorily by means of the Sibelius software with a preset piano timbre at a tempo of 60/quarter note. Participants were asked to decide whether the phrase was a correct version of the tune, or a modified/incorrect version. Both accuracy and response times were collected.

On accuracy (hits minus false alarms), participants achieved an overall performance of 81.74% (*SD* = 11.42). This performance was better than for visual input,

$t(18) = 2.21$, $p < .05$. The average median response times were 5.90 s ($SD = 2.43$) and 6.52 s ($SD = 1.50$) for the familiar and modified versions, respectively.

Summary of Normal Readers' Results

In sum, normal readers achieved good performances in all tasks, sometimes perfectly at ceiling, suggesting that the tasks were in general easy for them. There was a discrepancy between pitch and rhythm reading tasks, the rhythm reading task being performed more accurately than the pitch reading task. Possibly rhythm is intrinsically easier to read or pitch reading is more difficult because pitch production accuracy is harder to achieve than timing accuracy. In addition, performance in the pitch reading task was slightly increased by the absolute pitch possessors who performed at ceiling, so the discrepancy between pitch and rhythm accuracy was more evident when these individuals were removed. An indication that the criteria were not more severe for pitch than time, however, is the similar performance for the pitch and rhythm dimensions in the repetition task. The similar performance between pitch and rhythm in repetition suggests an important role of the auditory span since performance decreased rapidly with the increasing length of the stimuli. In the visual and auditory recognition tasks, auditory recognition was slightly better than visual recognition. Finally, performances in the symbol identification and discrimination tasks well reflected the intended difficulty of the tasks, both in music knowledge (symbol identification) and in visual confusability (symbol discrimination).

Case Description of IG

IG was referred to us by her ear training professor (CB) because of her persisting music-reading difficulties in the class. IG is a 24 year-old woman with French as her first language, who enrolled in independent studies preparatory year prior to entering a full-time music program (voice) at the university level. At the time of testing she was finishing her independent year and was taking vocal jazz lessons in private. She was admitted the following September in the regular program. As an index of her musical talent in performance, she obtained a B in combo jazz and 85% for her instrument (live concert exam). She had started private piano lessons (that included music reading) at six years old and had periodically taken music lessons with different instruments (flute, guitar, voice, choral singing, electroacoustic composition) until she was admitted at the university, for a total of about 14 cumulative years of music training. Voice is the instrument she studied for the longest period (about 11 years) and she was approximately in her 9th cumulative year of music-reading training at the time of testing. She did not report having absolute pitch. Since the beginning of her education she struggled with both text and music reading. She had been assessed for her text-reading abilities when attending primary school but this assessment had not been followed up on by rehabilitation or diagnosis at the time. The report produced was not available. IG was reassessed in this study by a clinical neuropsychologist and a speech pathologist for her cognitive and language functions, respectively.

1. Music Tasks with Visual Input

PITCH READING

On pitch reading, IG completed 13 of the 16 items that included one difficult stimulus. As for normal readers, the unattempted items were given the score "0." She achieved a global performance of 45.60% ($SD = 34.55$), which was 1.2 standard deviations below the normal readers' mean. IG's score fell outside the 95% confidence interval of the normal readers' (67.00 %– 94.60%). Figure 1a displays the score of IG in comparison with normal readers' performance as a function of the length of the stimuli.

RHYTHM READING

On rhythm reading, IG completed 17 items out of 18. She achieved a global performance of 66.02% ($SD = 42.55$), which was 7.1 standard deviations below the mean of normal readers. IG's score was again outside the 95% confidence interval of the normal readers (94.70%-98.90%). Figure 1b displays the score of IG in comparison with normal readers' performance as a function of the length of the stimuli. The difference in performance between the Pitch and Rhythm tasks was in the same direction as normal readers' performance, but did not reach conventional significance, $t(17) = -1.32$, $p = .21$ (for a paired t-test).

