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Eye Movement Patterns During the Processing of Musical and Linguistic Syntactic Incongruities

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It has been suggested that music and language share syntax-supporting brain mechanisms. Consequently, violations of syntax in either domain may have similar effects. The present study examined the effects of syntactic incongruities on eye movements and reading time in both music and language domains. In the music notation condition, the syntactic incongruities violated the prevailing musical tonality (i.e., the last bar of the incongruent sequence was a nontonic chord or nontonic note in the given key). In the linguistic condition, syntactic incongruities violated the expected grammatical structure (i.e., sentences with anomalies carrying the progressive *–ing* affix or the past tense inflection). Eighteen pianists were asked to sight-read and play musical phrases (music condition) and read sentences aloud (linguistic condition). Syntactic incongruities in both domains were associated with an increase in the mean proportion and duration of fixations in the target region of interest, as well as longer reading duration. The results are consistent with the growing evidence of a shared network of neural structures for syntactic processing, while not ruling out the possibility of independent networks for each domain.

Keywords: eye movements, syntactic incongruities, syntax, music, language, music reading

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For many years, researchers have sought to determine whether music and language processing are linked in the brain. According to some neuropsychological evidence from brain-damaged individuals, music and language are two distinct entities. The brain-damage evidence reports cases of "amusia without aphasia" (Ayotte, Peretz, Rousseau, Bard, & Bojanowski, 2000; Griffiths et al., 1997; Hébert & Peretz, 2001; Peretz, 1996; Piccirilli, Sciarma, & Luzzi, 2000) as well as "aphasia without amusia" (Basso & Capitani, 1985; Brust, 2001; Godefroy et al., 1995; Hébert, Racette, Gagnon, & Peretz, 2003; Mendez, 2001; Peretz, Gagnon, Hébert, & Macoir, 2004). The independence of amusia and aphasia suggests the complete domain specificity of the neural resources for language and music processing. Although some researchers (Dalla Bella & Peretz, 1999; Marin & Perry, 1999; Peretz, 2006; Piccirilli et al., 2000) still argue for separate or minimally overlapping entities, others argue that language and music processing are less distinct (Besson & Schon, 2001; Zatorre, Evans, & Meyer, 1994). Lately, increasing evidence from neuroimaging studies (e.g., Koelsch & Siebel, 2005; Koelsch et al., 2004) supports the shared processing hypothesis. For instance, Patel (1998) suggests that music and language processing are not as domain specific as previously believed, particularly for the processing of syntax. The notion of shared circuitry is therefore gaining increasing attention.

Both language and music involve perceptually discrete elements organized into hierarchically structured sequences called syntax. In language, syntactic conventions are used to indicate thematic relations, such as "who did what to whom," and to govern the rules of grammar and sentence composition (Patel, 1998, 2003, 2008; Figure 1a). In music, the role of syntax is to regulate tension–relaxation patterns (Meyer, 1956) related to harmonic and melodic rules (Jackendoff & Lerdhal, 2006; Figure 1b). However, musical syntax may also comprise other aspects such as rhythm, meter, and possibly timbre (Koelsch & Siebel, 2005; Meyer, 1956; Patel, 2003). According to Patel (2008), musical syntax refers to the principles governing the combination of discrete structural elements into sequences. Thus, they are combined according to certain structural norms. The cognitive significance of the norms is that they become internalized by listeners, who develop expectations that influence how they hear the music. Of course, there are important differences between linguistic and musical syntax, but these differences should not

