Structural integration in the processing of linguistic and musical syntax

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In recent years, a small body of research has developed surrounding the relationships between various aspects of music and language, which combines the disciplines of psycholinguistics and music cognition. Perhaps the most well-studied relationship to date involves the ways in which people process linguistic and musical structure, or syntax. The current study tests whether syntactic expectations which are found in various syntactic structures (object-extracted relative clause sentences, garden-path sentences, and subject- and object-extracted relative clause sentences) interact with musical expectations, and whether violating musical expectations magnifies the costs for violating those syntactic expectations. This study manipulated two independent variables, each with two levels: linguistic condition (easy, hard) and musical condition (consonant, dissonant). Each variable was measured based on the effect it had on reading times using self-paced reading in three different types of syntactic structures. Participants completed a self-paced reading task in which sentences were read one segment at a time and each segment was accompanied by a major scale (which sometimes contained a structural violation). The results of this study showed that the differences in reading times between the difficult and easy linguistic conditions were larger in the consonant musical condition than in the dissonant musical condition. This finding is the opposite of what was expected based on the results of previous studies (e.g., Slevc, Rosenberg, & Patel, 2009). This result suggests that the ways in which the linguistic and musical violations are manipulated may be of critical importance to the pattern of the interaction between them.

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PREFACE

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1.0 INTRODUCTION

Psycholinguistics combines the disciplines of psychology and linguistics in order to study the ways in which the brain perceives and uses language. The complexity of human language has led to a large body of research targeting specific processes in an attempt to understand exactly how people acquire and use language. Within the field of psycholinguistics there exist five very broad areas of study, which are based on the elements of language: phonology, morphology, syntax, semantics and pragmatics. These five areas, beginning with the smallest component of language, are central to the use and understanding of human language. Within each element, psycholinguists study how the brain works in perceiving and using that element.

Music cognition is a relatively new field, which combines cognitive science with the study of music in order to study the ways in which the brain perceives and uses music. As is the case with language, music is extremely complex and is an integration of many different components. However, there are very many unknown phenomena in the neurological processing of music. There has been some research conducted surrounding various aspects of music cognition. Patel, Gibson, Ratner, Besson, & Holcomb (1998), Patel (2003), Slevc & Patel (2011), Slevc, Rosnberg, & Patel (2009), and other studies have begun to answer some questions about how the mind processes music. It can be argued that music also has components, ranging from single notes to overall meaning of a composition, and that each of those components are central to a true understanding of one's ability to use music.

In recent years, a small body of research has developed surrounding the relationships between various aspects of music and language, which combines the disciplines of psycholinguistics and music cognition. Perhaps the most well-studied relationship to date involves the ways in which people process linguistic and musical structure, or syntax.

1.1 SYNTAX

1.1.1 Linguistic Syntax

Syntax is the component of language that governs how sentences must be structured. Every language has very specific rules for how a sentence must be formed. The syntactic rules of a language decide where each type of word must be placed. For example, in Standard American English, the most common form of a sentence contains the subject in the first position, followed by the verb and then the object. For example, take the sentence in (1) below.

(1) *The boy kicked the ball.*

This sentence has a simple subject-verb-object syntactic structure. Because this syntactic structure is not only structurally simple but very frequent in English, readers may expect that sentences which begin with a subject and a verb will continue with an object. For example, when they read (*The boy kicked*), they may anticipate that it will be followed by an object (most likely an object which is commonly kicked).

This simple structure can be modified to give the reader more information. Adding more information will increase the structural complexity of the sentence, as in (2) below.

(2) *The boy, who had brown hair, kicked the ball.*

The relative clause (*who had brown hair*) is included to add information about one participant in the main clause (the subject, *the boy*) without changing the meaning being expressed in that main clause.

The addition of the relative clause (*who had brown hair*) adds a level of complexity that is primarily due to a processing cost associated with memory. That is, by the time the reader gets to the verb, they have to jump back in the sentence in order to remember who or what is doing the action. In this case, who is kicking the ball? The reader has to jump over the information in the relative clause (*who had brown hair*) and connect the verb (*kicked*) back to the person doing the action (*the boy*). The added information in the relative clause physically separates the subject from the verb, forcing readers to use their memory to recall what the subject was in order to fully comprehend the meaning of the sentence.

The level of structural complexity that results from the addition of the relative clause is still a frequent syntactic structure in English. The sentence in (2) can be further expanded upon in order to create increasing levels of complexity. With every additional piece of information, the sentence becomes longer and more complex as in (3) below.

(3) *The boy, who had brown hair, kicked the ball to his friend.*

The addition of the phrase (*to his friend*) gives the reader more information about the action. Though more information has been added, this sentence is still grammatically well-formed and can be processed by a reader with relatively little difficulty.

Syntactic rules allow for complex structures that can become difficult to comprehend. Though readers may struggle initially with very complex sentences, they should be able to eventually comprehend and understand the sentence. However, if any syntactic rules are violated in constructing a sentence, readers may immediately have difficulty processing the sentence and may not be able to comprehend it at all. For example, if a sentence is missing an essential element of English language structure, as in (4), that sentence may have no meaning.

(4) *The boy the ball.*

In (4), the verb has been omitted, leaving the reader with almost nothing to work with. Without the verb (*kicked*), this "sentence" carries no meaning, and is in fact not a sentence at all. It is simply two nouns: (*the* boy) and (*the ball*). In another violation of syntax, a sentence may contain all necessary elements but they may be improperly ordered. As explained regarding (1) above, a simple English sentence contains a subject, verb, and object (in that order). If those elements appear in a different order, the sentence may be nearly impossible to comprehend, as in (5a) and (5b) below.

(5a) *The boy the ball kicked.*

(5b) *The ball kicked the boy.*

The example in (5a) is difficult to understand, because the positions of the verb (*kicked*) and the object (*the ball*) have been reversed. As is the case with (4), this is not a grammatically well-formed sentence in English.

The violation that occurs in (5b) is different and causes confusion not because of structure, but because of content. The structure is the same as in (1). In (5b), however, (*the ball*) acts as the subject and (*the boy*) acts as the object. This sentence sounds odd and causes difficulty in processing because of the meaning of the words in each position of the sentence. Readers know that a ball cannot kick a boy, given what is known about balls and kicking, and this knowledge affects processing, even though it has the structure of a typical English sentence.

Depending on the ways in which information is added to a sentence, and the structures which a speaker chooses to express that meaning, sentences can become very complex and difficult to comprehend. For example, relative clauses, like (2) can vary in the way that they are structured, with some forms being more difficult to process than others. There are two common types of relative clauses in English: subject-extracted and object-extracted. Subject-extracted relative clause sentences are constructed so that the subject is not within the relative clause, as in (6a) below.

(6a) *The chef, who distracted the cameraman, poured the flour onto the counter.*

In this example, (*the chef*) is the subject of the sentence and the relative clause (*who distracted the cameraman*) contains a verb (*distracted*) and an object (*the cameraman*). As in (2), there is a memory cost associated with this type of sentence in which the reader must jump over information to connect the main clause verb (*poured*) to the main clause subject (*the chef*).

In an object-extracted relative clause sentence like (6b), the object is not in the relative clause. Rather, it contains a subject and a verb.

(6b) *The chef, who the cameraman distracted, poured the flour onto the counter.*

Here, the relative clause contains a subject (*the cameraman*) who performed the action (*distracted*). This type of sentence is associated with three kinds of processing costs: the same cost for memory (connecting the main-clause verb to the main clause subject), a second memory-based cost, and a cost associated with expectation violations. The second memory-based cost in (6b) occurs at a different place than in (2) or (6a). Here, the memory cost occurs at the relative clause verb (*distracted*). At this point, readers must connect the verb (*distracted*) to the person who is being distracted (*the chef*). When readers get to the verb, they must jump back to the start of the sentence in order to understand how the information given in the relative clause (*who the cameraman distracted*) modifies the main clause (*The chef poured the flour*). This process of retrieving the object in memory creates a processing cost that will be further discussed in 2.2 below (Gibson, 1998, 2000).

The expectation cost occurs because of the frequency of this particular syntactic structure, as discussed in sentence (1), and the expectations generated by readers about the syntactic structure of this sentence at a particular word (Gibson, 2000; Hale, 2006; Levy, 2008; Levy & Keller, 2013). Readers,, after seeing (*The chef, who*), expect a verb to follow. This is because subject-verb-object sentences are the most frequent structures in English, and a subject relative clause (like (6a) above) has this same frequent order and basic structure. The relative clause in (6b) is constructed by placing the subject of the relative clause immediately after the subject of the main clause, violating readers' expectations of what is coming next. Readers expect that the relative clause will continue as a more-frequent subject relative clause rather than a less-frequent object relative clause.

1.1.2 Musical Syntax

Similarly to linguistic syntax, musical syntax involves a specific set of rules that govern how musical notes must be structured. In music, this refers specifically to the harmonic rules for building chords (Patel, 2003, 2008). Harmonic structure involves playing two or more notes simultaneously. In Western Classical Music, there are twelve major keys and each has a corresponding minor key. The major key is defined by a specific set of notes, in ascending intervals. The major chord is built by layering three notes to create a full and generally pleasing sound. The root of the major scale forms the base of the chord and serves as the tonic tone for that chord. The third and the fifth of the major scale are played simultaneously with the root, forming the major chord. When this structure is violated, the music sounds displeasing, or "not good.” As discussed above, a violation of syntactic structure in a high-frequency sentence immediately causes difficulty for a native speaker of that language. The same is true for violations of musical syntax. That is, in a high-frequency structure (for example, a major key), a violation of that structure will be immediately noticed by anyone who has had exposure to that particular style of music, regardless of whether or not they have been formally trained (Patel, 2003). See Figure 1.

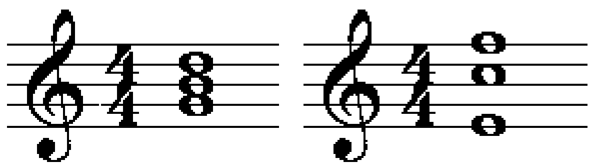

Figure 1. Visual depiction of good and bad musical chords. The first chord shows evenly spaced notes on the staff: the first, third, and fifth of a major scale. The second shows a chord that violates this basic structure, showing the first, sixth, and ninth of a major scale.

1.2 SYNTACTIC INTEGRATION

The question has been raised of exactly what it is that comprises musical syntax. The five components of language can be assimilated with five equally important elements of music. The first three elements involve form. The smallest unit of language is the phoneme. That is, a single sound that forms one part of a word (Yule, 2010). In classical music, the smallest unit is a note. Single notes (in a variety of pitches) form one part of a melody.

The next unit of language is the morpheme – the smallest unit of meaningful language. A free morpheme can stand on its own because it has meaning. A bound morpheme must be connected to a free morpheme because it contains structural information which can change the meaning of a free morpheme (Katamba & Stonham 1993). Similarly, musical morphology is expressed in two types: melody and rhythm. Melodies can stand alone and have some meaning, but they also need structure which comes in the form of rhythm. The notes combine to form melodies and rhythmic values leave some notes standing freely and others attached to one another.

Syntax is perhaps the most intricate and complicated aspect of language and also of classical music. As stated above, syntactic rules determine the structure of a sentence. The syntactic rules of a language determine what types of words must be present in a well-formed sentence, as well as the structural relationship among those words. In music, there are very specific rules that determine the structure of a combination of sounds, or a chord. Two or more notes are often played at the same time and if those two notes do not follow the rules, the resulting chord will be unpleasant. Musical syntax encompasses the set of rules that determine the layering of multiple notes in order to create a “pleasant” sound. As described above, violations of linguistic syntax and violations of musical syntax both result in combinations (sentences or chords) that sound “bad” to listeners or readers.