SYMBOL IDENTIFICATION

On symbol identification, IG's performance was also sensitive to the level of difficulty, although with much lower accuracy than normal readers: 82.00%, 70.00%, and 54.00% for Levels 1, 2, and 3, respectively. An ANOVA with items as the random factor and Level of difficulty as the inter-item factor yielded a significant effect of Level, $F(2, 147) = 4.79$, $p < .01$. Level 1 was better than Level 3 ($p < .01$) but not than Level 2, in contrast

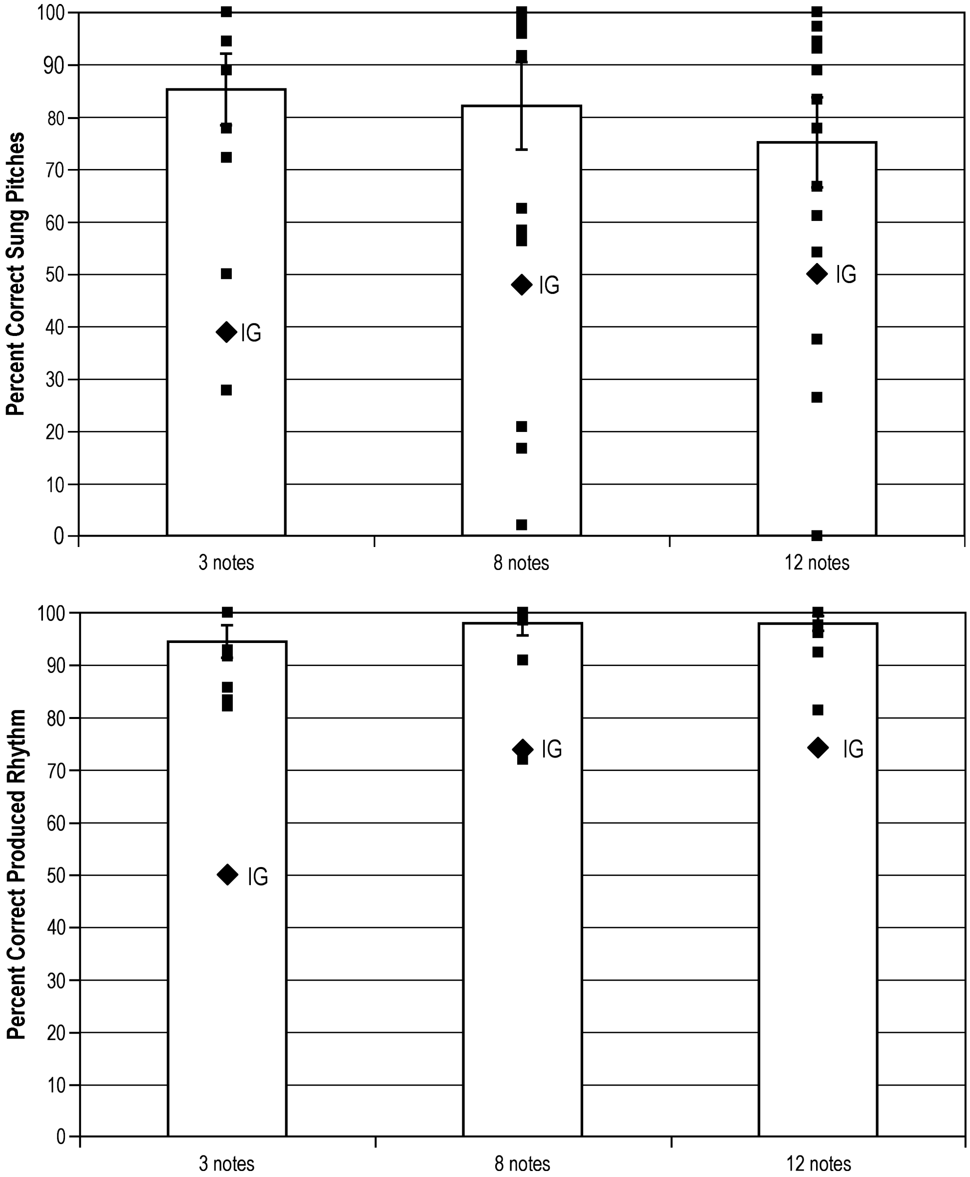

FIGURE 1A AND 1B. Percent correctly sung notes for IG and normal readers in the Pitch reading task (1a) and in the Rhythm reading task (1b). Standard errors of the mean are shown.

