The Language of Music and Math: An Investigation of Cross-Domain Effects of Structural Priming

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The Language of Music and Math:
An Investigation of Cross-Domain Effects of Structural Priming

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Abstract

There is an ongoing debate as to whether the processing of complex systems (such as language, mathematics, and music) is domain-general or domain-specific. Language, math, and music all involve cognitive systems that organize discrete elements in a hierarchical manner. If processing is domain-general, then the structures of these systems would be processed using shared mental mechanisms. Previous studies suggest that language and math share mental mechanisms for building hierarchically structured representations in real time. This thesis explores the possibility that these mental mechanisms are also shared by the cognitive systems for processing music. An experiment was designed to reveal whether the structures of musical phrases and mathematical expressions can prime equivalent structures in English sentences. Participants listened to musical recordings and solved mathematical equations, after which they completed target sentence fragments that were structurally ambiguous with regard to relative clause attachment. Findings from this study could potentially impact the extent to which human language processing is seen as domain-general or domain-specific. If humans process the structures of musical phrases and math equations similarly to that of linguistic expressions, this would suggest that these domains share mental mechanisms.
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1. Introduction

The human mind represents and processes language by structuring its elements in a hierarchical manner. For the purposes of this thesis, the “elements” of language are considered to be words and phrases. Humans read or hear sentences as linear strings of words, but their minds create abstract hierarchical groupings to make sense of those words. The fundamental question behind this thesis is whether the mental mechanisms responsible for creating and processing this hierarchical abstraction are shared by other complex systems, specifically those that support the processing of mathematics and music.

Evidence for hierarchical structures in language comes from the observation that the meaning of a written statement or utterance can change purely as a result of the way in which its elements are hierarchically grouped. This is known as structural ambiguity because the ambiguous meaning arises from the multiplicity of structures that a sentence can have. For example, consider the sentence in (1), which is borrowed from Scheepers et al. (2011).

1) I visited the friend of a colleague who lived in Spain.

This sentence is ambiguous and can be interpreted in at least two ways. One interpretation is that the friend of the colleague is the one who lived in Spain. On the other hand, it could be that just the colleague lived in Spain. The difference between these two meanings can be represented structurally. In (1), the noun phrase a friend of a colleague contains a smaller noun phrase (a colleague) embedded within it. The larger noun phrase is the object of the verb visited. After this noun phrase appears a relative clause, who lived in Spain. The ambiguity of this sentence arises from the fact that the relative clause can attach to either the larger object noun phrase, or the smaller one embedded within it. The structure in (2a) conveys the interpretation that the friend of the colleague lived in Spain. In this case, the larger noun phrase
a friend of a colleague is the head of the relative clause who lived in Spain. In contrast, the structure shown in (2b) conveys the interpretation that the colleague alone lived in Spain. This is because the smaller embedded noun phrase a colleague is treated as the head of the relative clause who lived in Spain.

Because the relative clause attaches at a higher level of the hierarchy in (2a), this is an example of what Scheepers (2003) calls “high-attachment” structure. It is labeled as such because the relative clause modifies the entire noun phrase a friend of a colleague, which is represented at a higher point in the tree. By contrast, (2b) exemplifies “low-attachment” structure because the relative clause modifies the noun phrase a colleague that is represented lower in the tree.

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1 (2a) and (2b) are reprinted from Scheepers et al. (2011).
However, in certain cases, the possibility of different attachment sites for a restrictive relative clause does not always lead to ambiguity. Consider, for example, the sentence fragment in (3).

3) Scientists described the discovery of the remains that...

This fragment contains similar types of elements as the sentence in (1). It contains an object noun phrase (the discovery of the remains) in which is embedded a smaller noun phrase (the remains). The fragment ends with a relative pronoun that, implying that a relative clause would make it a complete sentence. Imagine for a moment that this fragment were completed as shown in (4).

4) Scientists described the discovery of the remains that was made last week.

This completion consists of a relative clause that was made last week which one can see unambiguously modifies the noun phrase the discovery of the remains. This noun phrase, like a friend of a colleague in (1), is the head of the relative clause that was made last week because the relative clause verb was agrees in number with the discovery. The verb was is singular in number, which allows one to conclude that it refers to the singular noun discovery and not the plural noun remains. Therefore, because the two noun phrases differ in number, the relative clause attachment is made unambiguous in this sentence by verb agreement. This is unlike the sentence in (1), in which both noun phrases (a friend of a colleague and a colleague) are singular in number, resulting in ambiguity regarding relative clause attachment. Since the relative clause in (4) refers to the larger noun phrase represented higher in the sentence’s structure, completing the sentence in this way makes it an example of high-attachment. Alternatively, it could be completed as in (5).
5) *Scientists described the discovery of the remains that were found near a mountain.*

Unlike (4), this sentence completion contains a verb in the relative clause that is plural in number (*were*). The plural relative clause verb *were* agrees with the plural noun *remains*. This verb agreement indicates that the relative clause attaches to the smaller embedded noun phrase *the remains*. Because the relative clause attaches to the noun phrase existing lower in the structure, this demonstrates low-attachment.

As these example sentences show, verb agreement is one of the factors that can determine the place of attachment for linguistic elements (such as relative clauses) that can appear at different levels in a hierarchical structure. The previous examples, for instance, demonstrate the importance of verb agreement in determining whether a relative clause attaches high or low in a sentence’s structure. Another factor that can determine structural attachment is semantic plausibility. For example, if one were presented with the sentence in (6), they would know that the relative clause verb phrase *was missing* refers to the first noun phrase *The key* rather than *the storage room* because it is much more likely for keys to be missing than rooms.

6) *The guard searched for the key to the storage room that was missing.*

This sentence is structurally ambiguous because both nouns (*key* and *storage room*) agree in number with the verb *was*. Therefore, the only factors determining one’s interpretation of this sentence are plausibility judgments of its two possible meanings. The reader ultimately concludes that the key is missing because it is the more realistic interpretation. This is not like (4) and (5), which do not require one to judge the plausibility of the meanings implied by the different structural attachment possibilities. It is also unlike (1), in which the meanings implied
by the different attachment possibilities are equally plausible (it is equally believable that either the friend or the colleague lived in Spain).

In addition to verb agreement and semantic plausibility, there is yet another factor that can affect how people interpret structurally ambiguous sentences such as the ones presented thus far. Certain interpretations can seem more favorable or more plausible purely based on the structure of previously encountered sentences or phrases. This phenomenon, referred to here as structural priming, is generally understood as the tendency to more easily process a structure that was recently experienced (Pickering & Branigan, 1999). For example, consider the pair of sentences in (6a). They are equivalent in meaning, but they have different syntactic constructions. The first is active, whereas the second is passive.

6a) The bird ate the worm. / The worm was eaten by the bird.

If someone were to hear the first (active) sentence spoken, they would be more likely to then produce a sentence with an active construction in a directly following utterance. This is because the active construction would be more highly activated in the listener’s mind, and thus more easily retrievable. Likewise, if they heard the second (passive) sentence, they would more likely produce a sentence with a passive construction. Such effects have been found in multiple studies (for example, Bock, 1986 and Weiner & Labov, 1983). This processing phenomenon is known by a variety of names, such as the one adopted here, ‘structural priming’ (Pickering & Ferreira, 2008), as well as ‘syntactic repetition’ (Bock, 1986) and ‘syntactic priming’ (Pickering & Branigan, 1999). This thesis uses the term ‘structural priming’ because it is less restrictive and leaves room for the possibility that priming can affect structural representations that are not strictly syntactic (Pickering & Ferreira, 2008). Structural priming effects in language have been found by many earlier studies, which are discussed in the next section on previous literature.
An important feature of structural priming in language is its ‘bidirectionality’; that is, it can occur between language comprehension and production (Branigan, Pickering, Liversedge, Stewart, & Urbach, 1995). Therefore, if one hears or reads a sentence, they are more likely to produce a sentence which exhibits a similar structure to that of the one previously experienced. This shows that the human mind creates abstract hierarchical structures that are not tied to the specific words in a sentence in order to make sense of language. Structural priming in production has been found in writing as well as speech, but the effect is only applicable if no additional stimulus comes between the priming sentence and the production of the written statement (Branigan, Pickering, & Cleland, 1999). The presence of such priming effects in a number of previous studies provides strong evidence for a key point expressed earlier in this thesis, that the mind creates structural abstractions to make sense of language. This is made clear by the fact that being exposed to a sentence can make one more likely to reproduce the structure of that sentence without necessarily reproducing any of the phonological or semantic qualities of the previous sentence (Bock, 1986; Pickering & Branigan, 1998).

This independent power over processing which syntax possesses relates to the principle of structural ambiguity discussed before with regard to high or low relative clause attachment. Consider again the sentence presented in (1), displayed again here for convenience: *I visited the friend of a colleague who lived in Spain.* It is ambiguous as to whether the relative clause *who lived in Spain* is attaching high (thereby modifying the larger noun phrase *a friend of a colleague*) or low (thus modifying the embedded phrase *a colleague*). Suppose someone were to first read or hear the sentence in (4), and then read or hear the sentence from (1). The sentence in (4), as seen earlier, has a relative clause that unambiguously attaches high. Thus, (4) would ‘prime’ the high-attachment structure and make one more likely to interpret the relative clause in
(1) as also attaching high, thereby conveying the idea that the friend of the colleague lived in Spain. This is an example of how structural priming can impact relative clause attachment. Likewise, if one were to hear the sentence in (5), in which the relative clause unambiguously attaches low, one would be more likely to interpret the relative clause in (1) as attaching low also.

