Mythili Menon, 'Domain-General Representations Shared across Music and Language'. *Studies in Humanities and Social Sciences,* Volume XXIII, Number 2, Winter 2016: 64-86.

DOMAIN-GENERAL REPRESENTATIONS SHARED ACROSS MUSIC AND LANGUAGE

Mythili Menon

Introduction

Music is part of human nature and culture, just like language, raising the question of what the relationship between the two is. Recent research has shown that language and music share a number of characteristics (Besson and Schön 2001; Maess et al. 2001, Patel 2003, Patel 2008, Koelsch 2005, Koelsch 2009). One of the crucial characteristics shared across the domains is that language and music use rules and representations. Both the domains use basic units (e.g., words and notes) to build rule-governed higher order representations (e.g., phrases and melodies). Neither language processing nor musical processing proceeds by retrieving 'already-constructed' well-formed sentences or melodies from long-term memory. Sentences are constructed in real-time processing by putting together constituents. Humans can, therefore, understand the meaning of a completely novel sentence, which suggests that language processing proceeds by accessing certain rules, which puts together certain elements from an existing small inventory of primitives. In a similar fashion, music involves production and processing of novel elements combining in a principled manner. Studies have shown that such sequences are perceived in a meaningful way (Antović 2009, Koelsch 2011). How are these two processes inter-related? What commonalities does musical processing share with language processing, in that there

* I would like to thank Elsi Kaiser, Khalil Iskarous, Maria Luisa Zubizarreta, and Roumyana Pancheva for valuable guidance, encouragement and suggestions throughout the inception and running of the study. I am also grateful to the members of the University of Southern California psycholinguistics lab and for useful comments and feedback. I also want to thank the audiences at 26th Annual CUNY Sentence Processing Conference held at University of South Carolina, 20th AMLaP held at Edinburgh, and the Music, Cognition, Poetics Workshop held at Osnabrueck, Germany. This work is partly funded by a University of Southern California Del-Amo fellowship.

are activated and shared representations across these domains? An inquiry into the nature of processing across the two domains will shed light on some of the controversial issues of possibly shared cognitive resources between language and music (Jackendoff and Lerdahl 2006, Pesetsky and Katz 2011).

The rest of the paper is organized as follows: contrasting evidence from neuro-psychology for domain specificity is provided with evidence for domain generality from neuro-imaging in Section 1.1. Patel's (2003, 2008) shared resource hypothesis for language and music is in Section 1.2. In Section 2, the aims of the paper are discussed after which a brief overview of structural priming across domains is summarized in Section 3. In the next section, (Section 4), we talk about the rationale behind the stimuli and the notion of priming in the musical domain followed by the Experiment in Section 5. Section 7 summarizes the results of the experiment, followed by a general discussion and possible future work and follow up experiments.

Shared Processing Mechanisms/Representation between Language and Music?

The connection between language and music has been the subject of a longstanding debate in the field of cognitive science (and recently, neuroscience), especially regarding the question of whether language and music are processed by distinct and separate psychological substrates or whether these substrates overlap with each other. This has been partly due to contrasting evidence from dissociations (Peretz and Colheart 2003, Peretz 2006) standing alongside evidence for processing mechanisms which show similarities (Koelsch 2000, Patel 2003, Patel 2008).

Let us first consider the evidence in favour of language and music sharing processing mechanisms. Early studies from neuro-imaging have shown that out-of-key chords elicited a bilateral P600 which was statistically indistinguishable from the P600 elicited by syntactically incongruous words (Patel et al. 1998). Later works have looked at early right anterior negativity (ERAN) that peaked at 200 ms when non-musicians (people with no musical training) heard out-of-key chords, similar to the early left anterior negativity (ELAN) associated with word category violations (Koelsch 2000, Koelsch and Mulder 2002, Koelsch 2009). Chords violating harmonic rules have been shown to elicit activation in areas that are related to syntactic processing in language, such as Broca's area (Maess et al. 2001). There is also evidence from children's processing where children with syntactic processing difficulties in language also tend to have more problems in processing musical stimuli (Jentschke et al. 2008, Jentschke & Koelsch 2009). These studies point us towards the direction of an overlap of cognitive resources shared between language and music, and largely challenge the domain-specific view.