with normal readers ($p = .09$). Level 2 was better than level 3 ($p < .01$). These scores were respectively 3.6, 3.8, and 3.1 standard deviations below the normal readers' mean.

SYMBOL DISCRIMINATION

In symbol discrimination, IG's performance was not sensitive to visual confusability, in contrast with normal readers, with 86.67%, 93.33%, and 83.33% for the three levels of difficulty, respectively (statistics could not be run on hits-false alarms with items as a random factor). These scores were not very far from those of normal readers, that is, they were 1.4, 0.5, and 0.5 standard deviations below normal readers' scores. The most striking difference, however, appeared in median response times. IG's performance on RTs was between 3.0 and 4.8 standard deviations or more below the controls' times in all conditions.

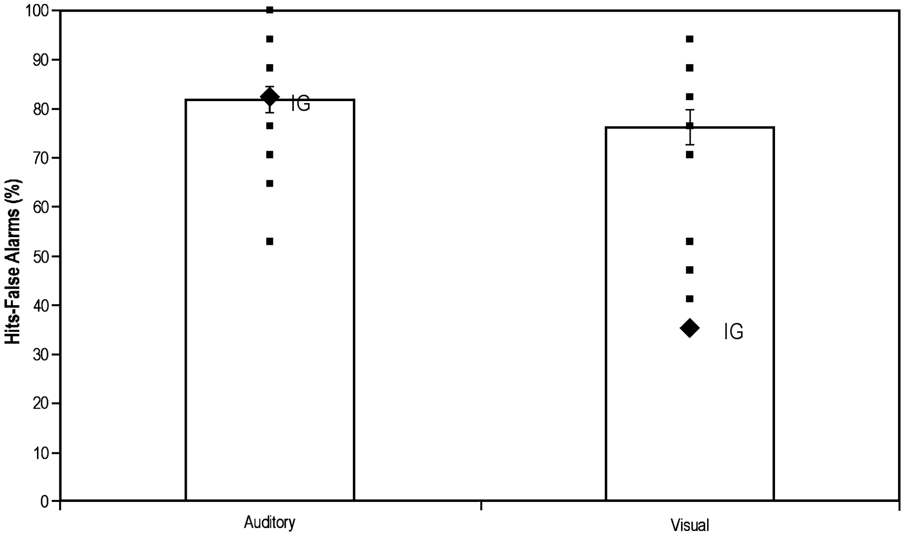

FIGURE 2. Hits minus false alarms performance for IG and normal readers in the familiar recognition task for the visual and the auditory input.

VISUAL RECOGNITION OF FAMILIAR TUNES

On visual recognition of familiar tunes, IG achieved an accuracy of 94.12% and 41.18% on the familiar and modified versions, respectively. Her hits-false alarms score was 35.30%, which was 2.7 standard deviations below the normal readers' mean. On response times, IG was also much slower than normal readers, with a median response time of 63.02 s and 21.43 s for familiar and modified versions, respectively. These scores were 5.9 and 0.8 standard deviations from the mean. Figure 2 and 3 (right hand side) display the scores of IG with respect to normal readers, for accuracy and response times, respectively.