It turns out that the type of linguistic structure that comprehenders build can also be influenced by non-linguistic stimuli, such as mathematical equations. This is due to the fact that solving math equations involves creating hierarchical representations similar to those created when processing language (Scheepers et al., 2011). This, along with other findings, has indicated that the mind represents non-linguistic systems (particularly mathematics and music) by ordering their elements in a hierarchical manner similar to language. If this is truly the case, then it might be expected that structures in math and music prime similar structures in language. Evidence of structuring priming effects across different domains that employ hierarchical representations supports the existence of domain-general mental mechanisms for processing. This is not to say that the structural representations in these systems are exactly the same, but that the mechanisms underlying the formation and processing of those representations are shared. The stance put forth here is that these systems may still create domain-specific structural representations in terms of their elements and the knowledge they represent, but that the mechanisms behind the processing of those representations is domain-general. This view has been suggested as a result of many neuroimaging studies finding shared activation while processing language and music (Patel, 2012).

These findings and their implications for the domain-generality of processing mechanisms inspired the experiment presented in this thesis. The experiment tested the theory
that non-linguistic complex systems which exhibit hierarchical structures (namely mathematics and music) can prime similar structures in language. This was measured by evaluating the ability of math equations and music examples to effectively prime high or low relative clause attachment in sentence fragments like the one shown in (3). The ways in which these systems exhibit hierarchical structure resembling linguistic syntax, along with previous findings regarding structural priming from math to language, are presented in the following section.

2. Discussion of Previous Literature

2.1 Structural Priming in Language

The effect of structural priming in language has been found in a number of earlier studies. Among the first of these is Bock (1986), in which the presence of ‘syntactic repetition’ was found to determine the production of active versus passive constructions (shown in (6a)), as well as prepositional dative versus double object dative constructions. Participants had to listen to a priming sentence, repeat it back through speech, and describe an action shown in a picture. For example, for the active and passive sentences, the pictures displayed a scene in which an agent was performing an action on a patient. The scene could have been described equally well using an active or passive construction. It was found that if participants heard a priming sentence with an active construction, such as the one in (7a), they were more likely to use an active construction in describing the picture presented thereafter. If the prime exhibited a passive construction, such as (7b), they were more likely to describe the action in the picture with a passive construction.

7a)  A gunshot shattered the forest’s stillness.

7b)  The forest’s stillness was shattered by a gunshot.
Bock found similar priming effects for two types of dative constructions, prepositional (8a) and double object (8b).

8a) The lifeguard tossed a rope to the struggling child.
8b) The lifeguard tossed the struggling child a rope.

Evidence for structural priming has also been found in speech production outside an experimental setting. Weiner and Labov found such effects on choice of active versus passive constructions, such as in (7a-b) (1983). A study using data from the British component of the International Corpus of English (ICE-GB) found priming effects on producing the two types of dative constructions shown in (8a-b) that were similar to those found experimentally (Gries, 2005). These findings are important because they suggest that priming is a very natural (and seemingly implicit) process that occurs in normal linguistic communication.

Structural priming effects such as these have been shown to occur in written language production as well (Pickering & Branigan, 1998; Branigan, Pickering, & Cleland, 1999). The presence of a priming effect was evaluated based on the constructions participants used to complete sentence fragments after reading a priming sentence. The priming constructions used in these studies are identical to those in (8a-b). Priming effects in written production have also been found with regard to high or low relative clause attachment of the kind discussed earlier. In a study by Scheepers, German priming sentences were used that matched the form of those in (4) and (5) above. In these sentences, the object noun phrase of the main verb contained a smaller noun phrase embedded within it, and the relative clause that followed could either attach high, thus modifying the larger noun phrase (4) or low, thus modifying the embedded noun phrase (5). However, unlike (4) and (5), whose relative clause attachment is made unambiguous by the nouns’ number, the attachment in Scheepers’ primes was made unambiguous by the nouns’
gender. This same study also found a priming effect on high- versus low-attachment with regard to adverbial clauses. The relative clause priming sentences were modified to appear like the one shown in (9), in which an adverbial clause contains a pronoun that co-indexes either the larger object noun phrase or the one embedded in it.

9) Don envied the servant of the actress because (he / she) was abroad all the time.

Unlike previous studies involving syntactic priming, Scheepers added baseline priming sentences that did not resemble either high- or low-attachment. This was crucial because it allowed for more precise measurement of the effectiveness of high- versus low-attachment primes.

As these various studies show, priming is not exclusive to one type of syntactic structure. Importantly, it also occurs regardless of a sentence’s semantic content, a property of priming described by Bock as the ‘isolability of syntactic repetition’ (1986). This is reinforced by Pickering and Branigan, who found evidence that priming occurs regardless of the semantic content encoded in the verb of a priming sentence (1998). In light of these findings, some have questioned whether priming is not just an example of short-term memory for patterns. A later study with a similar procedure found evidence contradicting the possibility that priming has a basis in short-term memory rather than being a reflection of a higher-level cognitive mechanism for creating syntactic structure (Bock & Griffin, 2000). This was studied by comparing priming effects over different time lag conditions. In each condition, participants were exposed to a different amount of filler sentences between the priming sentence and the picture they had to describe. For example, in the condition with no lag, the participants heard two filler sentences, then the priming sentence, and were then shown a picture. In the first lag condition, they heard the prime, then a filler, and then saw the picture. In the second lag condition, they heard two
fillers between the prime and seeing the picture. It was found that priming effects did not differ significantly across these time lags. This does not support a theory of priming as a function of short-term memory; rather, it reinforces the idea that priming is a robust effect caused by the presence of a higher-level mechanism for creating and processing hierarchical structure.

All these findings of structural priming reinforce the reality that, during comprehension and production of language, the minds of humans construct abstract representations that are independent of semantic content or individual lexical items.

2.2 Priming by Non-linguistic Hierarchical Structure

What is particularly interesting and pertinent to the current study is the fact that non-linguistic expressions that exhibit hierarchical structure resembling linguistic syntax have been shown to effectively prime similar structures in language. Scheepers et al. (2011) found effects of structural priming from a non-linguistic domain (specifically math) to language. Their claim was that mathematical equations are mentally represented by ordering their elements in hierarchical structures that are similar to those of language. This was motivated by the existence of operator precedence rules in math, which determine the order in which certain operators should be applied when solving an equation. For example, elements (such as numbers or variables) enclosed within parentheses must be dealt with first. Elements bound by division or multiplication receive next highest precedence, and lastly elements bound by subtraction or addition. The theory put forth by Scheepers et al. was that equations exhibit hierarchical structure corresponding to the order in which each operator in an equation must be applied. For example, consider the following equation: $80 - (9 + 1) \times 5$. It can be represented hierarchically based on the order in which portions of the equation are solved, shown in (10a). The elements enclosed in parentheses and joined by addition, $(9 + 1)$, must be addressed first, and thus form
the ‘addition phrase’ presented lowest in the structure. The number 5 appears at the next highest level of the structure, joining to the addition phrase in parentheses by multiplication, which comes next in the order of operations. The addition phrase and the number 5 thus form a ‘multiplication phrase’. Finally, the number 80 appears highest in the structure and forms a ‘subtraction phrase’ with the multiplication phrase because subtraction is the last operation to be performed. The hierarchy presented in (10a) thus represents the order in which one would solve the equation, beginning with the elements in the lowest operator phrase. The diagram in (10b) illustrates hierarchical groupings for the equation \(80 - 9 + (1 \times 5)\), which are also built upon the same operator precedence principles. In this equation, the expression in parentheses, \((1 \times 5)\), form a multiplication phrase. This multiplication then forms an addition phrase with the number 9 because the product of \((1 \times 5)\) is added to 9. Finally, the addition phrase forms a subtraction phrase with 80, because the sum from the addition phrase is subtracted from 80 to solve the equation.

\[\text{10a) } 80 - (9 + 1) \times 5 \]
\[\text{10b) } 80 - 9 + (1 \times 5)\]

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\(^2\) (10a-b) are reprinted from Scheepers et al. (2011).
The way in which elements are combined to form operator phrases in math is similar to
the way in which words combine to form phrases in language. Specifically, the tree diagrams
presented in (10a-b) can be equated with the linguistic structures shown in (2a-b). The structures
in (2a-b) differ based on the place of relative clause attachment (high or low) in a sentence. In
much the same way, the structures in (10a-b) differ based on multiplication phrase attachment
(high or low) in an equation. For example, the addition phrase \((9 + 1)\) from (10a) functions
similarly to the noun phrases a friend of a colleague in (2a) and the discovery of the remains in
(4). The number 5 then functions in a structurally similar way to the relative clause in both (2a)
and (4) because it attaches “high” in the hierarchy and modifies the entire \((9 + 1)\) addition
phrase. Therefore, (2a) and (4) exemplify high-attachment structure in language, and (10a)
demonstrates this same structure in math. By contrast, in (10b), the numbers 9 and 1 belong to
separate phrases (the former to an addition phrase and the latter to a multiplication phrase). The
number 5 is joined only to the 1 by multiplication, and consequently both exist at a lower level in
the hierarchy. In this equation, the number 1 has a function similar to that of the noun phrases a
colleague in (2b) and the remains in (5). Therefore, (10b) represents low-attachment structure in
math in much the same way that (2b) and (5) represent low-attachment in language.