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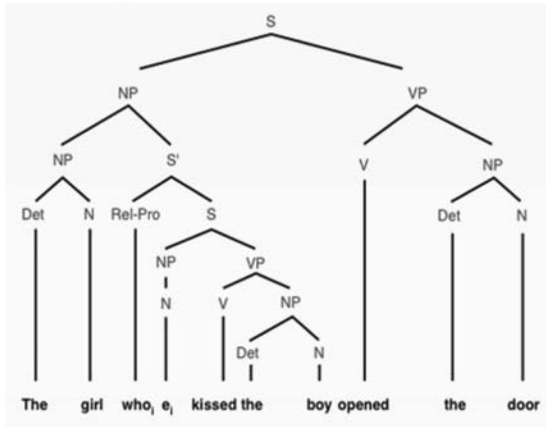
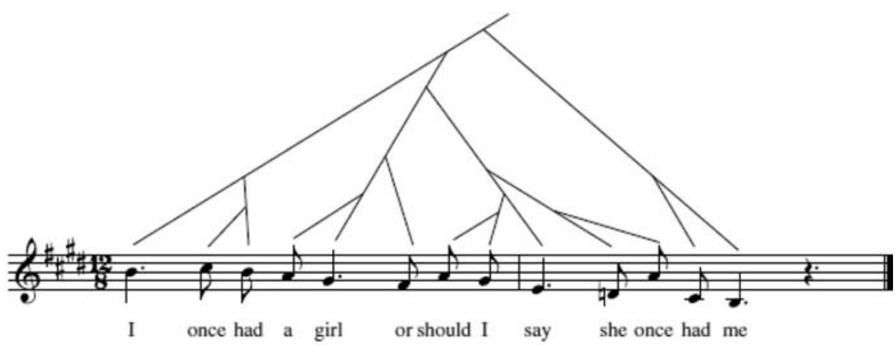
a) Syntactic structure in language: hierarchical phrase structure



Patel, A. D. (2003). Language, music, syntax and the brain. Nature Neuroscience, (6) 7, 675.

b) Syntactic structure in music: hierchical patterns of pitch, tension and resolution



Jackendoff, R., Lerdhal, F. (2006). The capacity for music: What is it, and what's special about it?. Cognition (100) 1, 56.

Figure 1. Hierarchical structures in language and music: a) Hierarchical structure of an English sentence with syntactic tree above the sentence (S, sentence; NP, noun phrase; VP, verb phrase; S′, sentence modifier (relative clause); N, noun; V, verb; Det, determiner; Rel-Pro, relative pronoun). b) The first phrase of *Norwegian Wood* with hierarchical tension-relaxation patterns according to tonal pitch space theory (TPS). Right-branching indicates increased tension and left-branching indicates decreased tension (i.e., relaxation). These patterns arise from the perception of melody with reference to the tonic or point of reference. (Lerdahl, 2006).

prevent us from recognizing and exploring formal similarities between the syntaxes of the two domains, which could in turn suggest basic principles of syntactic organization. In his analysis of language and music, Patel (2008) identified formal similarities in the hierarchical structures, with hierarchically organized sequences at multiple levels. For example, in language, morphemes are combined to form words, words are combined to form phrases, and phrases are combined to form sentences. In music, tones are combined to form chords, chords are combined to form chord progressions, and the resulting keys or tonal areas are regulated in terms of structured movement from one to another.

The integration of syntactic information can help us combine words in language or harmonies in music to extract meaning (Kaan & Swaab, 2002; Koelsch & Siebel, 2005). In addition to the similar syntactical function for both domains, the two neural networks involved in syntax processing could also be similar. Thus, language and music processing may not entail two completely separate mechanisms. Patel suggests the "shared syntactic integration resource hypothesis" (SSIRH) for this overlap (Patel, 2003, 2008).

Because syntactic processing is a form of mental sequence organization from which we can extract meaningful information, our comprehension of linguistic and musical passages should be directly influenced by how well we manage to extract and integrate that information. Accordingly, syntax processing could directly predict comprehension. Thus, by studying comprehension, we could gain useful insights into the cognitive processes behind syntactic integration. The following section explains how eye movements can be used to examine syntactic processing.

Eye Movements as an Indication of the Comprehension Process

Eye tracking could provide particular insight into syntactic processing in music and language. The study of eye movements to demonstrate and examine comprehension has gained popularity in the past decade (Rayner, Cook, Juhasz, & Frazier, 2006). Due to recent advancements in eye-tracking technology, studies on eye movements in reading have increasingly focused on cognitive strategies for regular text reading (Rayner, Chace, Slattery, & Ashby, 2006) and music sight reading (Drai-Zerbib & Baccino, 2005; Goolsby, 1994; Sloboda, 1984; Wurtz, Mueri, & Wiesendanger, 2009).