2. Music Tasks with Auditory Input

REPETITION OF UNFAMILIAR TUNES

On the pitch dimension, IG's performance followed the same pattern as normal readers, but lower. She achieved

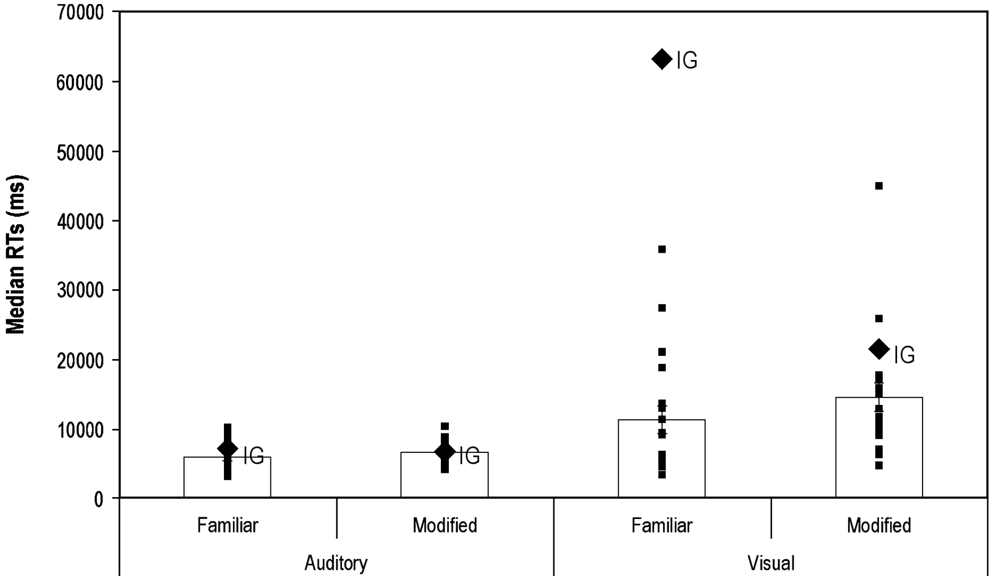

FIGURE 3. Median response times for IG and normal readers in the familiar recognition task for the familiar and modified versions for the visual and auditory input.