Taking into account these superficial structural similarities between math and language, it
was found that math equations exhibiting high- or low-attachment structure could effectively
prime equivalent high versus low relative clause attachment in the written completion of
sentence fragments (Scheepers et al., 2011). As in Scheepers (2003), these priming effects were
measured relative to a baseline. Baseline priming equations were structurally irrelevant; in other
words, they did not exhibit either high- or low-attachment structure as shown in (10a-b). As one
might presume from the discussion on hierarchical structure in math, one must have adequate
knowledge of operator precedence rules to be subject to priming effects by mathematical equations. For this reason, Scheepers et al. screened their participants to ensure that they had such knowledge before beginning the experiment.

The presence of structural priming effects of math equations on relative clause attachment in English found by Scheepers et al. (2011) suggests that math and language share mental mechanisms for structural representation and processing.

3. The Present Study

The current study explores the ubiquity of domain-general processing by investigating whether music can trigger structural priming effects on language just like math. Some scholars have posited that the mental processing of music requires the ability to order its elements in a hierarchical manner like language (Lerdahl & Jackendoff, 1983; Lerdahl, 1988; Rohrmeier, 2011; Van de Cavey, 2011; Fitch & Martins, 2014). If this is true, one might expect to find priming effects of music to language just as these effects were found to occur from math to language. This would suggest that music, too, shares processing mechanisms with language.

One of the first to make a claim about the likeness of musical structure to linguistic syntax was Lerdahl (1988). His “Generative Theory of Tonal Music” from 1988 was an attempt to improve upon an earlier theory of the same name created by him and Jackendoff (Lerdahl & Jackendoff, 1983). It is important to note that Lerdahl and Jackendoff’s claims made about music (as well as all claims made in this thesis) only refer to the Western tonal music system, which arose out of western Europe and has influenced many other areas around the world. Before providing specific examples explaining how musical structure may resemble that of language, it is important to explain the basis for why music has structure at all. In the Western
tonal system, every musical creation has a single note, or “tonic”, that provides a harmonic context in relation to which all other notes in the piece of music are perceived. The tonic can be thought of as a sort of “home” that the piece’s harmonic progression generally wants to return to. Groups of notes combine to form chords, and each chord has one note that is the “root” and determines how the chord is named. Groups of chords combine to form harmonic progressions. Within this harmonic progression, certain chords are more closely tied to each other based on the harmonic tension that one chord creates and the way that another chord resolves that tension. Feelings of harmonic tension and relaxation between chords are purely a function of the harmonic context generated by the tonic. That is, if a certain chord creates a lot of tension in a certain harmonic context, it will sound most satisfying if it is followed by the chord that resolves the tension in the best way possible for that context. This tension and relaxation is essential to Lerdahl’s theory of structure in music, and is what allows chords to be grouped in a hierarchical phrase structure that resembles language.

Expanding upon the pre-existing literature describing why music exhibits hierarchical structure, one can apply the harmonic tension-relaxation theory to the high- and low-attachment structures. Earlier, examples were provided of these structures in language (see (2a-b), (4), and (5)) and math (see (10a-b)). Now, it is shown how these structures are realized in music. Assuming that harmonic progressions do indeed consist of hierarchically ordered chords, as sentences consist of hierarchically ordered phrases and words, one could propose the following tree diagrams to show how high-attachment (11a) and low-attachment (11b) patterns might be realized in music. Both of these examples are harmonic progressions placed in the harmonic context of the tonic, C. “C major” in this case is the chord whose root is the tonic. In the first progression, C major – A7 – D minor – G major – C major, each chord produces a different level
of tension in the harmonic context of C. For example, A7 and D minor do not produce as much tension that is relevant to the tonic (C) as G major does. In the Western tonal system, G major naturally produces a high amount of harmonic tension that is resolved extremely well by C major. Likewise, A7 produces a high amount of tension which D minor resolves very well, but this tension and relaxation relationship is not very relevant to the context of C. Therefore, because A7 and D minor are more closely related to each other than to the rest of the chords in the progression, they form the “D minor phrase”, which functions similarly to a friend of a colleague in (2a), the discovery of the remains in (4), and (9 + 1) in (10a). Thus, Figure (11a) illustrates high-attachment. By contrast, the progression in Figure (11b) contains a D minor phrase that acts like a colleague in (2b), the remains in (5), and (1 x 5) in (10b), thereby illustrating low-attachment.

11a)³

C major – A7 – D minor – G major – C major

\[ C \]
\[ C \]
\[ G \]
\[ C \]
\[ Dm \]
\[ G \]
\[ A7 \]
\[ Dm \]

11b)

C major – G major – C major – A7 – D minor

\[ C \]
\[ G \]
\[ A7 \]
\[ C \]
\[ Dm \]
\[ A7 \]
\[ Dm \]

³ (11a) is reprinted from Rohrmeier (2011).
Others have supported the idea that harmonic tension and relaxation are the basis for hierarchical structure in music that resembles language (Rohrmeier, 2011; Van de Cavey, 2011). The question remains whether the minds of humans actually represent music in this way. There is evidence from neuroimaging studies for activation in the same areas of the brain while listening to music and during the processing of linguistic syntax (Fitch & Martins, 2014; Patel, 1998; Patel, 2003). However, shared activation does not necessarily indicate that language and music (and possibly math) share mechanisms for structural representation or processing. The experiment presented by this thesis was carried out in order to offer experimental evidence regarding this question of whether different complex systems exhibiting hierarchical structure (including, but not limited to, language, math, and music) share cognitive mechanisms for creating and processing that structure.

4. Experiment

4.1 Overview

The experiment reported in this thesis tested the hypothesis that high- and low-attachment structures in math and music can prime equivalent structures in written language production. In order to provide a baseline off of which to interpret any findings regarding music, the experiment sought to replicate the cross-domain priming effects found by Scheepers et al. (2011). Priming effects of music were investigated using the same methods used to investigate the effects of math; that is, all primes (math and music) were followed by a target sentence fragment which participants had to complete. This template for prime-target pairs is similar to those used in previous studies (Pickering & Branigan, 1998; Branigan, Pickering, & Cleland, 1999; Scheepers, 2003; Scheepers et al., 2011), except that the music priming items were experienced aurally rather than visually. If structures in both math and music have a priming effect on linguistic
ones, this lends support to two main theories. The first is that music exhibits hierarchical structure resembling that of language (and possibly mathematics), as posited by Lerdahl (1988), Rohrmeier (2011), and Van de Cavey (2011). The second is the broader-reaching theory that the mental mechanisms underlying the representation and processing of linguistic (and possibly mathematical) hierarchical structure are also shared by music.

4.2 Participants

The participants for this study were 30 undergraduate students from the College of William and Mary. These participants represented a variety of different academic disciplines and backgrounds. All 30 were native speakers of English and were pre-screened for knowledge of basic mathematical operator precedence rules. This pre-screening consisted of six math equations that were simple but roughly resembled the types of equations participants would see in the experiment. They required exact knowledge of operator precedence in order to be solved correctly. For example, one of the equations was as follows: $17 - 8 \times 2 + 1 = \_\_\_$. In order to solve this correctly, participants had to know that they could not just apply operators in a linear fashion; rather, the multiplication between the numbers in the middle (8 and 2) had to be applied before anything else. If participants provided incorrect answers for any of these equations, they were shown how to solve the equation correctly and were reminded of proper precedence rules. After completing the experiment, they were asked to complete a questionnaire designed to assess their musical experience. Participants’ musical experience was evaluated in terms of what musical instruments (if any) they had studied, what types of ensembles they had performed in, or what music courses they had taken. This information was recorded in the interest of determining whether studying or performing music has any influence over the extent to which musical phrases can have a structural priming effect on language.
4.3 Design

Forty-eight sets of test items were created. Each set consisted of a target sentence fragment which was paired with one of six possible primes: a high-attachment (HA) math equation and music example, a low-attachment (LA) math equation and music example, and a baseline (BL) math equation and music example. Therefore, the three structural priming conditions (HA, LA, or BL) were equally represented across both types (math or music). The target sentence fragments were in the same format as the sentences in (4) and (5), in which an object noun phrase containing a smaller embedded noun phrase was followed by a relative pronoun (that for inanimate noun phrases or who for animate). The two nouns within the object noun phrase were both either animate or inanimate, and differed in number to reduce the possibility of ambiguous relative clause attachment. This format matches the target sentence fragments created by Scheepers et al. (2011) for their study. Appendix A shows the math priming equations and target sentence fragments, and Appendix C shows the music primes written out in lead-sheet notation.

The priming mathematical equations were created in an effort to make them solvable without the aid of a calculator, while still requiring correct knowledge of operator precedence rules. High-attachment and low-attachment equations resembled those used by Scheepers et al. (2011) in their second experiment, in which redundant parentheses were placed around elements of the equation joined by multiplication or division operators. For example, high-attachment equations appeared as such: \( 2 + \left( \frac{3 + 30}{3} \right) \), in which the redundant parentheses are the outermost ones encompassing the two elements joined by division. Low-attachment equations appeared as such: \( 2 + 3 + \left( \frac{30}{3} \right) \), in which the parentheses are again redundant by encompassing the elements joined by division. This was done as a visual cue to prevent against
the possibility that participants would accidentally violate precedence rules. Baseline equations were created to be structurally irrelevant in terms of priming effect, and were intended to be only visually similar to the structurally relevant primes. For example, a baseline equation would have appeared as such: \((2 + 3) + (30 / 3)\). This is structurally dissimilar to the high-attachment and low-attachment structures because it contains two phrases, \((2 + 3)\) and \((30 / 3)\), that hold an equal level in the equation’s hierarchy. The first two operators in all math equations were either addition or subtraction, and the third was either multiplication or division.