The content of language is discussed in terms of semantics. Semantics, in language, involves the meaning of specific words and sentences (Yule, 2010). Musical semantics involve the meaning of specific chords and musical phrases. Composers convey meaning through dynamics, rhythmic and harmonic patterns, and mode in order to tell stories and create meaningful music.

The final component, pragmatics, deals with the function of language. That is, it combines the previous four elements in ways that allow people to function and to engage in social situations. This can involve changes in tone, loudness, and speaking rate. In classical music, these types of greater meanings are conveyed through emotions written by the composer, as well as dynamic and phrasing techniques employed by the musicians performing a piece and listeners' interpretations.

The five elements of language are well-known and understood, as are the musical elements of melody, harmony and rhythm. It is important, however, to understand how they relate to one another and can, to some extent, parallel each other. Identifying the connections between music and language at a fundamental level is essential in attempting to understand how the two are related in the brain. For the purposes of this study, the focus will be primarily on syntax in both music and language.

2.0 BACKGROUND

2.1 SYNTACTIC PROCESSING COSTS

As discussed in the introduction, the addition of information to sentences can create varying levels of difficulty for readers in processing those sentences. Complex sentences cause readers to work very hard in order to achieve understanding. There are two main types of processing costs which can occur due to complex structure in sentences: memory-based and expectation-based costs, which are discussed in detail below.

2.1.1 Memory-based costs

Memory is one of the most prominent cognitive domains involved in processing and understanding sentences. In terms of syntax alone, memory plays a very important role. At the end of a grammatically correct and not exceptionally difficult sentence, readers have an understanding of what happened in that sentence. That is due, in part, to the fact that as they read, readers' minds have successfully connected the parts of the sentence in memory and determined how each word or phrase is associated with each other word or phrase. Gibson (2000) developed a theory which explains how the mind makes some of these essential connections.

Gibson's Dependency-Locality Theory (DLT) explains that memory works in two major ways during the reading of a sentence. First, the reader must remember the structure of the sentence as they add each new word. Second, the reader must "integrate" each new word into the existing structure. The DLT also explains that the physical distance between two elements of a sentence which are being integrated has an effect on the complexity or difficulty of that integration (Gibson 2000). When there is greater physical distance between two elements that must be integrated, the memory-based costs are greater.

2.1.1.1 Embedded relative clause sentences

This memory-based processing cost is evident in subject-extracted relative clause sentences, as is shown in (7a) below.

(7a) ***The chef*** *who distracted the cameraman* ***poured*** *the flour onto the counter.*

The reader has to piece together the syntax of this sentence as they read, but they must also integrate each new word with the already existing structure. The words which are shown in bold in (7a) provide an example of the integration that must happen when the reader gets to (*poured*). If readers were somehow unable to connect the verb (*poured*) to the subject (*the chef*) in memory, this type of sentence could be easily misunderstood. Looking simply at word groups, the phrase (*the cameraman poured*) exists in the sentence. However, skilled readers and people without language or other cognitive impairments know that (*the cameraman*) did not pour anything. When proper syntactic integration between the main clause subject and verb occurs, the reader identifies the subject in memory, can recall the existing structure, and can integrate the action (*poured*) with the subject (*the chef*) who did the pouring.

The same type of memory-based processing cost occurs in object-extracted relative clause sentences, as in (7b) below.

(7b) *The chef who the cameraman distracted poured the flour onto the counter.*

In the above sentence, the same memory processes must occur in order to achieve sentence comprehension, connecting the main verb (*poured*) with the main-clause subject (*the chef*). However, this type of sentence is more complex due to an additional memory-based processing cost and an entirely different processing cost associated with expectation (discussed in detail below).

The second memory-based cost in (7b) occurs at the relative clause verb (*distracted*). King & Just (1991) used a self-paced reading task in order to examine these memory-based costs, and to study the effects of working memory on the processing of subject-extracted and object-extracted relative clause sentences. In this study, subjects read sentences in sets of one, two, or three. The final sentence in a set was always the critical (subject-extracted or object-extracted relative clause) sentence. Participants were asked to complete additional memory tasks by recalling the final word in each sentence and completing a comprehension probe (King & Just, 1991). The reading times at each part of the sentence were recorded in order to study the effects of memory tasks on reading time. The results of reading time measurements showed that reading times were significantly longer at the relative clause verb and the main clause verb in the object-extracted relative clause sentences than in the subject-extracted relative clause sentences for sets of one and two sentences. The experimenters noted that in sets of three sentences, recall and comprehension were poor and they were not sure that subjects had understood the sentences (King & Just, 1991). The results from the King & Just study show that reading times should be longer at (*distracted*) due to the memory cost associated with connecting (*distracted*) to the person who is being distracted (*the chef*). Based on these results, reading times should also be longer at (*poured*) due to the memory cost that occurs in order to connect (*poured*) to the person who is doing the pouring (*the chef*) (see Grodner & Gibson, 2005).

2.1.2 Expectation-based costs

As discussed in the introduction, the object-extracted relative clause sentence, in addition to producing two memory-based processing costs, also elicits another processing cost that is associated with expectation. This third processing cost adds another level of complexity to this type of sentence, making it more difficult to process than the subject-extracted relative clause sentence.

As noted in the introduction, there are certain sentence structures that occur very frequently in English and therefore readers tend to have more experience with those than with other, less frequently occurring, sentences. As discussed above, subject-verb-object sentence and subject-extracted relative clause sentences are more frequent than other sentence types. Readers generate expectations based on their experience with reading common sentence types (Levy, 2008). Complex structures can cause difficulty in sentence processing due to the fact that they often violate the reader's expectations regarding what comes next within a sentence. This type of processing cost occurs in various syntactic constructions and has been well-studied in recent years (e.g., Grodner & Gibson, 2005; Levy, 2008; Staub, 2010).

2.1.2.1 Embedded relative clause sentences

One type of sentence in which readers generate strong expectations is the relative clause sentence. Staub (2010) studied the expectation-based processing cost that occurs in two types of object-extracted relative clause sentences, seen in (8a) and (8b) below.

(8a) *The employees that the fireman noticed hurried across the open field.*

(8b) *The employees the fireman noticed hurried across the open field.*

In (8b), the relative pronoun (*that*) is omitted from the relative clause. Staub used eyetracking to record three different reading time measures (first fixation duration, gaze duration, and go-past time) for each part of the sentence. The results showed that reading times were significantly longer at the relative clause noun (*the fireman*) when the relative pronoun (*that*) was omitted (Staub, 2010). This result provided evidence that object-extracted relative clause sentences are more difficult to process when the relative pronoun is absent than when it is present.

In the same study, Staub compared reading times for subject-extracted and object-extracted relative clause sentences, as in (9a) and (9b) below.

(9a) *The employees that noticed the fireman hurried across the open field.*

(9b) *The employees that the fireman noticed hurried across the open field.*

The results showed that there was a greater processing difficulty in the object-extracted relative clause sentences than in the subject-extracted relative clause sentences, particularly at the relative clause verb (*noticed*). Reading times at the relative pronoun (*that*) were longer in the object-extracted relative clause condition, but they were not significantly longer. At the determiner (*the*), the go-past time was determined to be significantly longer in the object-extracted condition than in the subject-extracted condition. Regressions also showed evidence that at the relative clause noun (*fireman*), readers experienced a processing difficulty in the object-extracted condition, shown by longer go-past times (Staub, 2010). This difficulty is due, in part, to the violation of syntactic expectation in the object-extracted relative clause.

2.1.2.2 Garden-path sentences

Another type of sentence which is known to cause readers to generate strong expectations is the garden-path sentence. These sentences are known to produce difficulties in processing because they disrupt readers' expectations of how a sentence is going to unfold (Bever, 1970; Frazier & Rayner, 1982; Waters & Caplan, 1996). As readers progress through a sentence, they must integrate each new word with the already existing structure of the sentence, as in Gibson's (1998, 2000) DLT model. Garden-path sentences occur when at a certain word, readers cannot logically integrate that word into the structure of the sentence that they have read so far. Waters & Caplan (1996) studied three types of syntactic garden-path sentences compared with those of various non-garden path sentences in groups of people with low, medium, and high memory span. Examples of these three types of syntactic garden-path sentences are seen in (10), (11), and (12) below (Waters & Caplan, 1996).

(10) *The defendant confided to the lawyer he admired the judge was his brother.*

(11) *The horse raced past the barn fell.*

(12) *The picture books were lying beside was a landscape.*

These sentences are all difficult because they lead the reader to expect that the sentence will unfold one way, but then reveal that the sentence continues in a different way. The sentence in (10) is a sentence complement garden-path sentence where the processing difficulty occurs at the sentence complement (*the judge was his brother*). In (11), the sentence is a garden-path which results from a reduced relative clause (*raced past the barn*). Readers experience difficulty in this sentence when they arrive at (*fell*) because it no longer fits into the syntactic structure that they have assumed to that point. The sentence in (12) is an embedded clause garden-path sentence and the processing difficulty occurs at (*was*), because readers expect a noun and it is nearly impossible to integrate (*was*) with the syntactic structure that exists to that point.

Waters & Caplan used a reading span task and a sentence acceptability task to study the effects of these different types of garden-path sentences on readers' abilities to process and comprehend them. The sentence acceptability task involved reading full sentences as well as using rapid serial visual presentation (RSVP). Participants were asked to decide if each sentence made sense or did not make sense. The results of the sentence acceptability task showed that readers experience greater difficulty in reading the garden-path sentences (in all three syntactic constructions) than they did in reading non-garden-path sentences, as shown by lower A' scores. The results of the RSVP task also showed that readers experience greater difficulty in reading garden-path sentences, as shown by longer reading times (Waters & Caplan, 1996).

Similar findings have been reported using eyetracking, which provides a measure of how readers understand each word of the garden-path sentence. For example, Frazier and Rayner (1982) reported that readers spent longer on the critical word in garden-path sentences like (10-12) above. They were also more likely to have regressions from that critical word, re-reading previous parts of the sentences. Christianson, Hollingworth, Halliwell, and Ferreira (2001) also found that readers are likely to misunderstand garden-path sentences, frequently answering comprehension questions about the garden-path sentences incorrectly.

The processing difficulty that occurs in reading syntactic garden-path sentences has been well established in the psycholinguistics literature. This processing difficulty arises because the structure that readers have assigned to the first part of a sentence (most often, the simplest and most frequent structure) leads them to expect that the sentence will continue in a certain way.

They then encounter a word which is inconsistent with those expectations. Because they create an expectation-based processing cost, these types of sentences lend themselves naturally to be studied with the integration of musical processing. Musical processing, as discussed above, depends very much on syntactic expectations (or, expectations of harmonic structure). When a musical phrase begins, a listener expects that it will continue within the confines of the musical key in which it began. When that key is violated by an out-of-key note or chord, listeners often have difficulty integrating that note with the structure which they have already assigned to the phrase. As the phrase continues to unfold, the listener is able to find the new structure (perhaps a transposition to another key) which does indeed make sense by the end of the phrase. In that regard, a musical phrase can behave very much like a garden-path sentence in the way that it is processed.

Garden-path sentences involve a difficult process beyond a violation of expectation. The process of integrating an unexpected word into the rest of the sentence involves reanalysis of what readers believe to be the existing structure. In order to properly integrate a syntactically unexpected word, readers must rethink the structure of the sentence, and reassign certain words to certain roles within that structure. Once readers have successfully performed this reanalysis and integration, they are able to make sense of the sentence, provided that the word can actually be integrated with the sentence. The same is true for musical phrases, as discussed above. When a phrase is actually transposable, listeners can perform this reanalysis upon encountering the "bad" note or chord, and can successfully integrate that sound with the rest of the phrase.

However, this is not always possible, as with anomalous musical phrases or sentences. If the syntax or content of a sentence is bad, successful reanalysis is not possible and readers will not be able to integrate the difficult word with the rest of the sentence. Likewise, if the syntactic structure of a musical phrase is bad (e.g. a wrong note is heard), the listener will not be able to integrate that note with the rest of the phrase by transposition or reanalysis.