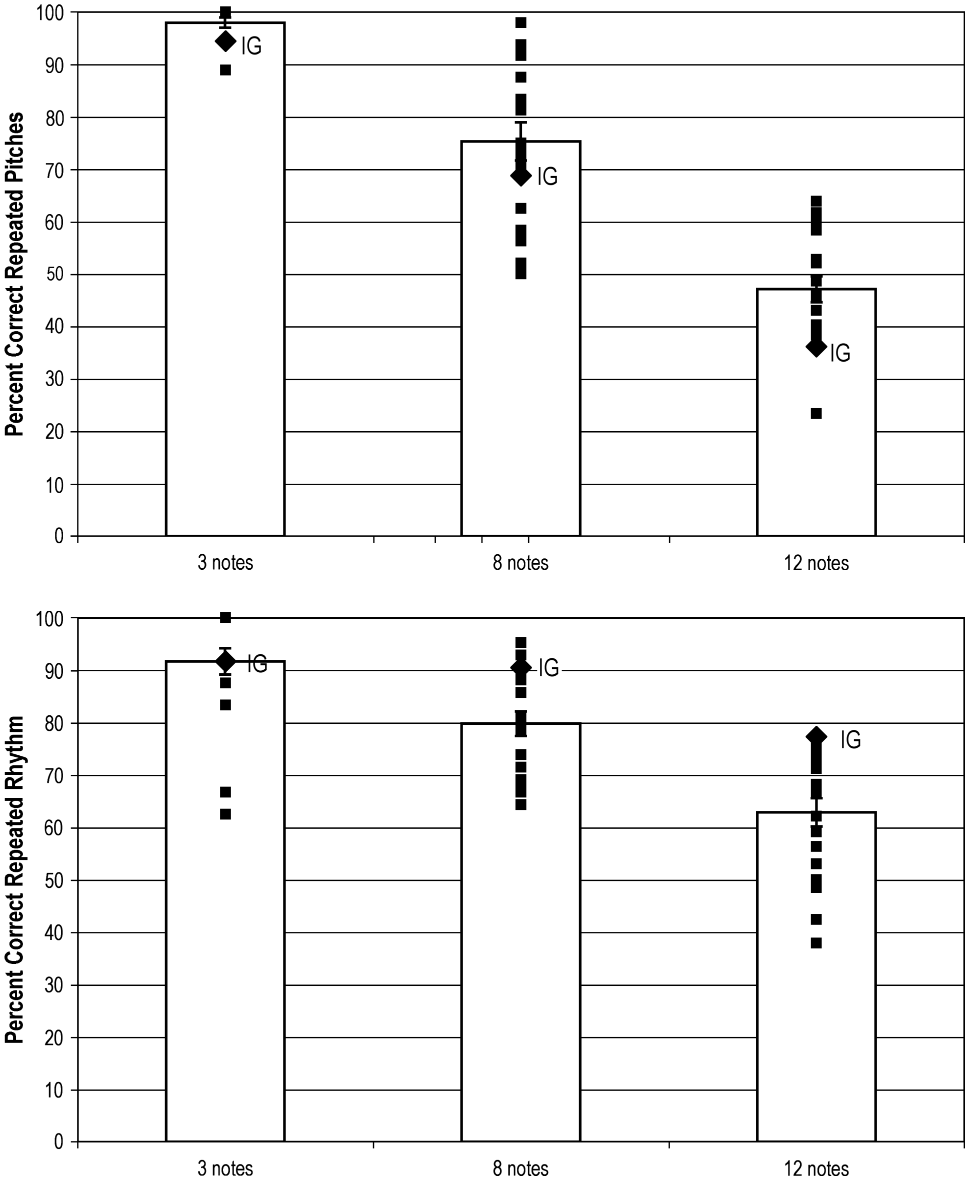

FIGURE 4A AND 4B. Percent correctly repeated pitches and rhythm for IG and normal readers in the repetition task. Standard errors of the mean are shown.

66.44% globally (*SD* = 30.30), with 94.44%, 68.75%, and 36.11% for the 3, 8, and 12-note sequences, respectively. An ANOVA on items revealed the same pattern as the normal readers, $F(2, 15) = 14.38$, $p < .001$. Performance on the 3-note stimuli was significantly better than on the 8-note stimuli ($p < .04$), which were significantly better than performance on the 12-note stimuli ($p < .01$). IG's performances were 0.83, 0.41, and 1.03 standard deviations below normal readers' performances. IG's overall performance fell just below the 95% confidence interval of the normal readers' (68.50%-78.40%).

In contrast, on the rhythm dimension IG achieved 86.47% globally (*SD* = 19.0), with 91.67%, 90.48%, and 77.27% for the 3, 8, and 12-note sequences, respectively. An ANOVA on items did not reveal any significant difference between the different lengths, $F(2, 15) = 1.07$, $p = .36$. Thus, her performance on the 3-note sequences was not different than that of normal readers' performance, and her performances on the 8-note and 12-note sequences were 1.0 and 1.2 standard deviations *above* normal readers' performance. Her global performance was *above* the 95% confidence interval of the normal readers' (72.8%-83.4%).

In order to directly compare IG's performance on Visual and Auditory presentations on the Pitch and Rhythm components, a 2 × 2 ANOVA was run with items as the random factor. This analysis revealed a significant main effect of Presentation (repetition better than reading), $F\ (1, 17) = 9.33$, $p < .01$, as well as a significant main effect of Component (rhythm better than pitch), $F(1, 17) = 6.80$, $p < .05$. In contrast to normal readers, however, who had a greater difference in performance between pitch and rhythm in the auditory mode than in the reading mode, there was no such effect for IG, for whom the interaction between these two factors was not significant ($F < 1$). For IG the Visual presentation was overall lower than the Auditory presentation, and the Pitch was overall lower than the Rhythm components.