The music examples were MIDI sound files created using Apple GarageBand software and were presented in the experiment in MP3 format. All files consisted of a simple melody as well as an accompaniment that provided rhythmic and harmonic context. A MIDI piano sound built in to GarageBand was used for both the melody and accompaniment on all test item musical examples. All 12 major key signatures were equally represented across the music examples. Each example had a time signature of 4 beats per measure (4/4), a tempo of 120 beats per minute (which is considered a standard, neutral tempo), and lasted 11 seconds. The examples had five distinct harmonic units (or chords) which lasted one measure each, thereby making each musical example five measures long. High-attachment music examples exhibited a structure like that in Figure (3a), in which the progression of harmonic units matched this framework: \(I \rightarrow V7/\text{ii} \rightarrow \text{ii} \rightarrow V \rightarrow I\). Low-attachment music examples possessed a structure like the one shown in Figure (3b), in which the harmonic progression was as follows: \(I \rightarrow V \rightarrow I \rightarrow V7/\text{ii} \rightarrow \text{ii}\). Baseline music examples, like the math equations, were designed to be structurally irrelevant with regard to priming effect. Therefore, these music examples possessed a structure that was unlike those found in either the high- or low-attachment examples in that harmonic units joined to form phrases that were at equal levels in the hierarchy (like the baseline math equations).
Ninety-six filler prime-target pairs were created in addition to the 48 test items. Half of these fillers contained math equations as primes (shown in Appendix B), while the other half contained music examples as primes (shown in Appendix C). These primes were created to be structurally irrelevant, much like the baseline primes in the test items. The math filler primes appeared superficially similar to the test primes by having the same amount and types of operators and parentheses. For example, \((11 - (2 + 6)) \div 3\) follows the typical structure of a math filler prime. This equation, although appearing roughly similar to the test primes, is structurally irrelevant to the priming effect investigated in this study because the ordering of its elements and phrases does not resemble high- or low-attachment structure. Like the test primes, the filler equations contained two operators that were either addition or subtraction, followed by one operator that was either multiplication or division. The music filler primes contained harmonic progressions that were structurally irrelevant to the priming effects investigated and exhibited structures that do not resemble high- or low-attachment. They exhibited one of three structurally irrelevant harmonic unit progressions: I – IV – I – V – I, I – V – IV – V – I, or I – vi – IV – V – I. As in the test primes, each harmonic unit (or chord) lasted for one measure, resulting in a total of five measures per music example. Three different progressions were used (rather than just one) to introduce some variety and to prevent participants from noticing a pattern among music primes in general. Like the test items, the filler music examples contained a simple melody with harmonic accompaniment created using the same MIDI piano sound provided by GarageBand. Also like the test items, the filler examples equally represented all 12 major key signatures, had a time signature of four beats per measure, had a tempo of 120 beats per minute, and were approximately 11 seconds long. Four of these fillers included an additional electronic harmonic accompaniment found as a preset in GarageBand. This was added to these
fillers in an effort to introduce some slight variety. The assumption was that since the fillers are structurally irrelevant in terms of any possible priming effect, it would be acceptable to introduce a small amount of textural variety in their harmonic accompaniment.

4.4 Procedure

The 48 test items were presented in a Latin-square design, so that participants only saw each target sentence fragment once. Therefore, each participant saw only one of six possible prime-target pairs (High-attachment math, low-attachment math, baseline math, high-attachment music, low-attachment music, or baseline music) for each of the 48 test items. The 96 filler items were randomly mixed in with the 48 test items, such that participants completed between 1 and 4 fillers before seeing the next test item. The experiment was hosted on Ibex Farm, a website for hosting and running experiments. Participants completed the experiment on a computer in a sound-proof booth in the Computational and Experimental Linguistics Lab (CELL) at the College of William and Mary. They were asked to type their answers to the math equations and their completions of the target sentence fragments. Music examples were played through headphones, which participants were asked to keep wearing until they finished the experiment. Only one prime-target pair was presented on the computer monitor at a time. Participants proceeded from one item to the next by clicking a link with the words “Click here to continue” shown below each target sentence fragment. Items containing math primes appeared as shown in (12a), in which the math equation was shown above the target sentence fragment. For items containing music primes, the music example played automatically, but the target sentence fragment was hidden. Participants were instructed to click the link to reveal the sentence fragment only after the music example had finished playing. The image in (12b)
displays what participants saw while the music example was playing (above the arrow) and after
the music had finished playing (below the arrow).

12a)

Before the experiment, participants were screened for knowledge of basic mathematical
operator precedence rules and completed a short test to ensure that they were native English
speakers. The test for knowledge of precedence rules is described earlier in section 4.2 –
Participants. After completing the experiment, participants completed another questionnaire
designed to determine their general experience with music over the course of their lives. These
data were collected to see if there might be any connection between one’s musical experience or
expertise and priming effects of the music examples. It turned out that all but one of the
participants reported having some amount of previous musical experience. Additionally, only one participant was a music major.

4.5 Data Coding

The completions which participants provided for target sentence fragments were coded based on a syntactic analysis of those completions: “HA” (high-attachment), “LA” (low-attachment), or “?” (irrelevant or unclassifiable, based on criteria described below). In order for a sentence completion to be coded as “HA” or “LA”, it had to refer unambiguously (either by verb agreement or semantic plausibility) to one of the object noun phrases in the target fragment. Completions that were ambiguous as to which noun phrase they modified, were grammatically incorrect, or that were structurally irrelevant (neither HA nor LA) were coded as unclassifiable ("?").

Answers provided to priming math equations were coded for being correct or incorrect. There were a couple test item equations for which no answer appeared to be input. These cases were regarded as errors on the participants’ part and were coded as “?” (unclassifiable).

4.6 Data Analysis

The data from this experiment were analyzed using R. As well as computing proportions of each type of sentence completion across priming conditions, the differences between the proportion of HA and LA sentence completions were also computed for each priming condition (HA math, LA math, BL math, HA music, LA music, and BL music). Two-sample t-tests were used to measure significance between the proportions of HA and LA sentence completions across priming conditions, as well as the difference between these proportions for each priming condition. This was done to evaluate the priming effect exercised by each condition. Thus, to
obtain the differences in proportion of HA and LA sentence completions, the proportion of sentence completions coded as “LA” was subtracted from the proportion of completions coded as “HA” for each priming condition. This difference gives an indication as to how much of an effect a certain priming structure (HA or LA) had. The two-sample t-test was used so that the proportions and proportion differences could be compared for pairs of priming conditions; for example, between the HA music condition and the BL music condition. Results from a t-test performed on the proportion differences (HA – LA) in these two conditions (HA and BL) would demonstrate the significance of the differences between HA and LA completions in the HA and BL music conditions. This significance is used as measure of the degree to which HA music primes more effectively primed HA structure than BL music primes. The results reported here include the computed differences in proportion of each sentence completion type across conditions, as well as results from the t-tests.

4.7 Results of Initial Analyses

The overall proportions of each sentence completion type (HA, LA, or unclassifiable(“?”)) were calculated by priming condition. These proportions are shown for the math conditions in Table 1 and for the music conditions in Table 2. On average, across all conditions, 31% of completions were HA, 47% were LA, and 22% were unclassifiable.

Statistical analyses of the proportions of HA and LA completions in the math conditions (Table 1) revealed no significance. Specifically, the proportions of HA and LA completions did not differ significantly between the HA and LA priming conditions ($p = 0.99$), between the HA and BL conditions ($p = 0.85$), or between the LA and BL conditions ($p = 0.83$). The same was found for the proportions of HA and LA completions in the music conditions (Table 2). There was no significant difference between the proportions of HA and LA completions between the
HA and LA priming conditions ($p = 0.89$), the HA and BL conditions ($p = 0.95$), or the LA and BL conditions ($p = 0.92$).

Table 1: Proportions of Sentence Completion Types by Priming Condition (Math)

<table>
<thead>
<tr>
<th>Priming Condition</th>
<th>HA</th>
<th>LA</th>
<th>?</th>
</tr>
</thead>
<tbody>
<tr>
<td>HA priming condition</td>
<td>0.286</td>
<td>0.498</td>
<td>0.216</td>
</tr>
<tr>
<td>LA priming condition</td>
<td>0.292</td>
<td>0.496</td>
<td>0.212</td>
</tr>
<tr>
<td>BL priming condition</td>
<td>0.308</td>
<td>0.421</td>
<td>0.271</td>
</tr>
</tbody>
</table>

Table 2: Proportions of Sentence Completion Types by Priming Condition (Music)

<table>
<thead>
<tr>
<th>Priming Condition</th>
<th>HA</th>
<th>LA</th>
<th>?</th>
</tr>
</thead>
<tbody>
<tr>
<td>HA priming condition</td>
<td>0.342</td>
<td>0.429</td>
<td>0.229</td>
</tr>
<tr>
<td>LA priming condition</td>
<td>0.305</td>
<td>0.502</td>
<td>0.192</td>
</tr>
<tr>
<td>BL priming condition</td>
<td>0.338</td>
<td>0.442</td>
<td>0.221</td>
</tr>
</tbody>
</table>

After failing to find significance from these analyses, the proportions of completion type across priming conditions were then calculated for each individual test item. Many items were found in which more than 30% or 40% of their completions were unclassifiable. In particular, there were three items for which 50% or more of their completions were unclassifiable. Statistical analyses were then performed on the data without these three problem items to determine if their removal would reveal any significance in these unpromising data (discussed in 4.8 – Post-hoc Analyses).

Additionally, comparisons of the differences in overall proportions of HA and LA sentence completions (that is, the LA proportions subtracted from the HA proportions) in both the math and music priming conditions indicated the presence of an overall low-attachment bias, which is in line with previous findings (Scheepers, 2003; Scheepers et al., 2011). This means
that participants had an overall tendency to provide low-attachment sentence completions. These differences are shown in Table 3.