Three main types of eye movements are typically studied: fixations, forward saccades, and regressions. They have deepened our understanding of how the brain works during the processing of information during reading. Fixations are moments during which the eyes remain still and new information is acquired. Saccades are rapid eye movements that move the fovea from one place to another between fixations. No new information is acquired because there is no foveation. Regressions refer to backtracking movements. Many studies suggest that longer regressions (i.e., higher amplitude of the reversing saccade) in text reading are due to comprehension failures (Rayner & Morris, 1991; Rayner, Cook et al., 2006). For instance, one study (Braze, Shankweiler, Ni, & Palumbo, 2002) observed eye movements during the processing of syntactically incorrect sentences and found longer fixations as well as increased regressions. Therefore, eye movements can help reveal the syntactical processes that underlie comprehension during text and possibly music reading. To date, however, most studies on music reading and eye movements have examined the effects of expertise, eye–hand and/or perceptual span, or melodic complexity, and none has systematically investigated the effects of processing musical syntactic irregularities on eye movements during reading (for a review of eye movements and music reading, see Madell & Hébert, 2008).

The present study is a first step toward investigating the eye movements of readers during the visual processing of music and linguistic syntactic incongruities. The linguistic stimuli, taken from a previous study (Braze et al., 2002), involved syntactic incongruities to which eye movements are known to be sensitive. New musical stimuli were constructed for this study. For the music-syntactic incongruities, we focus on expectations of harmonic structures and consider an incongruity as a violation of the norms of the harmonic sequence. More specifically, we look at syntactic violation at the phrase and chord progression level. Linguistic and musical stimuli were constructed to be similar. Thus, following the establishment of either a linguistic or harmonic syntactic expectation, a congruent or an incongruent word or chord was introduced. If syntax processing in music and language reading shares resources, as some studies have suggested (Koelsch, 2006; Koelsch, Gunter, Wittfoth, & Sammler, 2005; Slevc, Rosenberg, & Patel, 2009), then this should result in an observable motor component (Madell & Hébert, 2008). In addition, the eye-movement patterns when processing syntactic incongruities should be similar between the two domains. More specifically, this should translate into longer fixations and more regressions for incongruent than congruent sentences and musical phrases. In contrast, different eye movement patterns for music and linguistic incongruities would challenge the shared resources model.

We also wanted to examine the role of key signature and accidentals to establish tonality. Music uses not one, but two basic notation systems to establish tonality. Most beginner music students learn to read without using a key signature (Albergo, 1988; Muck, 2004). They decode music in various keys early on, using accidentals to establish tonality (Ballard, 2007). The concept of key signature is introduced only at the end of the first year or sometime during the second year (Baker–Jordan, 2004; Parker, 2006; Uszler, Gordon, & Smith, 2000). However, indicating tonality with accidentals is not completely abandoned, because musicians continue to read in modulated keys where accidentals, not key signatures, establish the new key. Because musicians use both systems to read and understand music, it is important to test participants on these two forms of musical notation. For experienced music readers who are familiar with key signature notation, the use of accidentals may pose a greater challenge due to the additional visual complexity, and the fact that it is a less frequently used notation system. We predict that musical excerpts with accidentals will affect readers' eye movements more than excerpts with key signatures, with longer trial duration as well as increased number and duration of fixations and regressions.

Method

Participants. Eighteen (three males, 15 females) right-handed volunteers (17 to 45 years old; mean [*M*] = 25.8; standard deviation [*SD*] = 6.8) participated in the study. All participants were trained and experienced pianists (*M* = 17.4 years; *SD* = 7.23) who were playing actively at the time and were native or fluent English speakers. All participants had normal or corrected-to-normal vision. Participants had no previous exposure to the test materials.

Materials. Linguistic stimuli consisted of 20 short sentences, half of which included a syntactic anomaly. The syntactic anomaly forms carried either the progressive (*–ing*) affix or the past-tense inflection. All sentences were taken from a previous study (Braze et al., 2002) and presented in a single run. See Figure 2a and 2c for examples of the syntactic forms used. Each sentence appeared in one of two presentation lists. Each list contained 10 sentences, half of which were syntactically incongruent, presented in random order.

Musical stimuli were composed specifically for this study by a graduate student in music composition. They consisted of 16 short musical phrases divided into groups of four. All musical stimuli were evaluated by an experienced music pedagogy expert and senior piano examiner to ensure intermediate reading difficulty. Each musical phrase consisted of five, six, or seven bars. In all musical sequences, the measures preceding the last one established the same melody expectation (from root or tonic chord to dominant seventh chord). Half the sequences were syntactically congruent, with the last bar of the congruent sequence presenting a note from

a) The motorcycle can easily swerve around the barrier and evade the police.
b) The truck can easily swerve around the barrier and evade the police? Yes or No?
c) Restaurants don't usually closing quite so early this near the holidays.
d) The wall | will surely | crack after | a few years | in this | harsh climate.