In addition to the data from neuro-imaging, there is also behavioural data that points to parallels between language and music. For example, in language, structural integrations occur when an incoming word is distant from a previous word with which it shares a syntactic dependency (Gibson 1998, 2000) or when there has been a violation of syntactic unexpectancy (Gibson 2006, Lau et al. 2006). During incremental sentence processing, different possible syntactic analyses of a sentence have different levels of activation, with the currently preferred analysis having the highest level of activation. An unexpectancy proves costly because resources must be reallocated to boost the activation of a different structure (MacDonald 1993, cf. Marslen-Wilson 1975). Such kind of unexpectancy violations have been shown to hold in musical processing as well. Events that are harmonically distant from the current context (e.g., out-of-key notes and chords) are also unexpected (Huron 2006). These require more activation and hence prove costly (Barucha 1984, Tillmann et al. 2000).

However, other researchers have argued for a dissociation between the processing mechanisms of language and music. For example, evidence from the behavioural studies of patients with musical deficits points to the independence of music and language processing (Peretz and Colheart 2003, Peretz 2006). Cases of amusics (people with congenital or acquired musical disability) and musical dissociations provide evidence for domain-specificity suggesting that may be language and music are processed differently with no overlapping of cognitive resources. These imply that brain networks can be specialized for musical functions without having considerable overlap with networks involved with language, sound perception etc. Amusics fail to show key sensitivity and they cannot distinguish between a tonal versus atonal melody.

Patel's Shared Syntactic Integration Resource Hypothesis (SSIRH)

Although some of the key findings from the neuropsychology literature have been challenged (the ones discussed above), the evidence provided by neuro-imaging opens up the possibility to test whether there are aspects of music and language (say, syntax) that exhibit either domain specificity or suggests that there is a neural overlap (Patel 2012). One such theory, which has received a lot of attention in the current literature, is that of the Shared Syntactic Integration Resource Hypothesis (SSIRH) (Patel 2003, Patel 2008) based largely on the positive evidence from neuro-imaging. Specifically, it was proposed that structural integration involves the rapid and selective activation of items in associative networks, and that language and music share the neural resources that provide this activation to the networks where domain-specific representation reside (Figure 1).

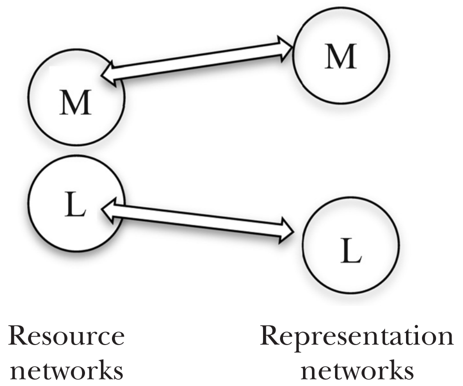


Figure 1. Schematic diagram of the shared relationship between language and music (adapted from Patel 2003, Patel 2008). Representation networks are domain-specific representations and Resource networks are domain-general activation resources.

Figure 1 shows that linguistic and musical syntactic representations are stored in different parts of the brain. In Figure 1, overlap of Resource networks is intended to schematically represent overlap in brain regions, and non-overlapping Representation networks are a schematic representation of domain-specificity. Thus, neural resources for the activation of the stored syntactic representations have considerable overlap. The relation between the neural networks and the neural architecture is an area for further research but currently the answer is unknown. Testing this requires localization techniques such as fMRI applied to within-subjects comparisons of syntactic processing in language and music (Patel 2003). One of the predictions made by the SSIRH is based on the idea that shared, limited resources activated across the two domains should show interference patterns.