Table 3: Differences in Proportion of HA and LA Sentence Completions by Priming Condition

<table>
<thead>
<tr>
<th></th>
<th>HA</th>
<th>LA</th>
<th>BL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Math</td>
<td>-0.21</td>
<td>-0.20</td>
<td>-0.11</td>
</tr>
<tr>
<td>Music</td>
<td>-0.09</td>
<td>-0.20</td>
<td>-0.10</td>
</tr>
</tbody>
</table>

A comparison of these differences in proportions of HA and LA sentence completions were not found to be significant between the HA and LA priming conditions for both math and music ($p = 0.56$), between the HA and BL conditions ($p = 0.59$), or between the LA and BL conditions, although this last comparison approached significance ($p = 0.03$). For math, the differences in the HA and LA conditions were virtually the same (-0.21 and -0.20, respectively), and both were lower than the baseline (-0.11), meaning that there were more HA sentence completions after BL priming equations than after HA or LA priming equations. For music, a comparison of the differences in proportions of sentence completion types revealed a trend which was more consistent with the hypothesis that musical structure can prime linguistic structure. The difference in the high-attachment music condition was -0.09, whereas the difference in the low-attachment condition was -0.20, with the baseline sitting in between the two at -0.10. Therefore, the difference in the high-attachment music condition was higher than both the baseline and low-attachment differences. Unlike the math conditions, this shows that more HA sentence completions followed HA primes than LA and BL primes.

4.8 Post-hoc Analyses

Approaching the data from a different perspective, the overall proportions of completion types were again calculated, this time with the three problem items removed from the data set.
There was no change in the average proportions across priming condition after the removal of these items: 31% were HA, 48% were LA, and 20% were unclassifiable. Table 4 shows these proportions across math priming conditions and Table 5 shows them across music priming conditions. For math, comparisons of the proportions of HA and LA sentence completions showed no significance between the HA and LA priming conditions ($p = 0.95$), the HA and BL conditions ($p = 0.81$), or the LA and BL conditions ($p = 0.88$). Likewise, comparisons of the proportions of HA and LA completions were not significant among the music priming conditions. This was the case for comparisons of proportions between the HA and LA priming conditions ($p = 0.90$), the HA and BL conditions ($p = 0.95$), and the LA and BL conditions ($p = 0.88$).

The differences in overall proportions of HA and LA completions across all priming conditions was also re-calculated after removing the three problem items (shown in Table 6). There was no change in these differences in the math conditions (high-attachment: -0.22, low-attachment: -0.24, baseline: -0.12). However, there was a change in the differences among the music conditions, with the high-attachment difference becoming -0.10, the low-attachment -0.22, and the baseline -0.14.

Table 4: Proportions of Completion Types by Priming Condition with Items Removed (Math)

<table>
<thead>
<tr>
<th>Priming Condition</th>
<th>HA</th>
<th>LA</th>
<th>?</th>
</tr>
</thead>
<tbody>
<tr>
<td>HA priming condition</td>
<td>0.305</td>
<td>0.522</td>
<td>0.173</td>
</tr>
<tr>
<td>LA priming condition</td>
<td>0.284</td>
<td>0.520</td>
<td>0.196</td>
</tr>
<tr>
<td>BL priming condition</td>
<td>0.317</td>
<td>0.438</td>
<td>0.246</td>
</tr>
</tbody>
</table>
Table 5: Proportions of Completion Types by Priming Condition with Items Removed (Music)

<table>
<thead>
<tr>
<th>Priming Condition</th>
<th>HA</th>
<th>LA</th>
<th>?</th>
</tr>
</thead>
<tbody>
<tr>
<td>HA priming condition</td>
<td>0.347</td>
<td>0.444</td>
<td>0.209</td>
</tr>
<tr>
<td>LA priming condition</td>
<td>0.304</td>
<td>0.522</td>
<td>0.174</td>
</tr>
<tr>
<td>BL priming condition</td>
<td>0.319</td>
<td>0.460</td>
<td>0.221</td>
</tr>
</tbody>
</table>

Table 6: Differences in Proportion of HA and LA Sentence Completions by Priming Condition with Items Removed

<table>
<thead>
<tr>
<th>Priming Condition</th>
<th>HA</th>
<th>LA</th>
<th>BL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Math</td>
<td>-0.22</td>
<td>-0.24</td>
<td>-0.12</td>
</tr>
<tr>
<td>Music</td>
<td>-0.10</td>
<td>-0.22</td>
<td>-0.14</td>
</tr>
</tbody>
</table>

Using the data without the three problematic items, a series of two-sample t-tests were performed on the differences between HA and LA sentence completions across all participants comparing the high-attachment priming condition to both the low-attachment and baseline conditions for both math and music. None of these tests revealed any significance between differences in the two conditions they were testing. Differences between HA and LA completions in the HA math condition were not significant compared to those in either the LA math condition ($p = 0.90$) or the BL condition ($p = 0.30$). This same pattern was found for the music conditions as well. Differences between HA and LA completions in the HA music condition were not significant compared to those in either the LA condition ($p = 0.26$) or the BL condition ($p = 0.68$).

Having found no significance using these approaches, the same two-sample t-tests were performed again, but using only the data from participants who showed a difference in HA and LA completions that was smaller than or equal in magnitude to 0.15 in the baseline math and music priming conditions. This was done because the proportions of HA and LA completions in
the baseline condition were expected to be as similar as possible, since the baseline was designed
to have no particular priming effect. After conducting these tests, none of the results were
significant. The differences in the HA math condition were not significant compared to those in
either the LA condition \((p = 0.84)\) or the BL condition \((p = 0.38)\). The same pattern was found in
the differences between the HA music condition and the LA condition \((p = 0.17)\) as well as the
BL condition \((p = 0.90)\).

4.9 Discussion

The results of this experiment are inconclusive and somewhat conflicting in that analyses
of different measures yielded numbers that varied in their distances above the threshold of
significance \((p < 0.01)\). This inconsistency within the data suggests that the experimental design
was flawed. The results show that the priming effect of math equations found by Scheepers et al.
(2011) was not replicated. Furthermore, no significant priming effect by the music examples
was found. This is made evident by the results of the tests performed on the differences in each
music priming condition listed above. A possible reason for this may be the fact that there were
many items for which the sentence completions provided by participants were coded as
unclassifiable. Because so many were unclassifiable, this diminished the proportions of
classifiable (HA or LA) completions and skewed the data.

The next section examines various aspects of the experiment’s design in order to provide
potential explanations for why the results turned out to be problematic. It consists mainly of
critiques regarding the creation of priming items and target sentence fragments, and offers
alternative approaches to creating items that are as free as possible of any ambiguity or structural
attachment bias.
5. General Discussion

The goal of this study was to investigate the question of whether complex cognitive systems that exhibit hierarchical structure (namely language, math, and music) share mechanisms for structural representation and processing. Motivated by previous studies suggesting that math and music order their elements hierarchically, an experiment was designed to test the hypothesis that high- and low-attachment hierarchical structures in math and music can prime similar structures in language. The existence of such priming effects would have suggested that structural processing mechanisms are indeed shared by these different systems, and any other cognitive domain that possesses hierarchical structure. However, no such priming effects were found from the results, most likely because of potential design flaws in the experiment.

In light of the results reported here, it is important to discuss possible reasons for why the data proved to be inconclusive. These reasons are most likely due to errors in the design of the experiment, particularly with regard to the methods used to create items. For example, the decision to allow the filler music examples to represent some slight variety in terms of the chord progressions they used, in hindsight, was certainly not wise. It is impossible to say whether this had a negative effect on participants’ performance in the experiment. However, it still would have been better to have complete continuity among the filler music items to avoid bias for any particular chord progression.

It was also found that the best target sentence fragments were ones in which the main verb could apply equally well semantically to either noun phrase in the relative clause. These sentences were ones that either had the least unclassifiable sentence completions or which did not show a large bias for one type of completion over the other. For example, for the sentence
fragment shown in (13), the tour guide could equally as well mention either the bells of the church or just the church.

13) The tour guide mentioned the bells of the church that...

An example of a sentence fragment in which the verb does not apply equally well semantically to either noun phrase is shown in (14).

14) The secret service confiscated all files of the organization that...

In this sentence, it is clear that the verb *confiscated* does not apply equally well to the two noun phrases *all files of the organization* and *the organization*. Files are generally confiscated, while organizations are not. Sentences like these showed larger biases for low-attachment completions because the main verb is so closely linked semantically with the first noun in the object noun phrase (in this case, *confiscated* is linked with *files*). Therefore, the second noun (in this case, *organization*) is more separated from the first noun (*files*), thus making low-attachment more likely. Therefore, in a follow-up study, it would be best to create all target sentence fragments to emulate (13), in which it is equally plausible for the main verb to apply to either noun phrase in the relative clause.

Another feature of the sentence fragments that made them less likely to be completed ambiguously was if the noun phrases in their relative clauses differed in terms of grammatical type (i.e., count or mass) or semantically (concrete or abstract). A good example of this is the target sentence fragment presented earlier in (3). In this example, *discovery* is a count noun that is abstract, since the act of discovering something is not physically tangible. The noun *remains* is a mass noun that is concrete, since the remains of something are physically tangible. If one

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4 (13) and (14) are actual experiment test items, and were borrowed from Scheepers et al. (2011).
were to replicate this experiment, it would probably decrease the likelihood of ambiguous and
other unclassifiable sentence completions if one were to create all target sentence fragments with
noun phrases differing in these ways. If the two nouns in the object noun phrase differ
grammatically (count or mass) and semantically (concrete or abstract), it will reduce the chances
that a relative clause used to the complete the fragment could be interpreted equally well as
modifying either noun.