The fact that both garden-path sentences and musical phrases cause people to generate very strong expectations is critically important to the design of the present study. Also important is the fact that due to the additional process of reanalysis that occurs with a syntactic violation of expectation in a garden-path sentence, it is nearly impossible to isolate the expectation-based processing cost. For that reason, it will be important to examine other types of sentences, such as embedded relative clause sentences, which also cause readers to generate strong expectations (as discussed above), in the presence of musical stimuli which do the same.

2.2 SYNTACTIC PROCESSING IN MUSIC

There is a small body of research which seeks to answer some big questions about how music and language are related in the brain. Much of that research is focused on how the processing of musical and linguistic syntax are integrated. Patel (2003) proposed the “shared syntactic integration resource hypothesis” (SSIRH), which states that “overlap in the syntactic processing of language and music can be conceived of as overlap in the neural areas and operations which provide the resources for syntactic integration.” This hypothesis has been very important in recent research involving the processing of musical and linguistic syntax, as researchers have investigated interactions which are related to shared processing resources (e.g., Slevc, Rosenberg, & Patel, 2009; Tillman, 2012; Perruchet & Poulin-Charronnat, 2013; Slevc, Reitman, & Okada, 2013).

2.2.1 Evidence supporting shared syntactic processing resources

Fedorenko, Patel, Casasanto, Winawer, & Gibson (2009) used a self-paced listening task t study the effects of subject- and object-extracted relative clause sentences paired with melodies on reading time and comprehension accuracy. In this experiment, SRC and ORC sentences were sung to novel, twelve-note melodies that followed the rules of western tonal music. Sentences were divided into segments and presented on a computer screen as listeners pressed a button. Each word was sung to one note within the melody. At the relative clause noun, there was sometimes an out-of-key note sung. After each sentence, participants answered a yes/no comprehension question about the sentence they had just heard (Fedorenko, et al. 2009). The results of this study supported the SSIRH, showing that listeners' comprehension was significantly poorer for the object-extracted relative clause sentences when the critical word was sung out-of-key than when it was sung in-key. There was no significant interaction seen when the critical word was sung at a louder volume, rather than out-of-key. These findings suggest that there is interaction of linguistic and musical structure, supporting the SSIRH.

Slevc, Rosenberg, & Patel (2009) studied the effects of garden-path sentences paired with musical stimuli on reading time using a self-paced reading task. This study focused on two types of complex sentences: syntactic garden-path sentences and semantically unexpected sentences. The first experiment, involving syntactic garden-path sentences, used sentence complement garden-path sentences as in (13) below (Slevc, Rosenberg, & Patel, 2009).

(13) *After the trial, the attorney advised (that) the defendant was likely to commit more crimes.*

Here, the word in parenthesis (*that*) was present in one condition and absent in the other. When it was absent, the hypothesis was that readers would encounter greater processing difficulty. As discussed in section 2.1.2.2, the processing cost that was expected to occur in this sentence is expectation-based and occurs because of the syntactic complexity of this sentence. As readers read this type of sentence with the subordinating conjunction (*that*) omitted, they expect that the sentence will continue with (*the attorney advised the defendant to…*). This is expected due to readers' experiences with common syntactic structures: they expect that (*the defendant*) will be a direct object of the verb (*advised*), which is the most frequent and simplest structure for this sentence. Instead, when readers encounter (*advised the defendant was likely…*), they have to reconstruct the sentence to this point in order to integrate (*was*) with what they have already read (Frazier & Rayner, 1982; see also Gibson, 2000).

The experiment was a self-paced reading task in which participants read sentences on a computer screen a few words at a time, and answered a yes/no comprehension question after each sentence. Each time a participant saw a part of the sentence on the screen, they were also presented with a musical chord. The chords formed a musical phrase as the reader progressed through the sentence. In some trials, an out-of-key chord occurred at the underlined word in (13). This was considered the critical segment where the processing difficulty would occur in the absence of the relative pronoun (*that*). It is important to note that the musical phrases which were created for this study were novel melodies and that all melodies ended perfectly resolved (Slevc, Rosenberg, & Patel, 2009). When an out-of-key (unexpected) chord occurred, listeners had to integrate that chord with the rest of the phrase in order to "comprehend" the resolution, as described in section 2.1.2.2 above.

The results of this experiment supported the hypothesis that garden-path sentences cause processing difficulty, demonstrated by longer reading times at and immediately following the critical word. The results also showed that this expected garden-path effect was amplified when the musical chord at the critical word was out-of-key, as the unexpected chord required listeners to reanalyze the musical phrase at the same time that they had to reanalyze the garden-path sentence. This suggests that syntactic integration in both music and language are related and may rely on shared neural resources (Slevc, Rosenberg, & Patel, 2009).

In the same experiment, there was a set of sentences which were semantically unexpected sentences, as in (14) below.

(14) *The boss warned the mailman to watch for angry (dogs/pigs) when delivering the mail.*

In this type of sentence, readers' expectations are violated not because of structure, but because of semantic content. Just like with garden-path sentences, the violation of expectation occurs because of common experiences (like common structures). Based on what is known about mailmen and angry "things," readers expect that (*the mailman*) should watch for something or someone that is typically encountered on a mail route and which may be angry, for example, a dog (as is shown in the control condition). When readers encounter (*angry pigs*), they experience difficulty integrating that with the content of the sentence so far. However, this sentence continuation is not only unexpected, but anomalous. Readers will always encounter difficulty integrating (*angry pigs*) with this sentence and even upon sentence completion, this will likely not make sense. Integration of the critical word with the sentence content in these semantically anomalous sentences is thus not possible: unlike the garden-path sentences, these sentences do not resolve to have an unexpected but ultimately sensible interpretation.

The results for this experiment set did show that reading times were longer at the critical word in the unexpected condition (*pigs*) than at the critical word in the expected condition (*dogs*). Interestingly, there was only a small difference in reading times between the expected and unexpected conditions when there was an out-of-key chord at the critical word. In addition, the reading time difference between the expected and unexpected linguistic conditions was in fact greater in the expected musical condition (consonant) than in the unexpected (dissonant) musical condition, though this measure was not statistically significant. This result supported the hypothesis that linguistic and musical syntax may share the same processing resources, and suggested that semantic integration uses other resources (Slevc, Rosenberg, & Patel, 2009).

The second experiment conducted in this study manipulated musical timbre, rather than harmonic structure. The sentences were exactly the same as those in the first experiment, and the musical phrases were the same, except that there were no out-of-key chords at the critical words. Instead, at the critical word, the chord sounded like a pipe organ, rather than a piano (Slevc, Rosenberg, & Patel, 2009). The results of this experiment showed the same main effect for linguistic condition (with longer reading times at the critical region in both the garden-path sentences and semantically unexpected sentences) as in the first experiment. There was also a main effect for musical condition (with longer reading times when the chord had an unexpected timbre than an expected timbre). However, there was no significant interaction between garden-path sentences or semantically unexpected sentences and musical condition. These results showed that readers did turn their attention to a chord when it was of unexpected timbre, but that happened regardless of linguistic condition. They also suggested that the interaction effect from the first experiment provides evidence for shared processing resources in linguistic and musical syntax specifically (Slevc, Rosenberg, & Patel, 2009). This particular study is of critical importance to the design and methods of the present study. As discussed previously (and will be discussed for the present study), it may be advantageous to use similar linguistic and musical manipulations to study these effects in different syntactic constructions.

2.2.2 Evidence for a general garden-path effect

As the body of research surrounding integration of syntax in language and music is rather limited, there is some debate among researchers about whether or not there is truly overlap in the processing of linguistic and musical syntax. Perruchet & Poulin-Charronnat (2013) conducted a study which replicated the setup of the first experiment in the Slevc, Rosenberg, & Patel (2009) study discussed in the previous section. The difference in this study was that the researchers replaced the syntactic garden-path sentences with new semantic garden-path sentences, as seen in (15) below. They also used the same semantically unexpected sentences (translated into French) and the same musical phrases (discussed in detail above) that were used in the Slevc, Rosenberg, & Patel (2009) study.

(15) *The old man went to (the river bank/the bank) to withdraw his* <u>*net*</u> *which was empty.*

These sentences involve a lexical-semantic ambiguity (related to the meaning of the ambiguous word *bank*) rather than a syntactic ambiguity. In this type of semantic garden-path sentence, the processing difficulty arises at the underlined critical word because readers' expectations about the sentence content are violated. When readers see (*went to the bank to withdraw his*), they expect that the next word will be something that is typically withdrawn from a bank (such as money). However, they see (*net*) instead, which causes them to reanalyze what they have read in order to integrate (*net*) with going to the (*river*) *bank.*

The results of this study showed that at the critical segment and post-critical segment, reading times were longer in the unexpected conditions than in the expected conditions for both semantic garden-path sentences and semantically unexpected sentences. The results also showed an interaction between musical and linguistic expectancy in the semantic garden-path sentences. In the semantically anomalous sentences, the results mirrored those of the Slevc, Rosenberg, &

Patel (2009) study, showing that the reading time differences between the expected and unexpected linguistic conditions were larger in the expected musical condition (consonant) than the unexpected condition (dissonant). Again, these differences were present, but small and not statistically reliable. (Perruchet & Poulin-Charronnat, 2013). The researchers attribute these results to a processing cost which is directly related to garden-path sentences (syntactic or semantic), and is not generalizable to other syntactic constructions (Perruchet & Poulin-Charronnat, 2013).

The conclusion of the Perruchet & Poulin-Charronnat (2013) study is that there is not enough experimental evidence to definitively support Patel's SSIRH, and that further experimental research is necessary in order to discuss the generalizability of the SSIRH. This question about the relationship between linguistic and harmonic expectancy – whether it is specific to syntactic expectation, and whether it generalizes to other linguistic or musical structures involving syntactic expectations – is critical in the design and methods of the present study. The current study tests whether syntactic expectations which are found in a different type of sentence (object relative clauses, like those studied by Staub, 2010) interact with musical expectations, and whether violating musical expectations magnifies the costs for violating those syntactic expectations.

3.0 THE PRESENT STUDY

3.1 RESEARCH QUESTIONS

The present study follows the work of Slevc, Rosenberg, and Patel (2009) in which they found, through a self-paced reading task, that when a hard linguistic condition was paired with a hard musical condition there was a significant effect on the reading time for that segment (identified as the critical segment). Specifically, there was an interaction of musical and linguistic anticipation, or expectation. Reading times at the critical segment were longer when unexpected musical information accompanied unexpected linguistic information than when expected musical information was presented. The specific research questions for the present study are as follows:

1. Do violations of syntactic expectations during sentence comprehension create processing costs in the presence of musical stimuli?
2. Do violations of musical chord structure during processing of a musical phrase create processing costs in the presence of linguistic stimuli?
3. Do violations of musical chord structure, presented simultaneously with violations of syntactic expectations create larger processing costs than readers experience in the absence of simultaneous musical violations?

To answer these questions, participants completed a self-paced reading task during which they read sentences a few words at a time, and listened to musical sequences at the same time.

Some of the musical sequences violated their expectations at various points. In addition, the sentences involved linguistic processing costs at various points. Of critical importance to the present study, some of the sentences violated expectations of how they would continue, creating expectation costs. In addition, some of the sentences forced readers to retrieve a distant word in memory, creating memory costs. Readers' reaction times in response to the words of each sentence were recorded and analyzed.

If reaction times are significantly longer when both musical and linguistic structural expectations are violated, that would suggest evidence for shared neural resources in processing musical and linguistic syntax (according to the SSIRH). It may help to resolve the question proposed by Perruchet & Poulin-Charronnat (2013) of whether the interaction of musical and linguistic processing is a garden-path effect, or is actually a structural processing effect that can be generalized to other types of sentences and syntactic violations.