RECOGNITION OF FAMILIAR TUNES

In the auditory recognition of familiar tunes, on accuracy (hits-false alarms) IG achieved 82.35%, which was not different from normal readers (81.73%). Similarly, IG's response times were within the normal range, with 7.11 s and 6.67 s for the familiar and modified versions, respectively. These were 0.5 and 0.1 standard deviations of the normal readers' mean, both values within the 95% confidence intervals of the normal readers' (4.7-7.1 and 5.8-7.2 s for the familiar and modified versions, respectively; see Figures 2 and 3, left hand side).

Summary of IG's Results for Music

In sum, on visual presentation, IG's scores were below those of normal readers on all music tasks. The most striking difference between IG and normal readers was in her pattern of performance in the pitch and rhythm reading tasks, especially when modes of presentation (reading vs. repetition) were compared. Normal readers were much better at reading than repeating, especially for the rhythm component. IG displayed a quite different pattern, by being much better at repeating than reading, with equal difficulties in pitch with respect to rhythm in both modes of presentation. This discrepancy between visual and auditory input was also observable in the recognition of familiar tunes task. When the input was visual, IG was poorer and slower than normal readers; when the input was auditory, IG was as good and as swift as normal readers.

IG's performance on the symbol identification and discrimination tasks was not noteworthy. In the symbol identification task, her performance followed the same pattern as normal readers, with performance level decreasing as the level of difficulty increased. In the symbol discrimination task, her performance contrasted with normal readers; normal readers were sensitive to the level of visual confusability, but IG was not. She was also much slower on this task, which is consistent with the neuropsychological and language findings to be reported now.

Neuropsychological and Language Assessments

IG was administered a battery of tests to measure written language, visual spatial abilities and executive function, attentional resources, and level of intellectual functioning (see Table 1). The WAIS III results illustrated that she was functioning intellectually in the average range with little significant scatter among subtests, though relative weaknesses supported evidence of her difficulties with maintaining attention (coding, symbol search, letter-number sequencing, digit span). Other measures indicative of the presence of attention deficit disorder (including Adult ADHD Rating Scale, DSM IV criteria, Test of Every Day Attention, Trail Making Test) indicated the strong likelihood of a diagnosis of an attention deficit disorder without hyperactivity. Her executive functioning and visual spatial memory as measured by the Rey Complex Figure test was also deficient, though in general both her visual and auditory memory (Wechsler Memory Scale) were average if somewhat inconsistent. This again may reflect attentional problems.

In terms of language processing, text reading was assessed with the two subtests of the IREP (2000). Both the reading speed and comprehension tests involve the silent reading of short paragraphs composed of 8 to 10 sentences. In the speed reading test, IG was asked to detect and mark the semantically incongruent word inserted in a short paragraph. For instance, "During the winter, Sarah loves to go swimming in the snow." IG was informed that the test would end after 8 minutes and was instructed to attempt the task as fast as possible without making mistakes. The test comprises 56 paragraphs, each with one error to be detected. In the comprehension test, she was asked to silently read short paragraphs and answer one question after each paragraph by encircling the right response among four. The test consisted of 11 texts, each with four questions to answer and stopped after 10 minutes. In both tests, the score corresponds to the number of correct responses.

TABLE 1. Results of IG on the Neuropsychological Testing.