Another possible flaw in some of the target sentence fragments is the fact that the two
noun phrases in the relative clause represent part-to-whole relationships. For instance, consider
the fragments in (15a-b).

15a) *The waiter brought over the cups of the coffee that...*

15b) *The researcher located the pile of the documents that...*

Target sentence fragments such as these were often completed in ambiguous ways, such
that the proportion of unclassifiable completions was greatly increased. The semantic
relationship represented by the nouns in the object noun phrase (that, part-to-whole) is more
likely to result in a high-attachment interpretation because this relationship signals a sort of unity
between those nouns. A replication of this experiment would most likely be much improved by
avoiding such part-to-whole relationships in the creation of its items.

Additionally, it has been shown that certain verbs prime one structure more effectively
when that verb is more closely associated with that structure in general (Gries, 2005). Many of
the target sentence fragments contained such verbs. For example, the verb in the fragment
shown by (16) is much more likely to prime the high-attachment interpretation than the low-
attachment one.
16) *The chef dropped the can of the beans that...*

A chef is much more likely to drop a can of beans than just beans alone. Therefore, the verb *dropped* is much more closely associated in this fragment with a high relative clause attachment. The two nouns in the object noun phrase are tied together by a familiar semantic connotation (that is, the act of dropping a can), and therefore the verb will more likely be interpreted as applying to the entire noun phrase.

After much consideration and scrutiny, it was found that the order of operators in the math priming equations was not the best to use for demonstrating high- and low-attachment structures. For example, in the equation $80 - 9 + (1 \times 5)$, the grouping was thought to be as follows: $(1 \times 5)$ form a multiplication phrase, which joins to the number 9 to form an addition phrase, which in turn forms a subtraction phrase with the number 80 (shown in (10b) above). This implies that one performs the multiplication in parentheses first, adds the product to 9, and then this sum is subtracted from 80. However, this is incorrect. Because of the subtraction operator preceding the number 9, it must be treated as a negative number. Therefore, a true hierarchy of groupings for this equation would either join $(1 \times 5)$ with the number -9 under an addition phrase, or join $(1 \times 5)$ with 9 under a subtraction phrase. This order of groupings shows that the equation must be solved either by subtracting 9 from the product of $(1 \times 5)$ and then adding this difference to 80, or by subtracting 9 from 80 and adding the difference to the product of $(1 \times 5)$. As can be seen, this difference in ordering changes the solution to the equation. During the data coding process, it was observed that many low-attachment priming equations were solved in a way that treated the number following the subtraction operator as positive rather than negative, thereby providing an incorrect solution. To ensure that participants solve equations in the correct order without error, the low-attachment priming equations from
this experiment could be improved by switching the addition and subtraction operators. Therefore, $80 - 9 + (1 \times 5)$ would be replaced by $80 + 9 - (1 \times 5)$. This flaw in the creation of math primes has significant consequences for interpreting the results of Scheepers et al. (2011), whose experiments utilized the flawed order of operators for low-attachment priming equations.

6. Conclusion

It seems that if the aspects of the experimental design discussed above were improved, a lower proportion of unclassifiable sentence completions would result. With a lower proportion of unclassifiable completions, the data would most likely be less noisy, and perhaps would reveal a significant effect of priming. Although the experiment may have experienced a number of unforeseen design flaws affecting the reliability of the results, this study has proved useful in identifying ways in which future research on cross-domain priming can be executed more effectively. It has provided important insights into what an experiment design would need to control (regarding both priming items and target sentence completions) to ensure that any effect of structural priming found across different cognitive systems is significant. The results of such an experiment could potentially contribute new and exciting knowledge surrounding whether these systems share mental mechanisms for the creation and processing of their hierarchical structure. Knowledge of this kind would be very important to our broader understanding of human cognition because it could offer answers regarding the degree to which the mind utilizes the same mental resources to approach seemingly different problems.
7. References


8. Appendices

8.1 Appendix A – Test Item Sets (Math Primes and Target Sentence Fragments)\(^5\)

1. a) HA-Math Prime: \(12 + ( ( 26 - 1 ) \times 4 ) = \)
b) LA-Math Prime: \(12 + 26 - ( 1 \times 4 ) = \)
c) Baseline-Math Prime: \(( 12 + 26 ) - ( 1 \times 4 ) = \)
Target: The porter smiled at the children of the hotel resident who ____.

2. a) HA-Math: \(3 + ( ( 6 - 2 ) \div 2 ) = \)
b) LA-Math: \(3 + 6 - ( 2 \div 2 ) = \)
c) BL-Math: \(( 3 + 6 ) - ( 2 \div 2 ) = \)
Target: Nora visited the students of the piano teacher who ____.

3. a) HA-Math: \(80 - ( ( 9 + 1 ) \times 5 ) = \)
b) LA-Math: \(80 - 9 + ( 1 \times 5 ) = \)
c) BL-Math: \(( 80 - 9 ) + ( 1 \times 5 ) = \)
Target: The pensioner complained about the content of the fliers that ____.

4. a) HA-Math: \(10 + ( ( 7 - 5 ) \times 3 ) = \)
b) LA-Math: \(10 + 7 - ( 5 \times 3 ) = \)
c) BL-Math: \(( 10 + 7 ) - ( 5 \times 3 ) = \)
Target: The manager waited for the musicians of the pop star who ____.

5. a) HA-Math: \(67 - ( ( 24 - 12 ) \div 3 ) = \)
b) LA-Math: \(67 - 24 - ( 12 \div 3 ) = \)
c) BL-Math: \(( 67 - 24 ) - ( 12 \div 3 ) = \)
Target: The commission referred to the source of the donations that ____.

6. a) HA-Math: \(41 - ( ( 8 + 3 ) \times 3 ) = \)
b) LA-Math: \(41 - 8 + ( 3 \times 3 ) = \)
c) BL-Math: \(( 41 - 8 ) + ( 3 \times 3 ) = \)
Target: The tour guide mentioned the bells of the church that ____.

7. a) HA-Math: \(7 + ( ( 28 - 4 ) \times 2 ) = \)
b) LA-Math: \(7 + 28 - ( 4 \times 2 ) = \)
c) BL-Math: \(( 7 + 28 ) - ( 4 \times 2 ) = \)
Target: The chauffeur met the representative of the guests who ____.

\(^5\) Math primes and target sentences in items 1-24 were borrowed from Scheepers et al. (2011).
8. a) HA-Math: \[ 20 + \left( \frac{32 - 6}{2} \right) = \]
b) LA-Math: \[ 20 + 32 - \left( \frac{6}{2} \right) = \]
c) BL-Math: \[ \left( 20 + 32 \right) - \left( \frac{6}{2} \right) = \]
Target: The tutor advised the students of the professor who____.

9. a) HA-Math: \[ 9 + \left( \frac{20 + 10}{5} \right) = \]
b) LA-Math: \[ 9 + 20 + \left( \frac{10}{5} \right) = \]
c) BL-Math: \[ \left( 9 + 20 \right) + \left( \frac{10}{5} \right) = \]
Target: The bus driver talked to the leader of the boy scouts who____.

10. a) HA-Math: \[ 56 - \left( \frac{5 + 3}{4} \right) = \]
b) LA-Math: \[ 56 - 5 + \left( 3 \times 4 \right) = \]
c) BL-Math: \[ \left( 56 - 5 \right) + \left( 3 \times 4 \right) = \]
Target: The superintendent checked the earnings of the company that____.

11. a) HA-Math: \[ 15 - \left( \frac{12 - 4}{2} \right) = \]
b) LA-Math: \[ 15 - 12 - \left( \frac{4}{2} \right) = \]
c) BL-Math: \[ \left( 15 - 12 \right) - \left( \frac{4}{2} \right) = \]
Target: The farmhand fed the calves of the cow that____.

12. a) HA-Math: \[ 31 + \left( \frac{8 - 5}{2} \right) = \]
b) LA-Math: \[ 31 + 8 - \left( 5 \times 2 \right) = \]
c) BL-Math: \[ \left( 31 + 8 \right) - \left( 5 \times 2 \right) = \]
Target: John met the supervisor of the employees who____.

13. a) HA-Math: \[ 2 + \left( \frac{8 + 4}{3} \right) = \]
b) LA-Math: \[ 2 + 8 + \left( 4 \times 3 \right) = \]
c) BL-Math: \[ \left( 2 + 8 \right) + \left( 4 \times 3 \right) = \]
Target: The frost ruined the harvest of the fruit farms that____.

14. a) HA-Math: \[ 43 - \left( \frac{27 - 9}{3} \right) = \]
b) LA-Math: \[ 43 - 27 - \left( \frac{9}{3} \right) = \]
c) BL-Math: \[ \left( 43 - 27 \right) - \left( \frac{9}{3} \right) = \]
Target: The scientist criticized the method of the studies that____.

15. a) HA-Math: \[ 85 - \left( \frac{14 + 21}{7} \right) = \]
b) LA-Math: \[ 85 - 14 + \left( 21 ÷ 7 \right) = \]
c) BL-Math: \[ \left( 85 - 14 \right) + \left( 21 ÷ 7 \right) = \]
Target: We were amused by the articles of the newspaper that____.