4.0 METHODS

This study was built using a parametric, within-subjects design which manipulated two independent variables, each with two levels: linguistic condition (easy, hard) and musical condition (consonant, dissonant). Each variable was measured based on the effect it had on reading times using self-paced reading. A Latin square design was used for each sentence set so that within each type of sentence, a participant read each sentence only one time and in one condition, but each sentence was presented equally across the experiment in all four (two musical, two linguistic) conditions. Musical keys (twelve major keys) were assigned to each sentence pseudo-randomly so that the number of scales of each key within a set was approximately equal.

Sentences were randomized for presentation to each participant and were presented in two blocks (of 50 sentences each). Blocks were switched for every other participant in order to minimize sequencing effects across participants.

4.1 PARTICIPANTS

Participants were divided into groups based on musical experience. Group 1 included participants that had no formal musical training. Group 2 included those participants who had five or more years of formal musical training. Group 3 had some formal musical training, but not more than five years. All participants were required to be between the ages of 18 and 25, be native speakers of English, have spent the majority of their lifetime in a Western country, have normal or corrected-to-normal hearing and vision, and have no history of speech-language, hearing, neurological, or neuropsychological disorders.

4.1.1 Recruitment

All participants were recruited from the University of Pittsburgh through the Department of Psychology Subject Pool. The subject pool puts students who require research participation credits in contact with researchers at the University. All participants were currently or previously enrolled in the Introduction to Psychology course. Each participant received 2 research participation credits toward their requirement for Introduction to Psychology for their participation in this study.

4.1.2 Demographics

All participants were students from the University of Pittsburgh. A total of 128 participants (52 males and 76 females) were enrolled in the study. Participants ranged from 18 to 22 years of age (mean = 18.6; SD = 0.9; median = 18.0). Participants were initially grouped by the number of years of formal musical training they had. Group 1 (no training) had 58 participants, group 2 (5 or more years of training) had 59 participants, and group 3 (1-4 years of training) had 11 participants.

4.2 MATERIALS

4.2.1 Screening Tasks

All participants were required to complete a three-question screening task through the Department of Psychology Subject Pool. Through this screening, participants provided their age range, which helped to determine preliminary eligibility. All participants completed a participant information form, which was reviewed by either the PI or a research assistant prior to beginning the experiment. This form asked the participants to provide information about their age, gender, native language, country of origin, brief medical history, and musical experience. All participants also underwent a pure-tone hearing screening where they were screened bilaterally at 40 dB using a standard audiometer and over-the-ear headphones. All participants who met the screening criteria were enrolled in the study.

4.2.2 Experimental Task

In order to determine whether or not there is competition for neural resources, the experimental task needed to be able to present musical and linguistic stimuli simultaneously. To do this, a self-paced reading task was created that paired musical chords with segments of sentences for simultaneous presentation. Participants read sentences on a computer screen a few words at a time while listening to musical chords. Each sentence was broken into either eight or nine segments, in order to be paired with the musical stimuli. The figure below shows one experimental sentence broken up into eight segments, including linguistic and musical stimuli.

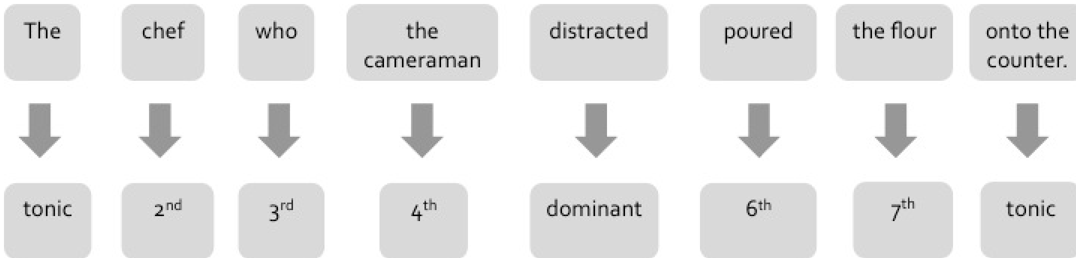

Figure 2. Experimental task. Participants saw each segment (displayed on top) and heard each chord (displayed on bottom) at the same time.

There were three sets of stimuli for this experiment. The first experimental set consisted of 24 object-extracted relative clause sentences, each in two linguistic conditions, as in (16a) and (16b) below. Each participant read only one version of each sentence in the set.

(16a) *Mona | saw | the thief | that | the artist | **chased** | in | the alley*.

(16b) *Mona | saw | the thief | the artist | **chased** | in | the | alley*.

In condition (16a) the relative clause contains the relative pronoun (*that*) and in condition (16b) the pronoun is omitted, adding an expectation-based processing cost to the already existing memory-based costs (Staub, 2010). The critical word in each of these sentences is the relative clause verb, shown in bold above. At the critical word in each sentence type, there was either a consonant musical chord or a dissonant musical chord.

The second set of stimuli were taken from Slevc, Rosenberg, & Patel (2009). These were used for replication in this study in order to provide reliability, and to test whether the slightly different musical manipulation used in the current study had a similar effect on language processing. This set consisted of 12 garden-path sentences, each appearing in two linguistic conditions. See (17a) and (17b) below. All participants read only one version of each of the sentences in the set.

(17a) *The chef | who wore | the poofy hat | remembered that | the recipe |* ***would*** *| require | using | fresh basil.*

(17b) *The chef | who wore | the poofy hat | remembered | the recipe |* ***would*** *| require | using | fresh basil.*

In condition (17b) the pronoun (*that*) is omitted, reducing the sentence complement and adding an additional level of complexity to an already syntactically complex sentence. The critical word for each of these sentences, shown in bold above, is the verb of the sentence complement (Slevc, Rosenberg, & Patel, 2009). The critical word was accompanied by either a consonant or dissonant chord.

The third set of experimental stimuli were partially taken from Staub (2010). This set consisted of 40 relative clause sentences, each in two linguistic conditions (subject-extracted and object-extracted) as in (18a) and (18b) below.

(18a) *The chef | who | distracted |* ***the cameraman |*** *poured | the flour | onto | the counter.*

(18b) *The | chef | who |* ***the cameraman*** *| distracted | poured | the flour | onto | the counter*.

The sentence in (18a) is a subject-extracted relative clause sentence, and the sentence in (18b) is an object-extracted relative clause sentence. The critical region in both of these sentence types is the noun within the relative clause (Staub, 2010). This critical region served as an object in (18a) and as a subject in (18b). Once again, the critical region was presented simultaneously with either a consonant or dissonant musical chord.

In addition to these three sets of experimental items, there were 24 unrelated filler sentences. An example is shown in (19) below.

(19) *The motivated student | studied | all night long | but then | overslept | and |* ***missed*** *| the test.*

Each participant read all 24 of these unrelated filler sentences during the experiment. The critical word in each filler item appeared in either segment 5, 6, 7, or 8, and varied regarding the role that it played within each sentence. At that critical word, the chord presented was either consonant or dissonant.

The musical stimuli throughout the experiment were major scales built according to the rules of Western Classical Music. See Figure 3. Each scale was presented one chord at a time. All of the scales in this experiment were created using a synthesized piano on Finale Notepad to ensure correct pitch and matched timbre (sound quality). Twelve different major scales were used in this experiment: one in each of the twelve major keys. Three linguistic conditions, the object-extracted relative clauses (experimental set 1) and the subject-extracted relative-clause sentences (experimental set 3), for a total of44 sentences per participant, were segmented into 8 parts and the scale was presented exactly as it appears in Figure 3 below. The other three linguistic conditions, the garden-path sentences (experimental set 2) and the object-extracted relative clause sentences (experimental set 3), for a total of 32 sentences per participant, were segmented into 9 parts and the scale was built by doubling the first chord (tonic) and then proceeding up the ascending scale, shown in Figure 3 below.

Figure 3. Major scale. An example of the major scale used in this experiment.

4.3 PROCEDURE

4.3.1 Informed Consent

All participants read and signed a consent form, providing informed consent to act as a participant in a research study. All experimental procedures, risks, and procedures for handling and storing information were explained in the consent form. The PI or research assistant answered any questions that the participant had. After informed consent was obtained, the participant began screening tasks.

4.3.2 Screening Procedures

All participants were asked to complete the participant information form prior to beginning the study. Eligibility was determined from answers given on this form. Once approved by the PI or research assistant, all participants completed the bilateral hearing screening.

4.3.3 Experimental Task

The experimental task was completed by all enrolled participants. Each participant completed the task on a Dell laptop computer running Windows XP Professional (2002). The experimental task was written using E-Studio and run using E-Run (both within E-Prime Professional 2.0). All auditory stimuli were created using Finale software and presented to participants through Sony Professional over-the-ear headphones.

For the task, each participant read a total of 100 sentences using the self-paced reading design. Each participant saw a single segment of the sentence displayed in the center of the screen and pressed the spacebar to advance to the next segment. Following some sentences, a yes/no comprehension question was displayed in the center of the screen. Participants used labeled keys on the keyboard to answer the questions, and were then prompted via on-screen instructions to press the spacebar to proceed to the next sentence. After 50 sentences, participants were prompted via on-screen instructions to take a break of self-determined length.

Participants were given verbal instructions by the PI or research assistant prior to beginning the experiment. The PI or research assistant answered any questions that the participants had and instructed them to begin the practice. The practice session contained four practice sentences which were unrelated to the experimental sentences. Two of the practice sentences were followed with yes/no comprehension questions in order to introduce the participant to the response keys and the question type. Once the practice was completed and all questions had been answered, the participant was left in the sound-attenuated booth to complete the experimental task. Upon completion of the task, participants were debriefed by the PI and were granted credits toward their requirements for Introduction to Psychology.

5.0 RESULTS

5.1 DESIGN

The present study used a parametric, within-subjects design to test the effects of linguistic condition and musical condition on reading times (RT) during a self-paced reading task. In order to control for sequencing and order effects, the design was created using a Latin square to pair linguistic condition and musical condition, pseudo-randomization of musical key assignments, randomization of sentence order for each participant, and counter-balancing the assignment of experimental block. The self-paced reading program (E-Prime) recorded the reading time of each segment in each sentence for all participants. The reading times for four selected segments were analyzed and compared using repeated measures analysis of variance (ANOVA). For each sentence, a critical segment was identified (as shown previously). ANOVA was performed on the pre-critical segment, critical segment, post-critical segment, and second post-critical segment for each sentence in all three sets.

All analyses included musical experience as a between-subjects variable. However, no significant differences in RTs were seen between groups. This is the same pattern found by Slevc, Rosenberg, & Patel (2009), who also did not find an effect of musical experience on the patterns they reported. The results reported below are those for all three groups, as musical experience did not have an effect.

5.2 ANALYSIS

5.2.1 Experimental Set 1: Object-extracted relative clause sentences

An ANOVA was performed on the reading time data for each of the four selected segments from the self-paced reading task sentences. The critical segment for each sentence in this set was the relative clause verb (*Mona saw the thief (that) the artist* ***chased*** *in the alley*). For each sentence in this set, ANOVA was performed for the pre-critical segment (*the artist*), the critical segment (*chased*), the post-critical segment (*in*), and the second post-critical segment (*the alley / the*). Because the easy condition contained an extra word (that) before the critical word, the difficult condition was broken up into smaller segments following the critical word, so that the number of linguistic segments and musical chords would be the same in the two conditions. This is why the second post-critical segment was shorter for the difficult condition. The set of sentences was analyzed and compared using ANOVA for items analysis and for subjects analysis. The RT results are shown in Figure 4 for all conditions in this set.