Objectives of the Paper

This paper is concerned with the relationship between language processing and musical processing at the structural level. Specifically, we test whether language and music have shared representations and whether they can be activated across domains. This ties in with the neuro-imaging evidence suggesting music and language share overlapping activation resources.

To investigate the question of whether language and music have shared representations, we used the priming paradigm. Priming refers to a change in the speed, bias or accuracy of the processing of a stimulus, following prior experience with the same, or a related stimulus (Bock 1986, Hartsuiker, Kolk, and Huiskamp 1999, Hartsuiker and Westenberg 2000, Pickering, Branigan and McLean 2002). For example, in the syntactic domain, it has been shown that people tend to produce sentences with the same structure that they have heard in the previous input (Bock, 1986; Branigan, Pickering, & Cleland, 2000; Corley & Scheepers, 2002; Pickering & Branigan, 1998)). This has been found in both production and comprehension. In sum, then, priming is a tool that allows us to probe for shared representations.

Priming of Relative Clause Attachment

In our experiment, we investigated whether musical primes influence comprehenders' choices about how to interpret ambiguous relative clauses. In particular, we focus on the well-known RC attachment ambiguity, where there are two nouns that the RC could potentially attach to, as in example (1) below. We used this structure because it is not the priming of the local syntactic representations in the representational network but rather the priming of the structural integration processes that makes use of syntactic representations to form a hierarchical structure (Scheepers 2003). The SSIRH suggests that indeed if language and music show overlap in resource networks, there should be priming possible, from music to language.

The two possible interpretations of an RC attachment ambiguity in English are shown below, for the sentence in (1). The relative clause 'who lived in Los Angeles' can be interpreted as modifying the higher noun 'doctors' (Figure 2, left tree), or as modifying the lower noun 'supermodel' (Figure 2, right tree). The two different interpretations are, that the doctors were the ones who lived in Los Angeles, or the supermodel lived in Los Angeles, respectively.

The global configurations of the two sentences differ according

(1) Jessica visited the doctors of the supermodel who lived in Los Angeles

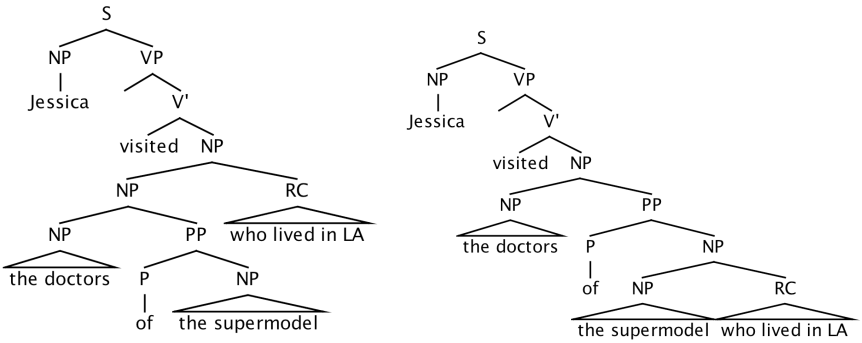


Figure 2: Hierarchical phrase structure showing high-attachment (HA) relative clause modification (left) and low-attachment (LA) relative clause medication (right).

to the modification (high attachment versus low attachment). Existing psycholinguistic research (Scheepers 2003, Desmet and Declerq 2006) has shown that when participants are primed with an unambiguous high attachment sentence, they subsequently produced a high attachment relative clause modification and vice versa. Language producers are not aware that they are reusing the structure this way. These effects can be shown in experiments where participants are constrained to use a particular structure in one trial (the prime) but are free to choose between two or more alternative structures in the following trial (the target). Priming has been shown to happen across active and passive constructions (Bock 1986, Bock and Loebell 1990, Cornelis 1996, Hartsuiker and Kolk 1998, Bernolet, Hartsuiker, Pickering 2009), for transitives in English and Dutch (Bock 1986, Bock and Griffin 2000, Bock, Dell, Chang, Onishi 2007) and recently priming has also been demonstrated across domains to which we turn to presently.