16. a) HA-Math: \[ 19 + \left( \frac{24 - 8}{4} \right) = \]
b) LA-Math: \[ 19 + 24 - \left( 8 ÷ 4 \right) = \]
c) BL-Math: \[ \left( 19 + 24 \right) - \left( 8 ÷ 4 \right) = \]
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17. a) HA-Math: \[ 10 + ( ( 6 + 3 ) \times 2 ) = \]
    b) LA-Math: \[ 10 + 6 + ( 3 \times 2 ) = \]
    c) BL-Math: \[ ( 10 + 6 ) + ( 3 \times 2 ) = \]
    Target: The social worker greeted the nurse of the senior-citizens who ____.

18. a) HA-Math: \[ 90 - ( ( 5 + 15 ) \div 5 ) = \]
    b) LA-Math: \[ 90 - 5 + ( 15 \div 5 ) = \]
    c) BL-Math: \[ ( 90 - 5 ) + ( 15 \div 5 ) = \]
    Target: The remover insured the furniture of the apartments that ____.

19. a) HA-Math: \[ 56 + ( ( 6 + 6 ) \div 2 ) = \]
    b) LA-Math: \[ 56 + 6 + ( 6 \div 2 ) = \]
    c) BL-Math: \[ ( 56 + 6 ) + ( 6 \div 2 ) = \]
    Target: A stranger blackmailed the butler of the royals who ____.

20. a) HA-Math: \[ 78 - ( ( 9 + 6 ) \times 2 ) = \]
    b) LA-Math: \[ 78 - 9 + ( 6 \times 2 ) = \]
    c) BL-Math: \[ ( 78 - 9 ) + ( 6 \times 2 ) = \]
    Target: The secret service confiscated all files of the organization that ____.

21. a) HA-Math: \[ 4 + ( ( 22 - 4 ) \div 2 ) = \]
    b) LA-Math: \[ 4 + 22 - ( 4 \div 2 ) = \]
    c) BL-Math: \[ ( 4 + 22 ) - ( 4 \div 2 ) = \]
    Target: The president saw the bodyguard of the diplomats who ____.

22. a) HA-Math: \[ 45 - ( ( 10 + 5 ) \times 3 ) = \]
    b) LA-Math: \[ 45 - 10 + ( 5 \times 3 ) = \]
    c) BL-Math: \[ ( 45 - 10 ) + ( 5 \times 3 ) = \]
    Target: The astronomer observed the stars of the spiral galaxy that ____.

23. a) HA-Math: \[ 98 - ( ( 50 - 30 ) \div 10 ) = \]
    b) LA-Math: \[ 98 - 50 - ( 30 \div 10 ) = \]
    c) BL-Math: \[ ( 98 - 50 ) - ( 30 \div 10 ) = \]
    Target: The scholar studied the language of the tribes that ____.

24. a) HA-Math: \[ 70 - ( ( 25 + 5 ) \div 5 ) = \]
    b) LA-Math: \[ 70 - 25 + ( 5 \div 5 ) = \]
    c) BL-Math: \[ ( 70 - 25 ) + ( 5 \div 5 ) = \]
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Target: The homeowner kept the letters of the office that ____.

25. a) HA-Math: \[1 + \left( \frac{18 - 9}{3} \right) =\]
b) LA-Math: \[1 + 18 - \left( \frac{9}{3} \right) =\]
c) BL-Math: \[(1 + 18) - \left( \frac{9}{3} \right) =\]
Target: The gardener purchased the seeds of the vegetable that ____.

26. a) HA-Math: \[35 + \left( \frac{8 + 16}{4} \right) =\]
b) LA-Math: \[35 + 8 + \left( 16 \div 4 \right) =\]
c) BL-Math: \[(35 + 8) + \left( 16 \div 4 \right) =\]
Target: The mechanic fixed the tires of the car that ____.

27. a) HA-Math: \[65 - \left( \frac{30 - 15}{3} \right) =\]
b) LA-Math: \[65 - 30 - \left( 15 \div 3 \right) =\]
c) BL-Math: \[(65 - 30) - \left( 15 \div 3 \right) =\]
Target: The exhibit showcased the painting of the flowers that ____.

28. a) HA-Math: \[40 - \left( \frac{7 - 3 \times 2}{2} \right) =\]
b) LA-Math: \[40 - 7 - \left( 3 \times 2 \right) =\]
c) BL-Math: \[(40 - 7) - \left( 3 \times 2 \right) =\]
Target: The researcher located the pile of the documents that ____.

29. a) HA-Math: \[87 - \left( \frac{6 + 1 \times 11}{11} \right) =\]
b) LA-Math: \[87 - 6 + \left( 1 \times 11 \right) =\]
c) BL-Math: \[(87 - 6) + \left( 1 \times 11 \right) =\]
Target: The waiter brought over the cups of the coffee that ____.

30. a) HA-Math: \[14 + \left( \frac{2 + 5 \times 10}{10} \right) =\]
b) LA-Math: \[14 + 2 + \left( 5 \times 10 \right) =\]
c) BL-Math: \[(14 + 2) + \left( 5 \times 10 \right) =\]
Target: Jill spoke with the lawyer of the individuals who ____.

31. a) HA-Math: \[33 - \left( \frac{12 + 8}{4} \right) =\]
b) LA-Math: \[33 - 12 + \left( 8 \div 4 \right) =\]
c) BL-Math: \[(33 - 12) + \left( 8 \div 4 \right) =\]
Target: The boy looked at the books of the library that ____.

32. a) HA-Math: \[27 - \left( \frac{6 - 3 \times 2}{2} \right) =\]
b) LA-Math: \[27 - 6 - \left( 3 \times 2 \right) =\]
c) BL-Math: \[(27 - 6) - \left( 3 \times 2 \right) =\]
Target: The reporter approached the coach of the players who ____.

33. a) HA-Math: \[5 + \left( \frac{23 - 3 \times 3}{3} \right) =\]
b) LA-Math: \[ 5 + 23 - (3 \times 3) = \]
c) BL-Math: \[ (5 + 23) - (3 \times 3) = \]
Target: The archivist examined the pages of the book that ____.

34. a) HA-Math: \[ 71 + ((4 + 20) \div 4) = \]
b) LA-Math: \[ 71 + 4 + (20 \div 4) = \]
c) BL-Math: \[ (71 + 4) + (20 \div 4) = \]
Target: The chef dropped the can of the beans that ____.

35. a) HA-Math: \[ 36 - ((28 - 14) \div 7) = \]
b) LA-Math: \[ 36 - 28 - (14 \div 7) = \]
c) BL-Math: \[ (36 - 28) - (14 \div 7) = \]
Target: The critic discussed the qualities of the movie that ____.

36. a) HA-Math: \[ 19 + ((50 - 25) \div 5) = \]
b) LA-Math: \[ 19 + 50 - (25 \div 5) = \]
c) BL-Math: \[ (19 + 50) - (25 \div 5) = \]
Target: Scientists described the discovery of the remains that ____.

37. a) HA-Math: \[ 6 + ((16 - 8) \times 2) = \]
b) LA-Math: \[ 6 + 16 - (8 \times 2) = \]
c) BL-Math: \[ (6 + 16) - (8 \times 2) = \]
Target: The committee reviewed all products of the company that ____.

38. a) HA-Math: \[ 73 - ((6 + 1) \times 8) = \]
b) LA-Math: \[ 73 - 6 + (1 \times 8) = \]
c) BL-Math: \[ (73 - 6) + (1 \times 8) = \]
Target: The journalist spoke about the location of the crimes that ____.

39. a) HA-Math: \[ 64 - ((5 + 35) \div 5) = \]
b) LA-Math: \[ 64 - 5 + (35 \div 5) = \]
c) BL-Math: \[ (64 - 5) + (35 \div 5) = \]
Target: The inspector examined the windows of the house that ____.

40. a) HA-Math: \[ 42 - ((22 - 10) \times 2) = \]
b) LA-Math: \[ 42 - 22 - (10 \times 2) = \]
c) BL-Math: \[ (42 - 22) - (10 \times 2) = \]
Target: The insurance company contacted the doctor of the patients who ____.

41. a) HA-Math: \[ 32 + ((55 - 33) \div 11) = \]
b) LA-Math: \[ 32 + 55 - (33 \div 11) = \]
c) BL-Math: \[ (32 + 55) - (33 \div 11) = \]
Target: The customer read the items on the menu that ____.

42. a) HA-Math: $18 + ( ( 5 + 3 ) \times 7 ) =$
   b) LA-Math: $18 + 5 + ( 3 \times 7 ) =$
   c) BL-Math: $( 18 + 5 ) + ( 3 \times 7 ) =$
Target: The collector skimmed the anthology of the stories that ____.

43. a) HA-Math: $44 - ( ( 19 - 15 ) \times 1 ) =$
   b) LA-Math: $44 - 19 - ( 15 \times 1 ) =$
   c) BL-Math: $( 44 - 19 ) - ( 15 \times 1 ) =$
Target: The school principal congratulated the parents of the child who ____.

44. a) HA-Math: $96 - ( ( 3 + 18 ) \div 3 ) =$
   b) LA-Math: $96 - 3 + ( 18 \div 3 ) =$
   c) BL-Math: $( 96 - 3 ) + ( 18 \div 3 ) =$
Target: The shop owner talked about the brand of the clothes that ____.

45. a) HA-Math: $67 - ( ( 8 - 4 ) \div 2 ) =$
   b) LA-Math: $67 - 8 - ( 4 \div 2 ) =$
   c) BL-Math: $( 67 - 8 ) - ( 4 \div 2 ) =$
Target: The host greeted the friends of the guest who ____.

46. a) HA-Math: $2 + ( ( 3 + 30 ) \div 3 ) =$
   b) LA-Math: $2 + 3 + ( 30 \div 3 ) =$
   c) BL-Math: $( 2 + 3 ) + ( 30 \div 3 ) =$
Target: Tom noted the publisher of the books that ____.