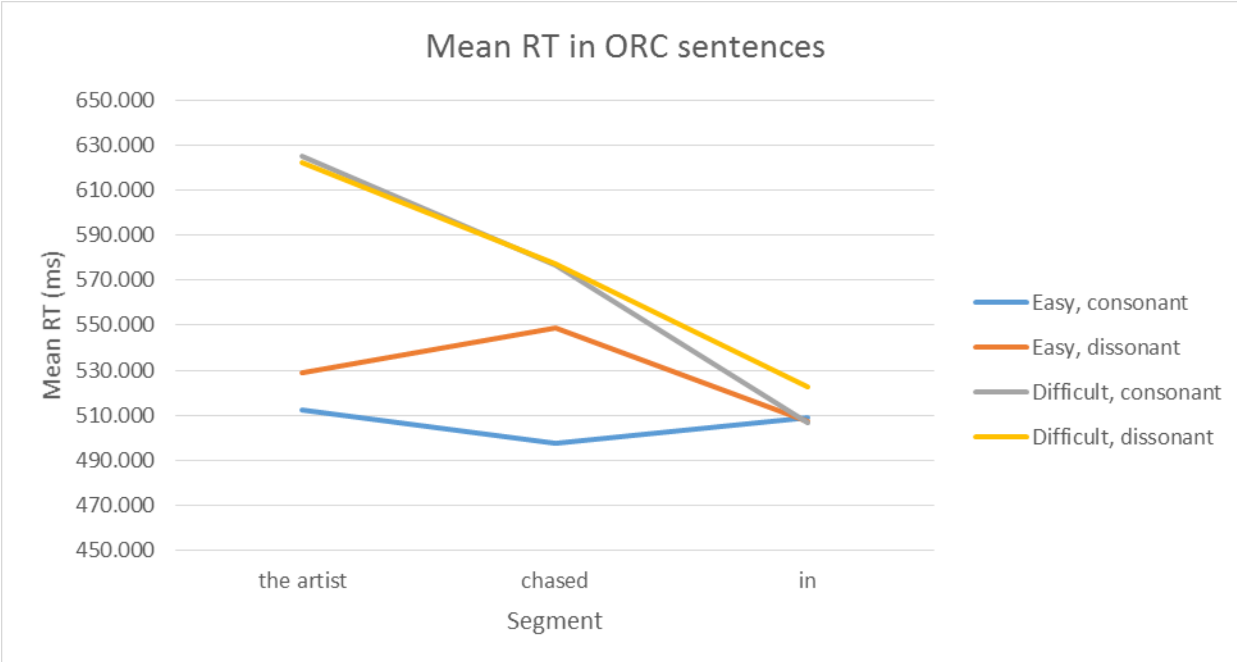

Figure 4. Mean RT data for all conditions of ORC sentences.

5.2.1.1 Analysis of linguistic condition

An ANOVA was performed for analysis of the easy versus the difficult linguistic conditions in the first set of object-extracted relative clause sentences. At the pre-critical segment, there was a significant main effect for linguistic condition in both the subjects ANOVA ($F[1, 127] = 92.538$, $p < .001$) and the items ANOVA ($F[1, 23] = 93.378$, $p < .001$), with longer RTs in the difficult condition than in the easy condition (mean RT (difficult) = 625.044 ms; mean RT (easy) = 512.558 ms). At the critical segment, there was also a significant main effect for linguistic condition, shown in both the subjects ANOVA ($F[1, 127] = 28.653$, $p < .001$) and the items ANOVA ($F[1, 23] = 7.983$, $p < .05$), with loner reading times in the difficult condition than in the easy condition (mean RT (difficult) = 576.803 ms; mean RT (easy) = 497. 836 ms).

In the post-critical segment, the results were non-significant in the subjects ANOVA ($F[1, 127] = .848$, $p > .3$) and the items ANOVA ($F[1, 23] = .229$, $p > .6$), with almost identical reading times between the easy and difficult conditions (mean RT (difficult) = 506.930 ms; (mean RT (easy) = 508.916 ms) conditions. Analyses were also performed on the second post-critical segment, though the content of that segment differed in the two linguistic conditions (easy: *the alley* vs. difficult: *the*). It is therefore not surprising that there was a significant main effect for linguistic condition in both the subjects ANOVA ($F[1, 127] = 91.720$, $p < .001$) and the items ANOVA ($F[1, 23] = 50.561$, $p < .001$), with longer RTs in the easy linguistic condition than in the difficult condition (mean RT (easy) = 607.807 ms; mean RT (difficult) = 468.515 ms).

5.2.1.2 Analysis of musical condition

An ANOVA was performed to compare the RTs of the same four segments in order to analyze the effects of consonant versus dissonant musical conditions. It was expected that an effect for musical condition would only be found at the critical segment, as that was the only segment which would have dissonant chords. As expected, there was no significant effect at the pre-critical segment, shown in both the subjects ANOVA ($F[1, 127] = .803$, $p > .3$) and the items ANOVA ($F[1, 23] = .504$, $p > .4$). There were only small differences between RTs in the consonant and dissonant musical conditions (mean RT (consonant) = 512.558 ms; mean RT (dissonant) = 528.674 ms). At the critical segment, there was a significant main effect for musical condition, shown in both the subjects ANOVA ($F[1, 127] = 4.291$, $p < .05$) and the items ANOVA ($F[1, 23] = 7.539$, $p < .05$), with longer reading times in the dissonant condition than in the consonant condition (mean RT (dissonant) = 549.068 ms; mean RT (consonant) = 497.836 ms).

As expected, there was no significant effect of musical condition at the post-critical segment, shown in both the subjects ANOVA ($F[1, 127] = 1.286$, $p > .2$). and the items ANOVA

(F[1, 23] = .690, p > .4), as the chords in both conditions were consonant. There were minimal differences in RTs between the consonant and dissonant musical conditions (mean RT (consonant) = 508.916 ms; mean RT (dissonant) = 507.304 ms). At the second post-critical segment, there was also no significant main effect for musical condition, shown in both the subjects ANOVA (F[1, 127] = .016, p > .8) and the items ANOVA (F[1, 23] = .034, p > .8), with slightly longer reading times in the consonant condition than in the dissonant condition (mean RT (consonant) = 607.807 ms; mean RT (dissonant) = 584.264 ms).

5.2.1.3 Analysis of interactions between linguistic and musical stimuli

An ANOVA was performed to analyze the ways in which interactions between linguistic and musical stimuli affected RTs for four segments of each sentence. The analyses at the pre-critical segment did not show a significant interaction, seen in both the subjects ANOVA (F[1, 127] = 1.385, p > .2) and the items ANOVA (F[1, 23] = .945, p > .3), as was expected due to the musical conditions being the same in both linguistic conditions. At the critical segment, a significant interaction effect was seen in both the subjects ANOVA (F[1, 127] = 4.955, p < .05) and the items ANOVA (F[1, 23] = 5.905, p < .05). The RT difference between the difficult and easy linguistic conditions was larger for the consonant musical condition (mean RT (difficult) = 576.803 ms; mean RT (easy) = 497.836 ms) than for the dissonant condition (mean RT (difficult) = 577.513 ms; mean RT (easy) = 549.068 ms).

The analyses at the post-critical segment did not reveal a significant interaction between linguistic and musical condition, shown in both the subjects ANOVA (F[1, 127] = .517, p > .4) and the items ANOVA (F[1, 23] = 1.189, p > .2). At the second post-critical segment, there was a significant interaction shown in the subjects ANOVA (F[1, 127] = 6.138, p < .05) and a marginally significant interaction shown in the items ANOVA (F[1, 23] = 3.687, p > .06), due to differences in linguistic content. The RT differences between the difficult and easy linguistic conditions were slightly larger in the consonant condition (mean RT (difficult) = 486.515 ms; mean RT (easy) = 607.807 ms) than in the dissonant condition (mean RT (difficult) = 488.521 ms; mean RT (easy) = 584.264 ms).

5.2.2 Garden-path sentences

The garden-path sentences for this experiment were analyzed using ANOVA in order to compare the effects of linguistic condition and musical condition on RTs. In each of these sentences, the critical word was the sentence complement verb (*The chef remembered (that) the recipe* ***would*** *require using fresh basil).* An ANOVA was performed for each of four selected segments: the pre-critical segment (*the recipe*), critical segment (*would*), post-critical segment (*require*) and second post-critical segment (*using*). Each segment was analyzed in two ways: by items and by subjects. Figure 5 shows RT data for all sentences in this set.

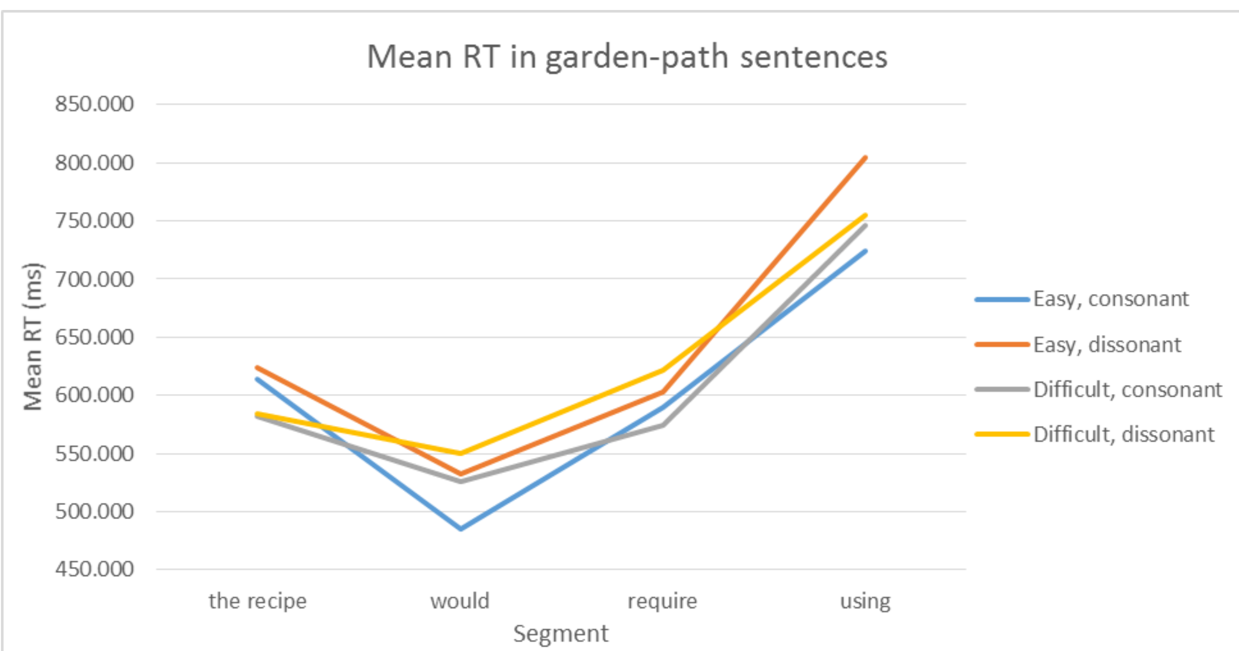

Figure 5. Mean RTs for all conditions of garden-path sentences.

5.2.2.1 Analysis of linguistic condition

ANOVAs were performed on each of four selected segments in the set of garden-path sentences to study the effects of easy versus difficult linguistic conditions. Analyses at the pre-critical segment showed a significant main effect for linguistic condition in both the subjects ANOVA ($F[1, 127] = 7.538$, $p < .01$) and the items ANOVA ($F[1, 11] = 4.369$, $p > .06$), with longer reading times in the easy condition than in the difficult condition (mean RT (easy) = 613.953 ms; mean RT (difficult) = 582.376 ms). At the critical segment, there was also a significant main effect for linguistic condition, shown in both the subjects ANOVA ($F[1, 127] = 7.101$, $p < .01$) and the items ANOVA ($F[1, 11] = 6.073$, $p < .05$), with longer RTs in the difficult linguistic condition than in the easy condition (mean RT (difficult) = 525.381 ms; mean RT (easy) = 485.263 ms).