Existing Work on Structural Priming across Domains

In addition to the large body of work on the phenomenon of syntactic priming (priming from one sentence to another), recent work suggests that syntactic priming can be found across domains (Kaiser 2009, Scheepers et al 2011) and across structures (Loncke et al. 2011).

Studies that have looked at priming across domains have shown that there are abstract domain-general processes which are shared. Kaiser (2009) shows this for pronoun resolution. Experiment 2 and Experiment 3 linguistic primes and visuo-spatial primes were used and both primed pronoun resolutions. The connections between structured representations between mathematical processes and language have also been explored using priming techniques (Dehaene et al., 1999, Scheepers et al 2011). Uncovering global shared representations between language and music is, therefore, not entirely unexpected.

Naturally, a question to ask is whether such effects can hold between language and music? The only study we know of probing this question suggests interaction and integration between the two domains (van de Cavey and Hartsuiker 2016). In this study, the question of whether music primes language was explored in three experiments. In Experiment 2, they conducted a study using priming to see if music can affect the way participants complete ambiguous sentences in Dutch.

In our work, we build on these findings by investigating what role the nature of the stimuli plays in priming effects. Specifically, the stimuli used by (van de Cavey and Hartsuiker 2016) were beeps. We use melodies created on a piano, which sound more melodious and natural. We also had different conditions and manipulations and a different design. How did we replicate a high attachment ambiguity versus low attachment ambiguity in the musical prime? We shall look at this in the next section.

Exploring Structural Priming in the Musical Domain

If our aim is to investigate whether musical representations can prime/influence people's processing of language, we need to be explicit about what the representations involved in music are. This section provides a detailed discussion of the musical 'equivalent' of attachment ambiguities.

Musical structures can be said to resemble a high-attachment relative clause modification and a low-attachment relative clause modification by changing the notion of harmonic distance. In Western tonal music, music within a given key selects a subset of 7 out of 12 available pitches within the octave which form a musical scale. The tonal hierarchy thus created crucially relies on physical distance between tones in a key. Listeners judge notes which are closer to each other as perceptually related whereas the more distant keys are considered further away or out-of-key (Krumhansl 1979). These can be spatially represented as in Figure 3.

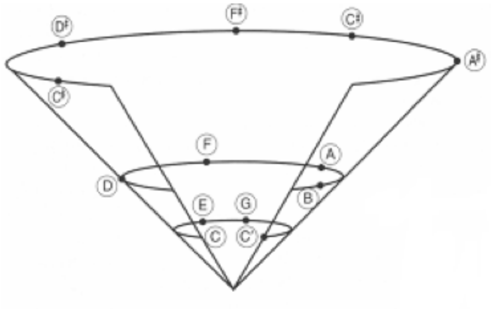


Figure 3: Multidimensional scale representation of perceived similarities between musical pitches in a tonal context (Krumhansl 1979)

A useful concept to capture and understand this notion is given by the 'Circle of Fifths' which is a foundational tool for any music learner. Tones from musical keys combine to form chords and chord progressions. These chord progressions follow a very orderly system given by the Circle of Fifths where increasing the distance between two keys along the circle corresponds to a decrease in the perceived relatedness between the keys (Thompson and Cuddy 1992). Figure 4 shows the Circle of Fifths.

The Circle of Fifths is designed to show the relations between different notes in a key signature. When read clockwise, each note is a fifth pitch apart from the preceding note. When read counter clockwise, each note is a fourth pitch apart from the preceding note. It also helps you determine how many sharps and flats there are in the key signature of each note. To illustrate, consider the key signature

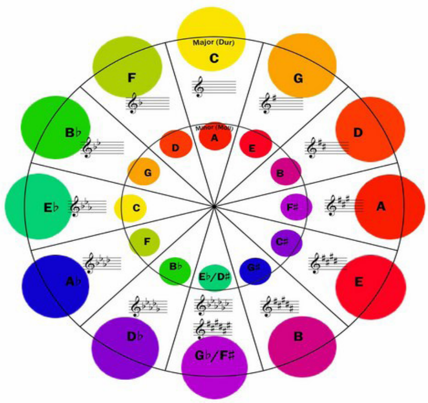


Figure 4: Circle of Fifths which was earlier called the Pythagorean Circle after Pythagoras who had discovered pitch frequencies in musical instruments and had defined an octave.