Figure 2. Presentation of linguistic stimuli: a) Example of a syntactically congruent sentence used for linguistic stimuli; b) Example of a comprehension question asked after reading a sentence; c) Example of a syntactically incongruent sentence used (carrying progressive [*–ing*] affix) as linguistic stimuli; and, d) Example of region of interest (ROI) separations in linguistic stimuli.

the tonic or root chord in the given key. The remaining sequences were incongruent, with the last bar a nontonic chord or note in the given key. The musical stimuli were written in two forms: with a key signature[1] or with accidentals.[2] The aim was to study the effect of key signature notation on music-syntactic processing. The following table summarizes the four different experimental conditions for the music stimuli.

Experiments were run four times in each of the four conditions, for a total of 16 trials. See Figure 3 for examples of the musical stimuli used. All music stimuli were presented in a single run. Stimuli were created using Finale 2007, Version 2007.r2 (MakeMusic, Inc.).

All stimuli (linguistic and musical) were presented on a Toshiba Tecra M4 Notebook Tablet, using a 14.1 in. monitor at 1024 by 768 pixel resolution. The laptop was placed on an open-lid Yamaha Disklavier grand piano with the monitor turned 180° to face the piano player.

Procedure. All participants gave their written consent to participate in the study and filled out a short questionnaire concerning their personal information, level of musical experience, and competency in English. Participants were briefed on the general functioning of the eye-tracking system and how the apparatus would be positioned on their head. Participants were also told how the stimuli would be presented and instructed to look at the laptop monitor during the experiment. Participants were seated at the piano and the eye tracker was installed on their head at a distance of 1.5 feet from the laptop monitor. The apparatus was calibrated and validated using a 9-point grid. Two practice musical sequences were then presented to familiarize the participants with the experimental procedure (mapped in Figure 4). Participants were instructed to play each musical sequence at the piano with hands together and no preview time, at any speed they liked. They were also asked to read the sentences aloud at normal speed. Brief calibration checks were performed before each trial, and the eye tracker was adjusted as necessary. The experimental session lasted approximately 30 min. Participants were not compensated for their time.

Eye-movement recording. Eye movements were recorded using the SR EyeLink II Eye-tracking system at a 250 Hz sampling rate for both eyes. The pupil-corneal reflection tracking device was adjusted for each participant to reduce errors caused by headband slippage, environmental vibration, and muscle tremor. Data on all participants were exported using EyeLink Data Viewer 1.9.1 (SR Research Ltd.).

Data analysis. In order to examine eye movements recorded during linguistic and musical stimulus processing, each stimulus was divided into separate regions of interest (ROIs) to aggregate the reading times and classify regressive eye movements. For each ROI, the proportion of total fixations, total regressions in, and total regressions out were analyzed, as well as mean fixation duration in the target ROI (congruent or incongruent) and total trial duration (i.e., reading time). All dependent variables were calculated for each participant for each area and material.

For the linguistic stimuli, each target sentence was divided into six ROI, each comprising an average of two words, as used in the study of Braze et al. (2002). See Figure 2d for an example of ROI separation for linguistic stimuli. The dependent variables are the proportion of fixations in the verb area (congruity or incongruity), the mean number of regressions into the subject area, and the mean number of regressions out of the verb area, for each stimulus type (syntactic and nonsyntactic). In addition, comprehension Yes/No questions were asked immediately following a few sentences (chosen at random) to ensure that participants were reading for comprehension (Figure 2c). Participants were instructed to answer the question with respect to the sentence they had just read.

For the music stimuli, each sequence was divided into separate ROI, each comprising one bar of music. ROI were separated according to simplicity of data export and not necessarily to syntactic divisions, although they reflect these divisions. Because the music stimuli were composed specifically for the study, with a specific syntactic structure in mind (with the violation, if applicable, in the last bar), the syntactic structure of each stimulus was consistent, and the last bar could be analyzed easily and independently. The dependent variables analyzed were the proportion of fixations in the last bar area (congruity or incongruity), the number of regressions out of the last bar area, the number of regressions into the first bar area, and the number of regressions in the second-to-last bar area. An ROI was counted as having a regression out if the final fixation in the area ended in a backward glance to an earlier part of the stimulus. Leftward eye movements in a same region were not classified as regressions. Regressions in an ROI were consistently omitted because the data export program did not allow these data (regressions in) to be exported once the ROIs were defined. An ROI was counted as having a regression in if a fixation in the area was the result of a backward glance from a later part of the stimulus.