As expected, there was no main effect for linguistic condition after the critical segment in the subjects ANOVA ($F[1, 127] = .046$, $p > .8$) or the items ANOVA ($F[1, 11] = .018$, $p > .8$), with minimal differences in RTs between the difficult condition and the easy condition (mean RT (difficult) = 574.567 ms; mean RT (easy) = 589.525 ms). There was also no significant effect at second post-critical segment in either the subjects ANOVA ($F[1, 127] = .633$, $p > .4$) or the items ANOVA ($F[1, 11] = 1.932$, $p > .1$), as was expected. There was minimal difference in RTs between the difficult and easy linguistic conditions (mean RT (difficult) = 745.760 ms; mean RT (easy) = 724.217 ms).

5.2.2.2 Analysis of musical condition

The same four segments of each garden-path sentence were analyzed using ANOVA in order to compare the effects of consonant versus dissonant musical chords on RTs. Analysis was performed by item and by subject for each sentence in the set. Once again, it was expected that there would only be a main effect of musical condition at the critical segment, as the musical chords were identical in all other segments. At the pre-critical segment, there was no significant effect for musical condition, shown in both the subjects ANOVA (F[1, 127] = .883, p > .3) and the items ANOVA (F[1, 11] = 1.256, p > .5), with minimal RT differences between the consonant and dissonant musical conditions (mean RT (consonant) = 613.953 ms; mean RT (dissonant) = 624.314 ms). There was a significant main effect for musical condition at the critical segment, shown in both the subjects ANOVA (F[1, 127] = 14.539, p < .001) and the items ANOVA (F[1, 11] = 23.023, p < .01), with longer reading times in the dissonant condition than in the consonant condition (mean RT (dissonant) = 532.892 ms; mean RT (consonant) = 485.623 ms).

The analyses of effect of musical condition on RT after the critical segment revealed surprisingly significant main effects. At the post-critical segment, there was no significant effect in the subjects ANOVA (F[1, 127] = 1.401, p > .2), but there was a significant effect in the items ANOVA (F[1, 11] = 17.978, p < .01), with longer RTs in the dissonant condition than in the consonant condition (mean RT (dissonant) = 603.281 ms; mean RT (consonant) = 589.525 ms). At the second post-critical segment, there was no significant main effect shown in the subjects ANOVA (F[1, 127] = 2.694, p > .1), but the items ANOVA, again, showed a significant main effect for musical condition (F[1, 11] = 17.204, p < .01), with longer RTs in the dissonant condition than in the consonant condition (mean RT (dissonant) = 805.149 ms; mean RT (consonant) = 724.217 ms).

5.2.2.3 Analysis of interactions between linguistic and musical stimuli

Each of the same four segments was analyzed by item and by subject in order to study the effects of interactions between linguistic and musical stimuli on RT. The pre-critical segment analysis did not show a significant interaction effect in the subjects ANOVA ($F[1, 127] = .844$, $p > .3$) or the items ANOVA ($F[1, 11] = .348$, $p > .5$). At the critical segment, there was a non-significant interaction effect shown in the subjects ANOVA ($F[1, 127] = 1.543$, $p > .2$) and the items ANOVA ($F[1, 11] = 2.422$, $p > .1$).

As expected, there were no significant interactions after the critical segment. There was no significant interaction at the post-critical segment in the subjects ANOVA ($F[1, 127] = .098$, $p > .7$) or the items ANOVA ($F[1, 11] = 1.130$, $p > .3$). At the second-post critical segment, no significant interactions were seen in the subjects ANOVA ($F[1, 127] = 2.456$, $p > .1$) or the items ANOVA ($F[1, 11] = 1.900$, $p > .1$).

5.2.3 Subject- and object-extracted relative clause sentences

The final set of stimuli was analyzed using ANOVA in order to compare the effects of linguistic condition, musical condition, and their interaction on RTs for four selected segments. The two linguistic conditions are the SRC (*The bus driver who followed* ***the kids*** *wondered about the location of a hotel*), which is the easy condition, and the ORC (*The bus driver who* ***the kids*** *followed wondered about the location of a hotel*), which is the difficult condition. For each sentence, the critical segment was the relative-clause noun (*the kids*), though it played a different role in each condition. ANOVA was used to analyze four segments in each condition: the pre-critical segment (*followed / who*), critical segment (*the kids*), post-critical segment (*wondered / followed*), and second post-critical segment (*about the location / wondered).* The RT data for the sentences in this set is shown in Figure 6.

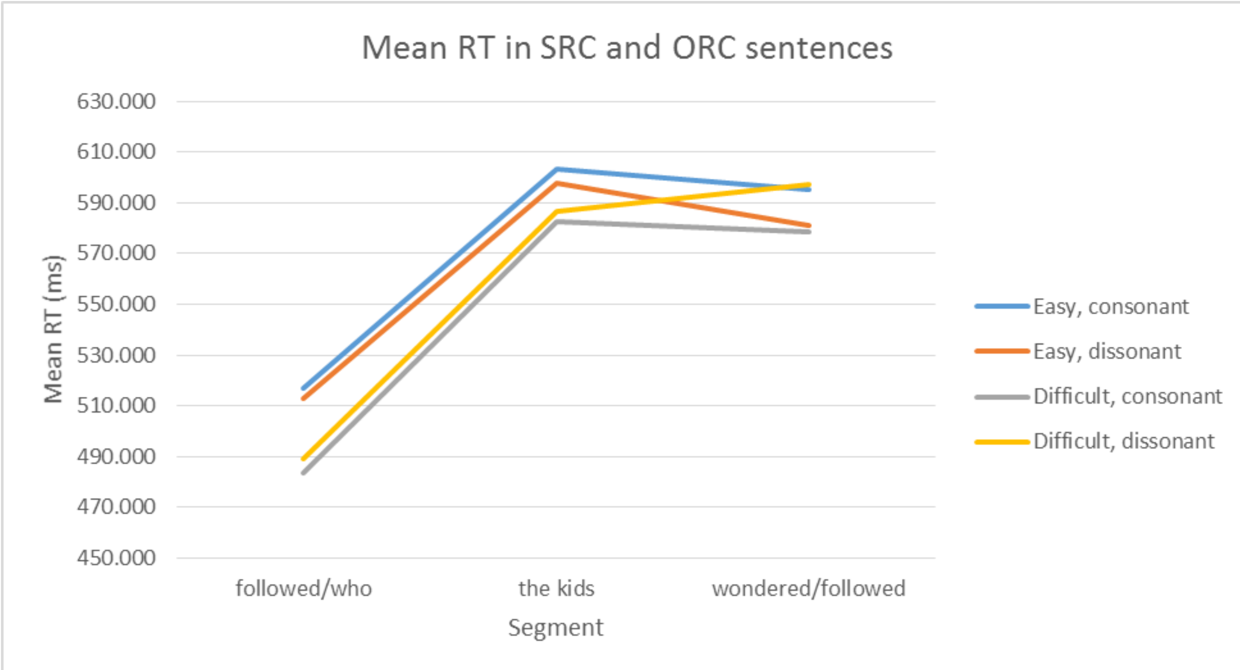

Figure 6. Mean RTs for all conditions of SRC/ORC sentences.

5.2.3.1 Analysis of linguistic condition

The analyses for linguistic condition in this set of stimuli presented some difficulty as segments differed between the two conditions. In the pre-critical segment, there was a significant main effect for linguistic condition, shown in both the subjects ANOVA (F[1, 127] = 38.619, p < .001) and the items ANOVA (F[1, 39] = 21.873, p < .001), though it should be noted that the content of the segment differed between the two conditions. The RTs were longer in the easy condition than in the difficult condition (mean RT (easy) = 516.903 ms; mean RT (difficult) = 483.617 ms). At the critical segment, the effect of linguistic condition on RT closely approached significance, though it was not reliable in the subjects ANOVA (F[1, 127] = 3.652, p > .05) or the items ANOVA (F[1, 39] = 3.258, p > .07) The reading times were longer in the easy condition than in the difficult condition (mean RT (easy) = 603.489 ms; mean RT (difficult) = 582.638 ms).

As expected, the analyses did not show a significant main effect after the critical segment (with one exception). The post-critical segment analyses did not show a significant main effect for linguistic condition in the subjects ANOVA ($F[1, 127] = .002$, $p > .9$) or the items ANOVA ($F[1, 39] = .001$, $p > .9$). It should be noted that there were, again, differences in content. Reading times were longer in the easy condition than in the difficult condition (mean RT (easy) = 595.487 ms; mean RT (difficult) = 578.435 ms). There was also no significant main effect for linguistic condition at the second post-critical segment in the subjects ANOVA ($F[1, 127] = 9.149$, $p < .01$) or items ANOVA ($F[1, 127] = 2.721$, $p > .1$), with slightly longer RTs in the difficult condition than in the easy condition (mean RT (difficult) = 599.496 ms; mean RT (easy) = 570.159 ms). It should again be noted that there were content differences between the two conditions.

5.2.3.2 Analysis of musical condition

Each segment in this sentence set was analyzed using ANOVA to study the effect of musical condition on RT during sentence processing. Each segment was analyzed for items and for subjects separately. At the pre-critical segment, there was no significant effect of musical condition in the subjects ANOVA ($F[1, 127] = .011$, $p > .9$) or the items ANOVA ($F[1, 39] = .022$, $p > .8$), with minimal differences in reading times between the consonant and dissonant musical conditions (mean RT (consonant) = 516.903 ms; mean RT (dissonant) = 513.009 ms). The analyses at the critical segment did not show an effect for musical condition in either the subjects ANOVA ($F[1, 127] = .042$, $p > .8$) or the items ANOVA ($F[1, 39] = .011$, $p > .9$), with minimal differences in RT between the consonant and dissonant conditions (mean RT (consonant) = 603.489 ms; mean RT (dissonant) = 597.564 ms).

As expected, the analyses did not show a significant effect for musical condition after the critical segment. At the post-critical segment, there was significant effect in the subjects ANOVA ($F[1, 127] = .064$, $p > .8$) or the items ANOVA ($F[1, 39] = .060$, $p > .8$), with minimal differences in RT between the consonant and dissonant conditions (mean RT (consonant) = 595.487 ms; mean RT (dissonant) = 581.160 ms). There was also no significant effect of musical condition at the second post-critical segment in the subjects ANOVA ($F[1, 127] = .283$, $p > .5$) or the items ANOVA ($F[1, 39] = .158$, $p > .6$), with almost identical RTs in the consonant and dissonant conditions (mean RT (consonant) = 570.159 ms; mean RT (dissonant) = 569.892 ms).

5.2.3.3 Analysis of interactions between linguistic and musical stimuli

The same four segments were analyzed by item and by subject in order to study the interaction effects of linguistic and musical syntactic violations on RTs. As expected, there was no significant interaction effect at the pre-critical segment in either the subjects ANOVA ($F[1, 127] = .730$, $p > .3$) or the items ANOVA ($F[1, 39] = .899$, $p > .3$). At the critical segment, there was no significant interaction effect in the subjects ANOVA ($F[1, 127] = .597$, $p > .4$) or the items ANOVA ($F[1, 39] = .464$, $p > .5$).

There was a significant interaction effect between musical and linguistic stimuli at the post-critical segment in both the subjects ANOVA ($F[1, 127] = 4.129$, $p < .05$) and the items ANOVA ($F[1, 39] = 4.404$, $p < .05$). It should be noted that there were differences in the linguistic content of this segment between the two conditions. There RT difference between the difficult and easy linguistic conditions was slightly larger in the consonant musical condition (mean RT (difficult) = 578.435 ms; mean RT (easy) = 595.487 ms) than in the dissonant condition (mean RT (difficult) = 597.290 ms; mean RT (easy) = 581.160 ms). At the second post-critical segment, there was no significant interaction shown in the subjects ANOVA ($F[1, 127] = .498$, $p > .4$) or the items ANOVA ($F[1, 39] = .193$, $p > .6$).