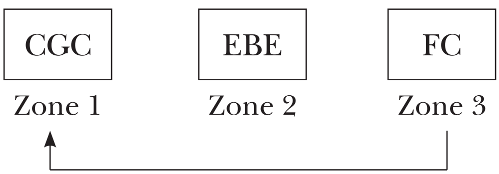
Figure 5: The key signature of C major

of C major which is the only key signature without any sharps or flats. The key signature of C major is F C G D A E B, as shown in Figure 5.

The two notes harmonically congruent to C major are F and G. F is a perfect fourth apart from C major and G is a perfect fifth apart. The notes that are harmonically distant from C major are A, E, and B. *Crucially, this harmonic distance can be used to model the high attachment versus low attachment alternatives in language.* In fact, this is what was done in our experiment. Melody sequences on eight notes can be divided into three zones where Zone 1 has three notes, Zone 2 has three notes and Zone 3 has two notes. In our study, the difference between a high attachment and low attachment comes from Zone 3 in terms of harmonic distance. Zone 3 either attached back to Zone 1 or back to Zone 2. As an illustration, consider a musical sequence in the C major key:

CFG EBE FC (Figure 6).

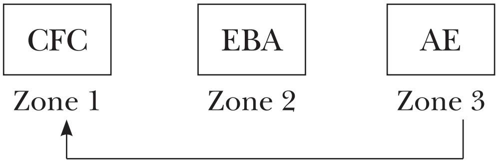
Figure 6: Toy melody created in C major for high attachment



In **our high attachment musical primes**, Zone 3 attaches back to Zone 1 in that the notes used in Zone 1 and Zone 3 are harmonically congruent with each other, whereas Zone 2 is harmonically distant from both Zone 1 and Zone 2. These comprise harmonically distant notes (cf. Circle of Fifths).

In **our low attachment musical primes,** we again had three zones, but now with Zone 3 attaching back to Zone 2, thus creating the appearance that there is only two zones. As an illustration, consider the musical sequence in C major- CFC EAB AE (Figure 7).

Figure 7: Toy melody created in C major for low attachment



A point to note is that the Zone 2 was always in a different octave just to make the difference more prominent. In cases where the Zone 3 attached back to Zone 1, the Zone 3 was in the same octave as Zone 2 (for example, if Zone 1 was in C3, then Zone 2 was in C4). Thus, except for a very general abstract nature of the similarities in structure, there was nothing else in common between the primes and the targets so that there were no other confounds suggesting priming. The details of the stimuli are given in the design and materials section below.

Experiment

In the experiment, we investigated whether hearing a music sequence with a high attachment structure or low attachment structure (as described above) influences how people complete ambiguous relative clause structures in language. In addition to the attachment structures as described above, we also manipulated whether a pause between Zone 2 and Zone 3 (the zone which always attaches to another zone) can play a role in people's comprehension and reactivation of shared structure. The pause crucially identified the notes grouped together and manipulated the timing.

Method

Participants. Twenty native English speakers from the University of Southern California participated (7 M, 13 F). Participants were not screened for prior musical training and musical training wasn't a prerequisite. Participants received $10/hour.

Design and Materials. As explained in the preceding section, the musical primes were created on the basis of Circle of Fifths. The key signature was always kept the same with the only difference being the attachment of Zone 3 to either Zone 1 (high attachment cases) or Zone 2 (low attachment cases). The primes were made on a piano in Macintosh's Garageband'11 software. Each note in the prime had a duration of 1000ms. In addition to a high attachment alternative and a low attachment alternative, we also manipulated the timing by using a pause. To maintain uniformity, the pause occurred before the Zone which was going to be attached back to another Zone. Thus, in both the conditions, the pause appeared after Zone 2 and before Zone 3. The timing was manipulated by increasing the timing of the notes to 3000ms. This was done uniformly across all the musical primes. The musical sequences were stored as .mp3s and converted into .wav files by using Audacity (ver. 2.0.2) [Refer to Table 1].