47. a) HA-Math: $9 + ( ( 5 + 2 ) \times 4 ) =$
   b) LA-Math: $9 + 5 + ( 2 \times 4 ) =$
   c) BL-Math: $( 9 + 5 ) + ( 2 \times 4 ) =$
Target: The snow collected on the branches of the tree that ____.

48. a) HA-Math: $15 + ( ( 13 - 2 ) \times 6 ) =$
   b) LA-Math: $15 + 13 - ( 2 \times 6 ) =$
   c) BL-Math: $( 15 + 13 ) - ( 2 \times 6 ) =$
Target: The bus passed by the street of the houses that ____.
8.2 Appendix B – Filler Items (Math Primes and Target Sentence Fragments)

Math Primes

1. \((11 - (2 + 6)) ÷ 3 =\)
2. \((27 ÷ (8 + 1)) - 3 =\)
3. \((13 + (20 - 1)) ÷ 8 =\)
4. \((5 + (23 + 27)) ÷ 5 =\)
5. \((30 ÷ (1 ÷ 1)) + 7 =\)
6. \((2 x (9 - 4)) + 8 =\)
7. \((10 - (27 - 19)) x 3 =\)
8. \((3 + 4 + 6) x 2 =\)
9. \((4 + (90 - 54)) ÷ 10 =\)
10. \((5 + 8 + 1) ÷ 2 =\)
11. \((14 + 3 + 15) ÷ 4 =\)
12. \((60 ÷ (15 - 5)) - 6 =\)
13. \((8 + (26 + 15)) ÷ 7 =\)
14. \((16 ÷ (3 - 1)) - 7 =\)
15. \((7 + (43 - 23)) ÷ 9 =\)
16. \((38 ÷ (4 + 15)) + 8 =\)
17. \((54 ÷ (5 + 1)) + 6 =\)
18. \((88 ÷ (49 - 5)) + 4 =\)
19. \((6 + 9 + 13) ÷ 2 =\)
20. \((7 x (13 - 9)) - 5 =\)
21. \((42 - (2 + 18)) x 4 =\)
22. \((1 x (15 - 12)) + 6 =\)
23. \((3 x (3 + 5)) - 9 =\)
24. \((29 - (30 - 6)) x 7 =\)
25. \((8 + 12 + 4) x 1 =\)
26. \((50 - (14 + 20)) x 2 =\)
27. \((2 x (15 - 5)) + 6 =\)
28. \((18 ÷ (12 - 3)) - 1 =\)
29. \((72 - (40 + 25)) x 3 =\)
30. \((33 - (28 - 1)) x 8 =\)
31. \((9 x (6 - 3)) - 5 =\)
32. \((4 x (6 + 2)) + 7 =\)
33. \((40 ÷ (17 - 13)) - 3 =\)
34. \((12 x (5 - 2)) - 6 =\)
35. \((3 x (45 - 38)) - 10 =\)
36. \((6 x (2 + 5)) - 8 =\)
37. \((27 ÷ (1 + 2)) - 7 =\)
38. \((32 - (4 + 3)) ÷ 5 =\)
39. \((66 - (40 - 18)) ÷ 11 =\)
40. \((30 + (53 - 47)) ÷ 3 =\)
41. \((9 + (15 - 13)) x 5 =\)
42. \((5 + 8 + 3) x 2 =\)
43. \((7 - (3 + 2)) \times 4 =\)
44. \((18 - (42 - 33)) \times 6 =\)
45. \((70 \div (41 - 6)) + 21 =\)
46. \((8 \times (39 - 32)) + 1 =\)
47. \((34 \div (5 + 12)) + 19 =\)
48. \((25 \times (1 + 2)) + 13 =\)

**Target Sentence Fragments**

1. The teacher wanted to tell the students in his class that _____.
2. The teenagers barricaded the main entrance of the school so that _____.
3. Mary decided to notify her employees about the incident that _____.
4. Bob needed to obtain information from the sales representative that _____.
5. The traveler asked the guard at the airport which _____.
6. Ted bought a new tennis racket from the store that _____.
7. Liz made a note in her calendar so that _____.
8. The scholars attended the event at the art museum that _____.
9. A few guests despised the food at the dinner party that _____.
10. The captain was worried about the part of the ship that _____.
11. The queen was offended by a few of the visitors who _____.
12. Nobody dared tell the referee of the match that _____.
13. The business executive never told the director of human resources that _____.
14. The author was disappointed by the reaction to the book that _____.
15. Most of the people were happy with the beach near the city that _____.
16. The exterminators found the nests made by the bugs that _____.
17. The girl asked her parents about the story that _____.
18. The actress enjoyed her role in the show that _____.
19. The members of the board wanted to pass the amendment to the by-laws so that _____.
20. The suspect denied the statement in the police report that _____.
21. The computer programmer added the feature to the software so that _____.
22. The commanding officer moved the troops away from the coast so that _____.
23. The politician aspired to be the chair of the committee so that _____.
24. A police officer came to inform the vendor on the street that _____.
25. The financial adviser wanted to discuss the problem with the money that _____.
26. The building used to be located in the area that _____.
27. The grocery store sells a lot of food that _____.
28. The editor was appalled to hear about the popularity of the magazine that _____.
29. The real estate agent was pleased with the condition of the home that _____.
30. The director did not know the history of the play that _____.
31. The eye doctor suggested a pair of frames that _____.
32. The taxi driver made a wrong turn off the road that _____.
33. The basketball player told the news reporters about the game that _____.
34. The angry landlord gave a warning to the resident so that _____.
35. The fishermen brought their daily catch to the market so that _____.
36. The architect called the consultant from the company that _____.
37. A disgruntled patron asked for the manager of the restaurant so that _____.
38. The jeweler took the necklace out of the glass case so that ____.
39. The photographer developed the pictures from the trip so that ____.
40. The schoolchildren really liked the swing set on the playground so that ____.
41. The firefighter ran through the front door of the building so that ____.
42. The pilot modified the course of the flight so that ____.
43. The art critic was impressed by the sculpture in the gallery that ____.
44. The farmer needed to water the fields of the crops so that ____.
45. The bakery delivered a cake for the wedding that ____.
46. The mailman delivered the package to the house that ____.
47. The bartender slid the beer over to the customer who ____.
48. The conductor let the people board the train that ____.
49. The investigator found the handbag of the diplomat’s wife that ____.
50. The woman complained about the bicycles of the neighbor’s kids that ____.
51. The lieutenant visited the floors of the battalion’s barracks that ____.
52. The racecar driver rounded the bend of the track that ____.
53. The city council told the manager of the supermarket that ____.
54. The jury heard the testimony of the witness who ____.
55. The host greeted the guest of the talk show who ____.
56. The auctioneer sold the item to the bidder who ____.
57. The team’s owner reviewed the contract of the coach who ____.
58. The ranger told the visitors of the park that ____.
59. The entertainer was given flowers by the fan who ____.
60. The hot-air balloon landed in the field near the town that ____.
61. The shopper bought a loaf of the bread that ____.
62. The zookeeper gave the food to the animal that ____.
63. The subway train made a stop at the station where ____.
64. The limousine arrived at the entrance of the hotel where ____.
65. The squirrel ran up the trunk of the tree so that ____.
66. The weather report predicted a storm for the day that ____.
67. The golfers started their game in the morning so that ____.
68. The nutritionist advised the patient to eat the cereal that ____.
69. The hungry vacationers ate the ice cream from the shop that ____.
70. The couple removed the box from their garage that ____.
71. The exhausted campers pitched their tent near the river that ____.
72. The paleontologist found the fossil of the organism that ____.
73. The secretary made a call on the telephone that ____.
74. The frustrated producer told the host of the radio show that ____.
75. The spokesperson assured the journalist at the press conference that ____.
76. The engineer explained to the builders of the bridge that ____.
77. The investor predicted the growth of the stock that ____.
78. The economist reported on the financial state of the country that ____.
79. The lifeguard immediately told the swimmers in the pool that ____.
80. The trophy was presented to the champion of the tournament that ____.
81. The hikers passed through the forest on the mountain that ____.
82. The marketing agent proposed the idea to the executives who ____.
83. The mathematicians presented the theory to their colleagues who ____.
84. The birdwatchers were disturbed by the visitors to the park who ____.
85. The journal published an article by the physicist who ____.
86. The flight attendant announced to the passengers on the plane that ____.
87. The cruise ship anchored by the dock of the bay so that ____.
88. Bill went up to the second floor of the department store so that ____.
89. Jane gave the gift to her friend who ____.
90. The screenwriter bought the rights to the novel so that ____.
91. The sunshine illuminated the room in the old house that ____.
92. The accident slowed down the traffic in the tunnel that ____.
93. The athletes arrived at the stadium in the city where ____.
94. The skiing instructor told the novices about the slope that ____.
95. The audience laughed at the jokes of the comedian who ____.
96. The hopeful explorers trudged through the middle of the forest so that ____.
8.3 Appendix C – Music Primes (Notated)\(^6\)

\(^6\) Fillers 33-48 could not be included because they were created directly in GarageBand and were not notated.
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Test Item 10(c)
Pno. 146

Test Item 11(d)
Pno. 156

Test Item 11(e)
Pno. 156

Test Item 11(f)
Pno. 156

Test Item 12(d)
Pno. 168

Test Item 12(e)
Pno. 176

Test Item 12(f)
Pno. 176

Test Item 13(d)
Pno. 188

Test Item 13(e)
Pno. 188

Test Item 13(f)
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