Statistical analysis. The mean number of regressions in and out was less than one in all conditions and materials, and these regressions were therefore excluded from further analysis. Trial and mean fixation durations were log transformed to reduce variability (Bland, 2000), although untransformed means and data are presented in the figures. Repeated-measure analyses of variance (ANOVAs) were run on the proportion of fixations, mean fixation duration in target ROI, and trial duration with trial type (language, music with key signature, music with accidentals) and congruence (congruence, incongruence) as within-subject factors. Main effects were examined with pair-wise comparisons, and simple effects on each domain separately were examined with *t* tests. All data were

Table 1
Experimental Conditions of Music Stimuli

Syntax violation in the ending	Presence of key signature	
	With key signature	With accidentals
No	Congruent ending, key signature	Congruent ending, with accidentals
Yes	Incongruent ending, key signature	Incongruent ending, with accidentals

[1] A key signature is a group of sharps or flats used consistently throughout a piece. It is written immediately after the clef sign.

[2] Accidentals are the sharps and flats written within the music, in addition to the key signature or with accidentals notation (as a replacement).

Figure 3. Examples of musical stimuli used in all four conditions: a) congruent ending with key signature; b) congruent ending with accidentals; c) incongruent ending with key signature; and, d) incongruent ending with accidentals.

statistically analyzed using PASW version 18.0 (SPSS, Inc.) and IBM SPSS version 19.0 (SPSS, Inc.) with alpha level set at .05.

Results

The results on the linguistic comprehension questions show that participants were reading for content: mean score was 5.06 correct answers on 6 questions ($SD = 0.94$).

Proportion of Fixations

An overall greater proportion of fixations was found for incongruent compared to congruent stimuli, with means of .13 and .11, respectively. This was supported by a significant main effect of congruence, $F(1, 17) = 26.58$, mean standard error [MSe] = .04, $p < .001$ (Figure 5a). The proportion of fixations also differed with stimulus type, as supported by a main effect of trial type, $F(2, 34) = 31.10$, $MSe = .09$, $p < .001$. Language stimuli yielded more fixations than music with key signature and music with accidentals, with means of .16, .09, and .11, respectively, both ps $<.001$. As expected, music with key signature yielded significantly fewer fixations than music with accidentals, $p < .001$. Finally, the effect of congruence differed with stimulus type, as supported by a significant interaction between trial type and congruence, $F(2, 34) = 7.07$, $MSe = .04$, $p = .003$ (Figure 5a). Incongruent stimuli yielded a greater proportion of fixations than congruent stimuli in language, $t(17) = -4.23$, $p = .001$, with means of .17 and .14, respectively. A similar pattern emerged for music with key signature, $t(17) = -5.44$, $p < .001$, with means of .10 and .08 for incongruent and congruent stimuli, respectively. In contrast, there was no difference between incongruent and congruent stimuli for music with accidentals, $t < 1$, $p = .96$, with means of .11 for both stimulus types.

Mean Fixation Duration in ROI

Overall, incongruent stimuli yielded longer fixation duration than congruent stimuli, at 1.540 and 1.159 ms, respectively. This was supported by a main effect of congruence, $F(1, 17) = 31.07$, $MSe = .02$, $p < .001$. As was the case for proportion of fixations, language and music stimuli also differed in mean fixation duration, as supported by a main effect of trial type, $F(2, 34) = 36.91$, $MSe = .04$, $p < .001$. Language yielded shorter fixation duration than music with key signature and music with accidentals, with mean durations of 687 ms, 1.419 ms, and 1.943 ms, respectively, both ps $< .001$. Music with key signature yielded shorter fixation duration than music with accidentals, although the effect did not reach the usual significance level, $p = .09$. Finally, the interaction between trial type and congruence was also significant, $F(2, 34) = 11.63$, $MSe = .02$, $p < .001$ (Figure 5b). Incongruent stimuli yielded longer fixations than congruent stimuli for language, with means of 813 and 560 ms, respectively,