Thirty sets of materials were created. Let us first consider the nature of the **musical primes**. Each set consisted of a musical high attachment condition (MHA), musical low attachment condition (MLA), musical high attachment pause condition (MHP) and a musical low attachment pause condition (MLP). These were paired with a baseline condition which was created as a repetition of three notes to seemingly create no structure (See Table 1). A total of 125 musical primes were created (120 musical primes in different conditions, 5 baselines), with the five baselines being repeated across different sets. Every musical prime consisted of eight notes divided into three zones and differed in the way Zone 3 attached back to either Zone 1 or Zone 2 and in the timing manipulated for the pause.

Let us now turn to the **target sentences** that followed the primes. Thirty target sentence fragments in English were compiled. Twenty sentences were used verbatim from Rhode et al. (2011) study, six sentences from Rhode (2008) and four sentences were made using verbs from Hartshorne and Snedecker (2012). See appendix for a list of targets. The target sentence fragments always had the format, *Subject verb the NP1 the NP2 who.* e.g., "*Kevin counted the fans of the singer who*". These fragments can be completed with either a high-attachment continuation (e.g., "were shouting praises") or a low-attachment continuation (e.g., "just finished playing *Bohemian Rhapsody*"). The subject was always a proper name counterbalanced to include equal number of female and male names. The two NPs were definite, animate nouns preceded by the definite article. The relative pronoun was 'who'. The NPs were controlled for number. Thus, fifteen targets had NP1 as singular and NP2 as plural and the rest fifteen targets had NP1 as plural and NP2 as singular. This was done to make the response coding easier. The completed verb would be assessed according to the number marking in order to determine whether the participant completed the sentence fragment with a high attachment or a low attachment.

We made sure that all verbs in the target fragments (e.g., 'counted') were non-implicit causality (non-IC verbs). This was because recent research has shown that relative clause attachment biases can be triggered by verb semantics (Rohde 2008, Rohde et al. 2011, Hartshorne and Snedecker 2012). In a series of off-line and self-paced experiments, Rohde et al. 2011 showed that when faced with an IC verb, participants were more likely to complete a sentence fragment with a high attachment bias which is unexpected since English has an overall low attachment bias (Cuetos and Mitchell 1998, Frazier 1990, Frazier & Clifton, 1996; Carreiras & Clifton, 1999; Fernandez, 2003). Thus, our targets had only non-IC verbs carefully chosen not to bias the participant towards high attachment. Twenty of the target sentences were taken verbatim from Rohde et al. 2011 (Appendix A.4). The sentences were truncated after the relative pronoun. Ten target items were created using Non-IC verbs described in Hartshorne and Snedecker (2012).

Table 1. Example sample stimuli used for Experiment 1. The underlining suggests where the attachment has taken place.

Category	**Example**
Musical high attachment (MHA)	<u>GCG</u>BF#E<u>GC</u>
Musical low attachment (MLA)	DAD<u>C#BF#C#F#</u>
Musical high attachment-Pause (MHP)	<u>CGC</u>EBE<u>FC</u> t
Musical low attachment-Pause (MLP)	ADA<u>C#G#F#C#G#</u>
Baseline prime (MB)	FCFFCFFC
Target sentence	Kevin counted the fans of the singer who

Procedure

Five randomized lists were created using a Latin square design. Each list comprised six randomized blocks. 120 fillers were created (60 language fillers, 60 musical fillers). Every block contained 20 musical fillers (these were sub-divided into nine types, resembling the prime music like and the prime pause like and they encoded no hierarchical structure), 20 language fillers (these were sub-divided into nine types, resembling the targets and contained some unrelated sentence types with connectives), five prime conditions and five targets (each block contained 30 items). The fillers were randomized and then inserted into the lists. It was manually ensured that no filler came in between a prime and a target sequence.