Tests	Score	Percentile	Score Range
Adult ADHD Rating Scale			
Inattention/memory problems	70	98th	
DSM-IV Inattention symptom	80	99th	
	Scaled Score		
Intellectual functioning			
Full scale IQ	95	37th	A
Verbal IQ	93	32nd	A
Performance IQ	94	34th	A
Visuo-perceptual and visuo-motor functions			
Perceptual organization	97	42nd	A
Picture completion	10		A
Block design	10		A
Visual scan	10		A
Coding	7		LA
Symbol search	7		LA
Information processing speed	82	12th	LA
Picture arrangement	11		A
Rey figure copy	27	< 1st	D
Working memory and attention			
Working verbal memory index	88		LA
Digit span (forward/backward)	8/2		A
Letter-number sequencing	8		LA
Spatial span (Corsi)	12		HA
Long term memory and learning abilities			
% Story retention	12		HA
Logical story immediate recall	11		A
Logical story differed recall	12		HA
Logical story % retention	14		S
Academic abilities			
Numerical operation	73		LA
Mathematical component	79		D
Executive functions			
Trails: visual scan	10		A
Switching	6		D
Motor	12		HA
Color naming	10		A
Word reading	13		HA
Inhibition	8		A
Inhibition + switching	7		LA
Naming + reading	12		HA
Verbal functions and language			
Verbal comprehension	96	39th	A
Vocabulary	11	63rd	A
Similarities	10	50th	A

Note: Scores on the WAIS-III are scaled scores. Score range are also presented, where A = average, LA = low average, HA = high average, D = 1 to 2 *SD* below average, and S = 1 to 2 *SD*s above average.

In the speed reading test, IG's score was 35. She produced no errors but her reading speed was slow and thus her score corresponds to the total number of paragraphs she read within the limited time of 8 and 10 minutes. In comparison, normal readers (n = 38 college students) have an average score of 46.7 (SD = 10.3), while students with documented reading disabilities (n = 28) have an average score of 30.6 (SD = 8.0). In the

TABLE 2. Results of IG on the Word Reading Test.

	IG
Regular words	100%
Regular nonwords	96%
Irregular words	83%
Irregular nonwords	83%

comprehension test, IG's score was 25. In comparison, the same normal readers have an average of 37.2 (*SD* = 5.8), while the students with documented reading disabilities have an average score of 25.8 (*SD* = 6.3). Therefore, IG's scores are comparable to the mean scores obtained by college students with reading disabilities in these subtests (King, Mimouni, & Courtemanche, 2006). The reading age corresponding to IG's scores in both tests was that of a 12 year-old child.

In the word reading tests, IG was shown four sets of 24 words on a computer screen. The sets consisted of one set each of regular words, irregular words, regular (phonetically correct) nonwords and irregular nonwords. All were taken from the BELEC (Mousty, Leybaert, Alegria, Content, & Morais, 1994). IG's scores are displayed in Table 2. There are no norms available for adults, only for children from Grade 2 to 6 (Vanasse, Bégin-Bertrand, Courcy, Lassonde, & Béland, 2005). As an indication, Grade 6 children achieved 99.4% and 89.1% for regular and irregular word reading, respectively.

Discussion

The results of this study can be summarized as follows. First, advanced level musicians, even those whose concentration was an instrument and not voice, achieved good to excellent performance in production tasks involving visual input. They showed an asymmetry between pitch and rhythm reading that favored rhythm reading over pitch reading. Indeed, some were extremely poor at pitch reading, a finding that was somewhat surprising, given they all reported being of average or above average caliber. Although singers were advantaged over non-singers in this task, they were not better than non-singers in the pitch repetition task. This finding suggests that their better performance reflects a genuine sight reading ability, perhaps due to ingrained motor patterns associated with specific pitches, rather than merely a better sung pitch accuracy. Musicians could easily and swiftly discriminate familiar tunes from modified versions. They could identify and discriminate music symbols, and they were sensitive to the difficulty of identifying the less familiar symbols and discriminating the most similar ones. In tasks involving auditory input, their performance was also very good when they had to discriminate familiar tunes from modified versions. However, in a repetition task their performance was more sensitive to the length of the stimulus, suggesting the involvement of auditory short-term memory. Altogether, we may conclude that our battery seemed to be adequate for the evaluation of music-reading abilities.