6.0 DISCUSSION

This study follows the work of two previous studies, Slevc, Rosenberg, & Patel (2009) and Staub (2010), and used stimuli from both studies. The Slevc, Rosenberg, & Patel (2009) study used a self-paced reading design to pair garden-path sentences with musical phrases and found that when both structures were violated at the same time, reading times were significantly longer. The Staub (2010) study used eyetracking to study reading times on subject- and object-extracted relative clause sentences, and found that there were longer reading times at the relative clause noun in the object-extracted condition. The experimental set of sentences for the present study was composed of object-extracted relative clause sentences with and without the relative pronoun. This study used self-paced reading to pair each sentence with a major scale in order to study the interaction between violations of expectation in music and language.

6.1 OBJECT-EXTRACTED RELATIVE CLAUSE SENTENCES

The results and analyses for object-extracted relative clause sentences supported the prediction that reading times would be longer in the difficult linguistic condition than in the easy condition, and that reading times would be longer in the dissonant musical condition than in the consonant condition. There was also a statistically significant interaction between the linguistic and musical conditions, which took the opposite shape than was expected. It was expected that the differences in RTs between the difficult and easy linguistic conditions would be greater in the dissonant musical condition, as was the case in the Slevc, Rosenberg, & Patel (2009) study. That is, however, not the way that interaction occurred in the present study. Here, the results showed a statistically reliable interaction where the RT differences between the difficult and easy linguistic conditions were greater in the consonant musical condition.

Though the resulting interaction was the opposite of the anticipated interaction, it is very similar to the pattern observed in both the Slevc, Rosenberg, & Patel (2009) study and the Perruchet & Poulin-Charronnat (2013) study for the semantically anomalous sentences. In both of those studies, there were numerically larger differences in RTs between the semantically expected and unexpected conditions in the consonant musical condition than in the dissonant condition. Neither of them showed statistically significant interactions. However, the general pattern of results is repeated in the present study and appears as a statistically reliable interaction in that direction. There are several possible explanations for the pattern of results shown in the present study, which is opposite of the pattern shown in previous studies.

This particular type of sentence (the object-extracted relative clause) was chosen for this experiment because readers generate very strong expectations about how this type of sentence will unfold. When those expectations are violated due to an unexpected syntactic structure (e.g. omitting the relative pronoun), there is a known processing difficulty which occurs at the relative clause verb (Staub, 2010). Although readers also generate similarly strong expectations about how garden-path sentences will unfold, garden-path sentences contain the added difficulty of reanalysis, which makes it difficult to isolate the expectation-based costs in those sentences. In using object-extracted relative clause sentences, it is possible to isolate the expectation-based costs, and it was expected that those costs would be amplified in the presence of simultaneous violations of musical expectancy. It should be noted, however, that the critical segment in this experimental set (the relative-clause verb) may not have been the best choice for observing effects of expectation violation, because of the fact that there is a significant memory cost associated with that segment. It would be useful to conduct another study in which the noun-phrase segment is studied as the critical segment, as that is the point where there is the clearest violation of readers' expectations in the object-extracted relative clause sentence.

The type of musical expectancy, however, seems to be of critical importance in producing the hypothesized patterns of interaction. As described in the background on musical expectancy (section 2.2), the musical phrases used in the Slevc, Rosenberg, & Patel (2009) study, which were also used in the Perruchet & Poulin-Charronnat (2013) study, were novel melodies which were always resolved by the end of the phrase, regardless of whether or not they contained an unexpected chord. These musical phrases mirror garden-path sentences in the way that listeners process them. When the out-of-key chord occurred, it was a violation of what listeners expected, and was difficult to integrate with the phrase they had heard. At that chord, listeners had to reanalyze what they had heard and figure out how to integrate that "bad" chord with the rest of the phrase as it continued. Because of the fact that these phrases resolved after the out-of-key chord, listeners were able to achieve "comprehension" of the musical phrase, in very much the same way as they were able to achieve comprehension of the difficult sentences (in the garden-path conditions). The pattern of interaction that was seen in both garden-path conditions (syntactic and semantic) may be attributable to the fact that the type of violation in the musical condition mirrored that of the linguistic condition.

The musical stimuli that were chosen for the present study were intentionally different than those in the Slevc, Rosenberg, & Patel (2009) study. All of the stimuli in this experiment were major scales, some of which contained an out-of-key (unexpected) chord at the critical segment in the sentence. This type of musical violation more closely approximates a syntactically anomalous sentence than a garden-path sentence. That is, when the out-of-key chord occurs in the major scale (definitely violating listeners' expectations), it is simply impossible to integrate with the rest of the musical phrase. The chords following the harmonic violation in a major scale do not move in such a way that they resolve the violation. The scale simply picks up where it left off after the out-of-key chord, leaving the listener baffled as to why that chord was played. This attempt at integration after a structural violation more closely mirrors the semantically unexpected sentences in the Slevc, Rosenberg, & Patel (2009) study, repeated in the Perruchet & Poulin-Charronnat (2013) study, where even upon sentence completion, readers have a difficult (or impossible) time making sense of the sentence. The pattern of results seen in this study is the same pattern shown in the semantically anomalous sentences in both of the above mentioned studies, though the result here is amplified and statistically reliable.

The key to the observed size and pattern of the interaction in this study may be in the matching (or mismatching) of violation type between the linguistic and musical stimuli. Here, "resolvable" sentences were paired with anomalous musical phrases. The difficult sentences in this experiment caused a processing difficulty at the critical word, but readers were able to integrate that word with the existing structure of the sentence and ultimately achieve sentence comprehension. In the major scales with which these sentences were paired, that was not the case. Listeners were not able to successfully integrate the out-of-key chord with the rest of the musical phrase, because it never resolved itself. It is interesting that the pattern of the interaction is the same (though more robust) as the pattern observed by Slevc, Rosenberg & Patel (2009), and replicated by Perruchet & Poulin-Charronnat (2013), in which the semantically unexpected sentences were anomalous, but the musical phrases were resolvable. The pattern shown in both those studies and the present study is the opposite of that shown in the garden-path sentences in both above studies, where both the linguistic stimuli and the musical stimuli were resolvable.

The current results indicate that the interactions observed in simultaneous violations of linguistic and musical expectancy may in fact depend greatly upon the nature of the violation. The observed pattern of interaction in this study leads to further questions regarding the effect of the nature of the violation on the interaction. It can be speculated, based on the results of the three studies described here, that if the difficult linguistic condition and musical condition are both resolvable, then the interaction of simultaneous expectation violations should amplify the difficulty in the dissonant musical condition. In the same way, if the difficult linguistic condition and musical condition are both anomalous, then the interaction should also amplify the processing difficulty in the dissonant musical condition. As shown in this study, and in the semantically unexpected conditions in the Slevc, Rosenberg, & Patel (2009) and Perruchet & Poulin-Charronnat (2013), if the difficult linguistic condition is resolvable and the difficult musical condition is anomalous (or vice versa), then the interaction pattern should be the opposite, showing greater differences in RTs between the easy and difficult linguistic conditions in the consonant musical condition.

These results are in support of the SSIRH and offer evidence that the observed interaction is indeed a result of syntactic expectation and integration (as there was no semantically difficult content in these sentences). It would be interesting to see further experimentation which pairs anomalous musical phrases (such as those used in the present study) with syntactically anomalous sentences, in order to see if the expected pattern of interaction is shown. It would also be interesting to pair musically transposable phrases (such as those used in Slevc, Rosenberg, & Patel, 2009) with syntactically anomalous sentences, in order to see if the pattern of interaction shown in this study can be replicated as predicted above.

This particular explanation suggests that there may have been learning that occurred over the course of the experiment. In order for listeners to struggle with an unresolved musical phrase before the phrase is completed, they may have learned throughout the experiment that the phrases were not going to resolve, causing the large interaction that was observed at the critical segment. It will be important to complete an additional analysis in which the reading times for each subject are studied in the order in which they saw the sentences, in order to compare reading times as readers progressed through the experiment. If listeners learned that the unexpected chord would not be resolved by the end of the phrase, it can be expected that reading times at the critical chord will increase as readers progress through sentences in the experiment. This would suggest that learning may have taken place and that the type of musical violation was indeed of importance to the observed pattern.

Also supporting the SSIRH, there is a possible alternative explanation for the observed pattern of results that centers on the allocation of neural resources. This explanation suggests that there is competition for neural resources in the simultaneous processing of linguistic and musical information. Following this explanation, it is plausible that the difficult linguistic condition paired with the dissonant musical condition is so difficult that readers have insufficient attention resources and are focused only on the linguistic stimuli, as they were instructed to do. In this case, it is completely understandable that the difference in reading times between the difficult and easy linguistic conditions would be larger in the consonant musical condition, because readers are able to actually focus their attention on both the linguistic and musical stimuli when the music is not difficult or distracting. This idea follows the results of the King & Just (1991) study in which a difference in reading times between the difficult (ORC) and easy (SRC) sentences did not exist when readers were asked to complete very demanding memory tasks, such as remembering the final word in a set of three sentences. This suggests that with the added memory burden, the task is simply too difficult for readers to do well. In the present study, it is possible that the added expectation violation in the musical stimuli made the processing of both sentences and musical phrases too difficult, causing readers to focus their attention primarily on the linguistic stimuli.

6.2 GARDEN-PATH SENTENCES

The garden-path sentences used in this experiment were taken from Slevc, Rosenberg, & Patel (2009). These sentences were segmented in the same was as in the above mentioned study, but were paired with different musical stimuli (major scales). As was expected, the results from the present study showed the same effect of linguistic condition, with longer reading times in the difficult linguistic condition than in the easy condition at the critical segment. The results presented here also showed the same effect of musical condition at the critical segment (and post-critical segments) with longer reading times in the dissonant than in the consonant conditions. However, unlike in the Slevc, Rosenberg, & Patel (2009) study, there was no observed interaction between violations of linguistic and musical expectation in the results of the present experiment.

There was not a significant interaction of musical and linguistic information for the garden-path sentence set. However, the observed pattern of results in this set of garden-path sentences follows the same general pattern as those in the previously discussed set (object-extracted relative clause sentences), where there is a greater difference in RT between the easy and difficult linguistic conditions in the consonant musical condition than in the dissonant condition. Again, this is the opposite of the effect seen in the Slevc, Rosenberg, & Patel (2009) study. This difference could be due to the differences in the nature of the musical manipulation, as mentioned above. The garden-path sentences are resolvable and the major scales which contain unexpected chords are anomalous, and do not resolve. While the data definitely show the same pattern that was seen in the previous sentence set, the differences in this set are smaller and are not statistically significant. Knowing that these results are delicate, it is possible that the small observed interaction in this experiment may achieve significance with the addition of more sentences of this syntactic structure. Readers only saw six syntactically difficult garden path sentences, only three of which contained an out-of-key chord. This may not have been a sufficient number of observations to show a fully significant difference.

6.3 SUBJECT- AND OBJECT-EXTRACTED RELATIVE CLAUSE SENTENCES

This particular set of stimuli did not show any of the hypothesized differences Due to the nature of the sentences and of the self-paced reading task, three of the four segments which were analyzed differed in content between the easy and difficult linguistic conditions. Only the critical segment (the relative-clause noun) was exactly the same between the two conditions. As the content differed, comparisons cannot be made between the two conditions except at the critical segment. At the critical segment, the effect of linguistic condition approached significance (p-value > .07 in the subjects and > .05 in the items) but were note fully reliable. Furthermore, reading times were marginally longer in the easy linguistic condition than in the difficult condition. This is the opposite of what was observed in the Staub (2010) study, where slightly longer reading times were observed in the difficult condition than in the easy condition. It is unclear why this pattern occurred in this experiment.