The lists were programmed in the Paradigm experimental software by Perception Research Systems. Participants were tested in individual sessions (~ 1 hour each), in which they were asked to perform two tasks—a language task and a music task. The language task required them to type in sentence completions into Paradigm. The music task asked them to do a rating on a scale of 1-5 (1- least melodious, 5- very melodious). They were told that there were no right or wrong answers with the sentence completion task and they should try not to skip any sentence completion. No details about the prime manipulations were revealed until debriefing. The program was run on a Windows 7 PC laptop, and the participants were told to click the left mouse button to continue onto the next screen. They listened to the music on a Philips headphones at a consistent volume of 40. Participants were given 4 trials as practice before they started the main experiment. Following completion of the experiment, participants were asked questions from a Music Training and Experience Questionnaire (adapted from Wei Looi 2006), designed to elicit information about the musical training and knowledge of the participants.

Results

Response Coding. Participants' written continuations were analysed and coded as High attachment (HA), Low attachment (LA), or not applicable/unclear (NA). The number marking of the verb following the relative pronoun aided the coding into a high or low attachment category (Refer Table 2). In some cases, the verb following the relative pronoun contained no information of number (Refer Table 2), in which case the responses were coded as "not applicable" due to missing information. These cases included fully ambiguous relative-clause attachments, ungrammatical responses, or responses that did not result in a relative clause.

Data Analysis. Statistical analyses were conducted using SPSS (ver 21). We performed a repeated measure ANOVA, two-tailed sample t-tests and one-tailed sample t-tests.

Rate of low attachment versus high attachment relative clause continuations. Overall 29 per cent of target completions were classified as high attachment, 65 per cent as low attachment, and 6

Table 2. Example target response completions

Response Type	Examples for target: *Angela gossiped with the secretary of the lawyers who*
High attachment	was arrogant about the results of the case; had affairs with everyone.
Low attachment	were busy with new interesting cases; were caught stealing the bag of Aztec gold.
Not applicable	conducted shady business; worked in the corner office

per cent as not applicable or unclassified. The finding that English has a basic low attachment bias fits with previous findings (Scheepers 2003, Desmet and Declercq 2006, Scheepers et al. 2011).

Now, let us take a look at the rates of high versus low attachment continuation rates in the five conditions. Overall, there is a low attachment bias in English which is not surprising. In the baseline condition (MB), we found an overall preference for low attachment completions (73.68 per cent of the total response completions were low attachments). However, with a musical high attachment prime (MHA) condition, the low attachment bias is weaker (73.68 per cent of low attachment continuations go down to 59.45 per cent). In the high attachment pause condition (MHP), the low attachment completions become weaker (only 57.27 per cent of the completions are low attachments). When the sentence fragment is preceded by a low attachment (MLA) prime, the low attachment bias is strengthened (73.68 per cent of low attachments in the baseline condition becomes 79.31 per cent in the MLA condition), and with the low attachment and pause prime, the low attachment bias is about the same as in the baseline prime (73.68 per cent in the baseline condition becomes 75.89 per cent in the low attachment and pause condition).

To see whether the different conditions had a significant bias for low attachments (or high attachments), we used one-sample t-tests conducted on the rate of low attachment continuations, with the mean hypothesized to be 0.5. We found that in the baseline condition (where the musical prime had no structure), the rate of low attachment continuations is significantly higher than chance (t_1 (19) = 3.890, $p< 0.001$, t_2 (29) = 3.890, $p < 0.001$). This is expected, given the existing finding showing that English RCs have a low attachment preference. The low attachment bias is also very strong in the two prime conditions where the musical cues bias low attachment: In the musical low attachment (MLA) condition, the rate of low attachment continuations is significantly higher than chance, as expected (t_1 (19) = 6.532, p< 0.001, t_2 (29) = 7.443, p < 0.001), similar to the musical low attachment and pause (MLP) condition (t_1 (19) = 5.138, p< 0.001, t_2 (29) = 4.557, p < 0.001). What about the conditions where the musical information is expected to bias high attachment? When the music prime was a high attachment prime (MHA condition), we see the rate of low attachment continuations is only slightly above chance (t_1 (19) = 0.781, p< 0.444, t_2 (29) = 0.925, p < 0.363). Furthermore, in the musical high pause condition (MHP) – where both the musical cues and the pause bias high attachment — we see that the results were not significantly above chance (t_1 (19) = 0.476, p > 0.5, t_2 (29) = 0.559, p > 0.5). In other words, the low attachment bias normally seen in English is completely absent in this condition, and also not reliable in the MHA condition.