On this battery of reading tests, IG exhibited difficulties. Depending on the input modality, her overall pattern of results either differed substantially or did not differ from the normal readers. Like normal readers, IG was worse at pitch reading than rhythmic reading tasks and showed similar difficulties when she had to reproduce the melodies. However, she was much better at reproducing melodies by ear than were the normal readers, which showed the reverse pattern. Moreover, she was *better* than normal music readers on reproduction of rhythm. Her better auditory span could well reflect compensatory mechanisms for her difficulties in reading music.

This contrast between written and auditory inputs suggests a specific difficulty to read music. Given that IG had a normal intelligence level and had had opportunities to learn to read music, her deficit could be considered as falling under the concept of music dyslexia. Since her profile for text reading is also typical of developmental text dyslexia, IG seems to represent an associated case of developmental text and music dyslexia. In terms of text based dyslexia it is difficult to be categorical about the presence of this condition because her neuropsychological profile is complex. Her level of text reading and her relative difficulty reading irregular words could be indicative of dyslexia. In fact, a comparative difficulty with reading irregular words has been posited as an indication of "surface" dyslexia as opposed to the more common phonological form (Castles & Coltheart, 1993). However, if IG had surface dyslexia, she should read nonwords correctly. Thus, according to Castles and Coltheart's terminology, she represents a *mixed* case. One could argue that her results could arise as a result of attentional difficulties. This may be particularly true given the nature of the reading text task which, given its format, would have required considerable ability to focus attention. However, in the comprehension reading text, IG was given all the time needed without pressure. Likewise, it is difficult to argue that the isolated word reading task was very demanding at the attentional level. Even if it were the case, it is difficult to argue that reading nonwords and irregular words requires more attention. Her dissociation between reading pitch and rhythm is also difficult to explain solely by an attentional deficit.

What remains unknown is whether IG's deficits originate from a single cause or are, as is the case in most brain damage cases, merely associated. Of course it is possible that her attentional disorder deficit is impacting on both her music and text-reading performance. This possibility is supported by her low performance in the symbol identification and discrimination tasks. Although it is likely that an attentional deficit would hinder her performance in both text and music-reading tasks, it would be doubtful that this low-visual attentional deficit would explain a specific rhythm reading deficit.

Another possible account of IG's deficits is that music and text reading share some processing component that is similarly affected in her case. A recent study of music reading and cortex stimulation revealed that some cortical areas are common to both music and text reading (Roux, Lubrano, Lotterie, Giussain, Pierroux, & Démonet, 2007). However, for music perception and production, music and language have been found in many studies to be underlined by distinct neural substrates, even in song production (e.g., Hébert, Racette, Gagnon, & Peretz, 2003; Peretz, Gagnon, Hébert, & Macoir, 2004). Examining music and text reading, Sergent, Zuck, Terriah, and MacDonald (1992) found neural networks that were adjacent, but distinct, for reading music and text. Not enough is known on music and text reading to take either position. Future work should focus on comparing these two dimensions so that an answer can be provided to this question.

It should be emphasized that although IG might represent the first documented case of music dyslexia, she is not a textbook case: For instance, her performances were sometimes lower than expected (e.g., symbol discrimination), sometimes better than expected (e.g., her pitch reading performance, which was better than some "normal" musicians). However, since there has never been any prior report of such developmental cases, it is difficult to foresee with certainty what types of profiles can be anticipated given that patterns of developmental deficits are always less clear cut than those of acquired, brain damaged ones (Ramus, 2004).

All in all, music reading is a complex skill that reflects the operation of many components. Each one of these many components may be a locus of impairment that could lead to a music-reading deficit. Moreover, dissociations can be found even in normal readers between components, such as the one reported here between pitch and rhythm. Finer paradigms such as eye-tracking combined with additional case reports of musicians with difficulty in learning to read music, with or without difficulty to read text, will help discover whether these different components of music reading may be dissociated and isolated from text reading, and further inform us about the different possible manifestations of music dyslexia.

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