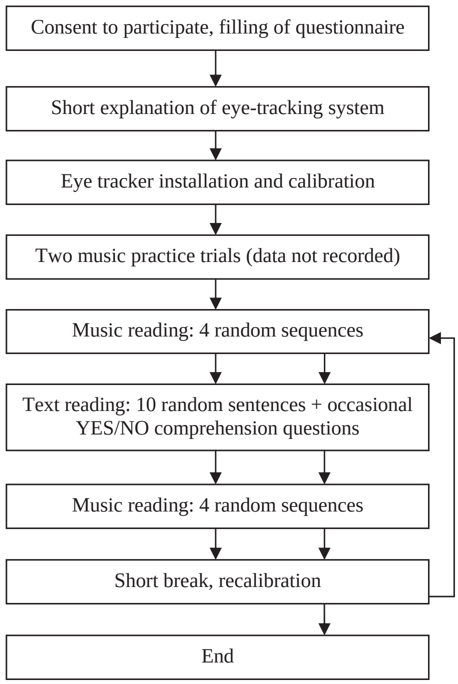


Figure 4. Mapping of experimental procedure.

$t(17) = -5.70$ $p < .001$. A similar pattern emerged for music with key signature, with means of 1.760 and 1.078 ms, respectively, $t(17) = -3.65$, $p < .001$. In contrast, the difference between incongruent and congruent stimuli was not significant for music with accidentals, with means of 2.046 and 1.840 ms, respectively, $t(17) = -1.46$, $p = .16$.

Trial Duration (Reading Time)

Incongruent trials yielded longer trial duration than congruent trials, as supported by a significant main effect of congruence, $F(1, 17) = 9.18$, $MSe = .01$, $p = .008$, with means of 15.707 ms and 14.352 ms, respectively. Language and music stimuli also yielded different trial durations, as supported by a main effect of trial type, $F(2, 34) = 105.43$, $MSe = .032$, $p < .001$, language trials were about four times shorter than music with key signature and music with accidentals, with mean trial durations of 5.291, 20.865, and 18.933 ms, respectively, both *p*s $< .001$ (Figure 5c). Music with key signature did not differ from music with accidentals, $p = .61$. The interaction between trial type and congruence was not significant, $F < 1$.

Discussion

The main findings of our study show that in both music and language, the proportion of fixations was greater, mean fixation duration was longer, and trial duration was longer for incongruent than congruent stimuli. Although the data on regressions were insufficient to support this finding, previous eye-tracking studies on comprehension during text reading (Braze et al., 2002; Rayner & Morris, 1991; Rayner et al., 2006) found similar results. However, no previous studies have made a similar comparison for music reading. Our study therefore provides the first evidence that eye-movement patterns are sensitive to music-syntactic incongruities.

Our study is also the first to examine music-syntactic processing in the visual modality. Recent neurophysiological studies have used electroencephalography (EEG) (Koelsch et al., 2005; Koelsch, Jentschke, Sammler, & Mietchen, 2007; Koelsch et al., 2004; Steinbeis & Koelsch, 2008), functional magnetic resonance imaging (fMRI; Koelsch, 2006; Koelsch, Fritz, Schulze, Alsop, & Schlaug, 2005), and magnetoencephalography (MEG; Maess, Koelsch, Gunter, & Friederici, 2001) to investigate brain activity during syntax processing, typically using auditory stimuli. EEG