There was, interestingly, no observed effect for musical condition. Reading times were almost identical in the consonant and dissonant musical conditions. This is very likely due to the placement of the critical segment within the sentence. In both the subject- and object-extracted relative clause sentences, the critical segment was the relative clause noun, which happened to be the fourth segment. The most probable explanation for the lack of effect of musical condition is that the fourth segment is very early for the musically unexpected chord to appear. Listeners were likely not able to establish strong expectations about the structure of the musical phrase in only three chords. In the other two experimental sets (ORCs and garden-path sentences), the unexpected chord never occurred until the fifth or sixth segment. The fact that it was so early in the subject- and object-extracted relative clause sentences likely did not give listeners enough time to establish the key and generate strong expectations about how the phrase would unfold.

The interaction in this sentence set did not approach significance. It would be interesting to study these types of sentences (with the same critical segment) in the presence of musical stimuli which give the listener enough musical information before the critical segment that they are able to establish a key and generate expectations about how the musical phrase will unfold.

7.0 CONCLUSION

The results of the present study have raised some interesting questions about the interactions between language and music. The prediction that the simultaneous violations of expectation in musical and linguistic stimuli would result in longer reading times, based on the findings of both Slevc, Rosenberg, & Patel (2009) and Perruchet and Poulin-Charronnat (2013), was not confirmed. Instead, the opposite pattern was found. That is, in the present study, the differences in reading time between the difficult and easy linguistic conditions were larger when there was no violation of musical expectation than when there was one. The most likely explanation for this difference seems to be that the type of violation differed between musical and linguistic stimuli. In the present study, the linguistic manipulations in all three sentence types were difficult, but they were grammatically well-formed and readers were able to achieve comprehension by the end of the sentence. The musical manipulations, however, were completely anomalous. That is, major scales contained a single chord violation and were unresolvable upon hearing the end of the phrase. The out-of-key chord was just out place and listeners could not integrate it with the rest of the musical phrase. In the Slevc, Rosenberg, & Patel (2009) study, both the linguistic and musical manipulations were resolvable, and the results were the opposite of what was seen in the present study.

From the results of these studies, it is clear that there are still unanswered questions regarding how music and language interact in the mind. The results suggest that further research is needed in order to understand how music and language interact. The results of this study have pointed in two specific directions for future research in order to better understand this interaction: an experiment pairing anomalous musical phrases (such as those used in this study) with syntactically anomalous sentences and an experiment pairing resolvable musical phrases (such as those used in Slevc, Rosenberg, & Patel, 2009) with syntactically anomalous sentences. If the patterns of interaction are the same patterns observed in the present study, the Slevc, Rosenberg, & Patel (2009) study, and the Perruchet & Poulin-Charronnat (2013) study, there will be a greater body of evidence to support shared neural resources for syntactic processing in music and language. That evidence will lead to more research in order to better understand exactly how this interaction works and how that knowledge can benefit people in the future.

APPENDIX A

LINGUISTIC STIMULI

A.1 EXPERIMENAL SET 1

1. Mona saw the thief (that) the artist chased in the alley.
2. The boy noticed the cat (that) the dog followed down the street.
3. The chef stirred the sauce (that) the assistant made for the pasta.
4. The fish ate the plant (that) the girl put in the tank.
5. The bartender poured the drink (that) the customer ordered from the menu.
6. The catcher caught the ball (that) the pitcher threw in the third inning.
7. The first mate cleaned the knife (that) the fisherman used to gut the fish.
8. The housekeeper cleaned the floor (that) the children destroyed when they came inside.
9. Henry watched the drummer (that) the guitarist liked during the concert.
10. Marc bought the ring (that) his fiancée dreamed about for their engagement.
11. The man grilled the steak (that) the butcher gave him for his birthday.
12. The mechanic fixed the car (that) the man brought to trade in.
13. The author edited the chapter (that) the publisher disliked before the book was printed.
14. The girl saw the lobster (that) the fisherman caught before he sold it to the restaurant.

15. Jill found the bike (that) the thief stole from the child.
16. The travel agent booked the vacation (that) the client wanted to take with his family.
17. The real estate agent showed the house (that) the couple liked on Wednesday.
18. The pilot flew the plane (that) the engineer fixed after a rough landing.
19. The funeral director embalmed the body (that) the family wanted to display at the wake.
20. The conductor stopped the train (that) the people rode to fix a problem.
21. The specialist fixed the computer (that) the angry college student threw out the window.
22. The teacher stopped the lecture (that) the students were not enjoying.
23. The architect designed the building (that) the company wanted to move in to.
24. The police officer stopped the car (that) the girl was driving under the influence.

A.2 EXPERIMENTAL SET 2

1. The chef who wore the poofy hat remembered (that) the recipe would require using fresh basil.
2. The scientist wearing thick glasses confirmed (that) the hypothesis was being studied in his lab.
3. At the ceremony, the director who was very famous accepted (that) the award would go to his brother this year.
4. The fan of the rock band heard (that) the song on the website would be played during the concert next week.

5. After the trial, the attorney advised (that) the defendant was likely to commit more crimes.
6. The author with the glasses wrote (that) the novel about pirates was likely to be a best seller.
7. During finals week, the student forgot (that) the solution was in the book so worked on the problem all night.
8. At the end of the day, the apprentice to the carpenter learned (that) the skill was quite marketable in the city.
9. After physics class, the teacher recalled (that) the answer to the hard questions was written in the back of the book.
10. In the movie, the superhero who wore a flowing cape promised (that) the woman would not get away with the crime.
11. During the fourth day of the trial, the jury doubted (that) the witness would arrive to testify against the defendant.
12. During his lecture, the professor with a long beard revealed (that) the solution to the difficult problem was not correct and poorly written.

A.3 EXPERIMENTAL SET 3

A.3.1 Subject-extracted relative clause sentences

1. The bus driver who followed the kids wondered about the location of a hotel.
2. The chef who distracted the cameraman poured the flour onto the counter.
3. The children who woke the father bothered him about the trip to the beach.
4. The class that disliked the teacher skimmed the reading for the week.
5. The dancer that loved the audience ignored some basic principles.
6. The employees that noticed the fireman hurried across the open field.
7. The farmer that approached the customers lifted the chickens from their coop.
8. The farmer who hired the rancher piled the seeds in long rows.
9. The firemen that called the residents attacked the house with high-powered hoses.
10. The girl who watched the parents changed a critical part of the story.
11. The investigator who phoned the agency considered Ms. Reynolds from accounting.
12. The judge who addressed the witnesses noticed the defense attorneys.
13. The manager who visited the boss remembered some inconvenient facts.
14. The mathematician who visited the chairman created a solution to the well-known problem.
15. The monkeys that watched the zookeepers charged the bars of their cage.
16. The movie star who visited the organizers proposed an annual prize.
17. The neighbor who observed the couple purchased the old Victorian house.
18. The pilot who delayed the ground crew remained on the runway for a long time.
19. The soldiers that helped the natives climbed the big rock that blocked the path.
20. The speaker who entertained the economists predicted a good year for the industry.
21. The table top that rested on the box screwed directly to the legs.
22. The trainer who called the jockey rubbed the horse’s skin.

23. The veteran who admired the coach defeated his greatest rival.
24. The visitor who introduced the student walked across the quad.
25. The professor who annoyed the students arrived late to class.
26. The Uncle who loved the children bought a new house.
27. The runner that helped the team won a gold medal.
28. The singer that amused the audience played a new song.
29. The lawyer who convinced the judge received a bonus.
30. The giraffe that saw the boy ate leaves from a tall tree.
31. The bank teller who talked to the customer typed the account number.
32. The waitress who disliked the customer spilled coffee on the floor.
33. The students that liked the art teacher created clay sculptures.
34. The box that hid the cloth contained a small animal.
35. The snail that found the crab hid inside its shell.
36. The squirrel that saw the person ran up a nearby tree.
37. The resident who worked with the surgeon performed a new operation.
38. The actor that admired the director won a Tony for best performance.
39. The economist who believed the citizens accurately predicted the recession.
40. The conductor who loved the musicians debuted a new composition with the orchestra.

A.3.2 Object-extracted relative clause sentences

1. The bus driver who the kids followed wondered about the location of a hotel.
2. The chef who the cameraman distracted poured the flour onto the counter.
3. The children who the father woke bothered him about the trip to the beach.

4. The class that the teacher disliked skimmed the reading for the week.
5. The dancer that the audience loved ignored some basic principles.
6. The employees that the fireman noticed hurried across the open field.
7. The farmer that the customers approached lifted the chickens from their coop.
8. The farmer who the rancher hired piled the seeds in long rows.
9. The fireman that the residents called attacked the house with high-powered hoses.
10. The girl who the parents watched changed a critical part of the story.
11. The investigator who the agency phoned considered Ms. Reynolds from accounting.
12. The judge who the witnesses addressed noticed the defense attorneys.
13. The manager who the boss visited remembered some inconvenient facts.
14. The mathematician who the chairman visited created a solution to the well-known problem.
15. The monkeys that the zookeepers watched charged the bars of their cage.
16. The movie star who the organizers visited proposed an annual prize.
17. The neighbor who the couple observed purchased the old Victorian house.
18. The pilot who the ground crew delayed remained on the runway for a long time.
19. The soldiers that the natives helped climbed the big rock that blocked the path.
20. The speaker who the economists entertained predicted a good year for the industry.
21. The table top that the box rested on screwed directly to the legs.
22. The trainer who the jockey called rubbed the horse’s skin.
23. The veteran who the coach admired defeated his greatest rival.
24. The visitor who the student introduced walked across the quad.
25. The professor who the students annoyed arrived late to class.

26. The uncle who the children loved bought a new house.
27. The runner that the team helped won a gold medal.
28. The singer that the audience amused played a new song.
29. The lawyer who the judge convinced received a bonus.
30. The giraffe that the boy saw ate leaves from a tall tree.
31. The bank teller who the customer talked to typed the account number.
32. The waitress who the customer disliked spilled coffee on the floor.
33. The students that the art teacher liked created clay sculptures.
34. The box that the cloth hid contained a small animal.
35. The snail that the crab found hid inside its shell.
36. The squirrel that the person saw ran up a nearby tree.
37. The resident who the surgeon worked with performed a new operation.
38. The actor that the director admired won a Tony for best performance.
39. The economist who the citizens believed accurately predicted the recession.
40. The conductor who the musicians loved debuted a new composition with the orchestra.

A.4 FILLER SENTENCES

1. During the exam, the nervous student wrote hurriedly.
2. The new waitress accidentally spilled coffee all over the grouchy customer.
3. The students cheered when the class bell rang.
4. At the circus, fifteen clowns managed to fit into a Volkswagen Beetle.
5. The farmer was concerned about the lack of rain.

6. As the parade passed by the school, the kids cheered.
7. While the guard watched the television, the prisoner escaped.
8. As the musician practiced the violin, the baby cried.
9. The bored spectators jeered when the quarterback fumbled the ball.
10. The guy was so hungry, he ate three cheeseburgers and a milkshake.
11. The computer froze before the document was saved.
12. The weather forecast predicted rain, but it was a sunny day.
13. The baseball manager turned away and spat after the star player struck out.
14. The jury debated for three days before returning a guilty verdict.
15. After watching the movie, the critic wrote a negative review.
16. When the monster suddenly appeared, the audience shrieked.
17. While the dog chased the ball, the boy talked to his friends.
18. While at the zoo, the kid saw a bunch of monkeys eating bananas.
19. The old man was furious when the kids ran across his lawn.
20. The motivated student studied all night long, but then overslept and missed the test.
21. While the construction worker fixed the house, the family went on vacation to Florida.
22. As the professor lectured about the boring topic, the students tried to stay awake.
23. During the football game, my girlfriend went shopping and bought three pairs of shoes.
24. After the party last weekend, everyone felt terrible at work on Monday.

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