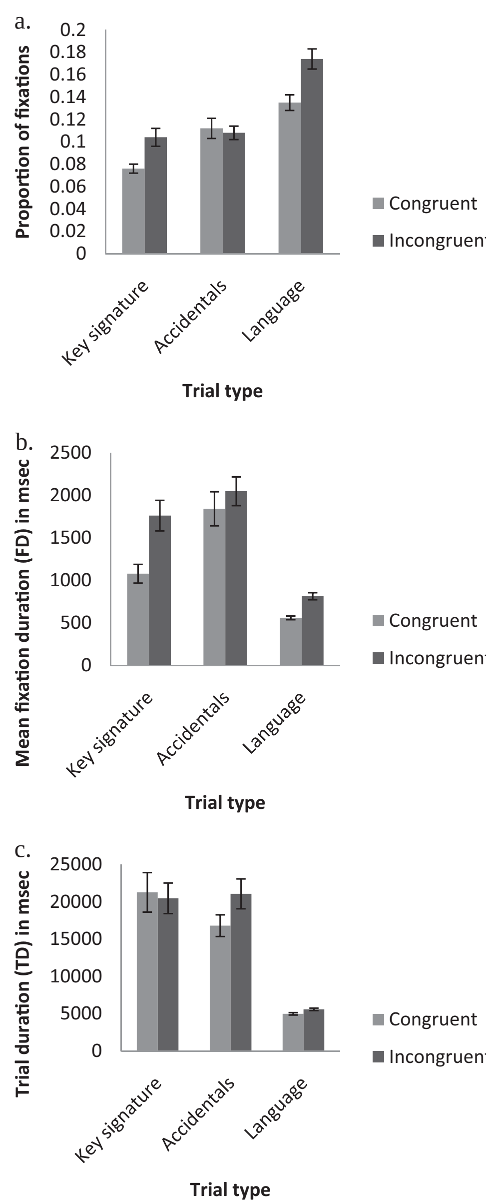


Figure 5. Comparison between music with key signature, music with accidentals, and language with congruent and incongruent stimuli relating to a) proportion of fixations in the last bar or verb area; b) mean fixation duration in the last bar or verb area (FD); and, c) trial duration (TD).

and MEG studies reveal that music-syntactic violations elicit an anterior brain response called early right anterior negativity (ERAN; Koelsch et al., 2007; Maess et al., 2001; Steinbeis & Koelsch, 2008). Similarly, syntactic language processes are correlated with left anterior negativity (LAN; Friederici, 2002). Patel (1998) compared syntactic processing in language and music and revealed that the processing of syntactic incongruities in both domains elicited event-related potential P600s (positivity occurring between 600 and 1000 ms) that are statistically indistinguishable from one another, pointing to a domain-general structural integration process for both language and music. Functional imaging studies using chord sequence paradigms (Koelsch, Fritz, et al., 2005; Koelsch, Gunter et al., 2005) suggest that musical syntax is processed in Broca's area and its right hemisphere analog as well as other cortical areas (BA44).[3] Broca's area was once thought to be responsible for language processing. However, many studies (e.g., Koelsch, 2006; Maess et al., 2001) have since concluded that there are similar cortical networks involved in both linguistic and musical syntax processing.

By demonstrating similar ocular responses in both domains, our data are consistent with a shared system for music and language syntax processing. That is, differing eye-movement patterns for music and linguistic incongruities would have argued against the shared resources model. However, this similar behavior may also be the result of a common response generated by independent processing in separate systems. As Patel (2008, p. 241) posits, linguistic and musical syntactic representations might be stored in distinct brain networks, but the networks that provide the neural resources to activate these stored syntactic representations would overlap. That is, the syntactic processing resources for language and music would converge.

Our study provides new data on the role of key signature in music reading. Although a consistent and general effect of congruency was found for all the dependent variables examined (i.e., number and duration of fixations, and trial duration), this effect was less pronounced for stimuli with accidentals than stimuli with key signature. Thus, significant interactions were found between congruency and trial type for the number and duration of fixations as well as trial duration. However, incongruent and congruent trials did not differ for music with accidentals, although the differences for number and duration of fixations were in the right direction. This finding suggests that although music with key signature and with accidentals are deciphered at equal speed, the unconventional presentation of music with accidentals provides no advantage for congruent over incongruent endings. Future studies should corroborate and expand on these findings with other musical instruments.

In summary, the main findings of this study suggest that during syntactic structural processing in language and music reading, eye movements show a similar behavioral trend: greater proportions of fixations, longer fixations, and longer reading time with incongruent compared to congruent stimuli. These findings are consistent with the hypothesis of a shared cortical network for syntax integration. However, the possibility of independent networks underlying each domain cannot be ruled out. A more robust test of the shared resources hypothesis would require a simultaneous manipulation of music and linguistic syntaxes, as was recently done by Slevc et al. (2009). Future studies could also examine eye movements during the reading of syntactically incongruent material and determine their cortical correlates.

[3] Brodmann's Area 44 is part of the frontal cortex of the brain, situated just anterior to the premotor cortex; together with BA45, it comprises Broca's area.

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