Now, let us take a closer look at the effects of the variables that we manipulated, namely the **high attachment versus low attachment musical cues and the presence versus absence of the pause.** For the ANOVA analyses, the baseline condition was excluded, and we ran an ANOVA with two factors, namely (i) musical attachment height (HA musical prime versus LA musical prime), and (ii) pause (presence versus absence of pause between Zones 2 and 3).

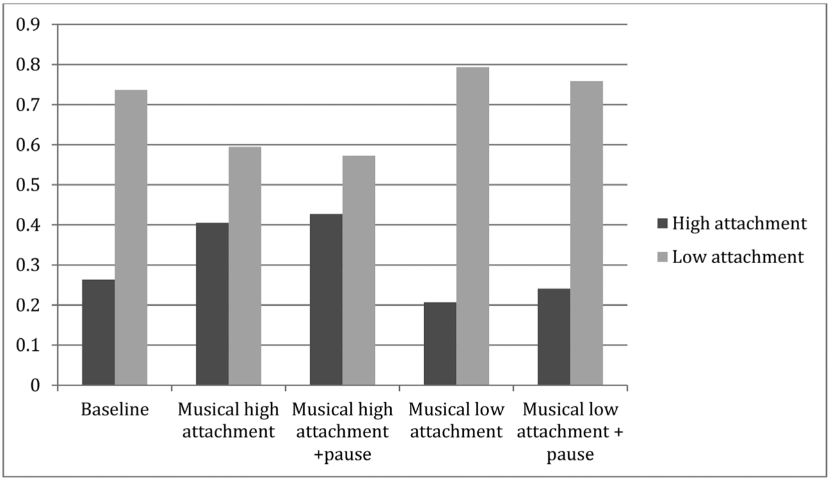


Figure 8. Results from experiment: Mean proportion of target response completions.

We next ran a repeated measures ANOVA on the independent variables- musical cues and pause versus no pause. Overall, we found a main effect of musical attachment height (f_1 (1,19) = 12.305, p = 0.002, f_2 (1,29) = 14.490, p = 0.001): low attachment musical primes resulted in a higher rate of low attachment RC continuations than did high attachment musical primes. In other words, the structure of the musical primes had an effect on people's linguistic completions. There was no main effect of pause versus no pause (f_1 (1,19) = 0.828, p= 0.374, f_2 (1,29) = 1.114, p = 0.3), and there was no interaction between the two factors (f_1 (1,19) = 0.088, p = 0.77, f_2 (1,29) = 0.066, p = 0.8).

Planned comparisons using paired t-tests were also conducted. We compared the rate of low attachment completions in the baseline condition and the musical high attachment condition, and found that there was a significant difference in the low attachment completions in the baseline condition (M=0.7, SD=0.19) and musical high attachment conditions (M=0.6, SD=0.32) conditions; t_1 (19)=2.102, p = 0.05, t_2 (29)=1.979, p = 0.05. We also compared the baseline to the musical high attachment pause condition, and found that there was a significant difference in the low attachment completions in the baseline condition (M=0.7, SD=0.19) and musical high attachment conditions (M=0.5, SD=0.3) conditions; t_1 (19)=2.437, p = 0.025, t_2 (29)=2.525, p = 0.017. In contrast, the rate of low-attachment continuations in the baseline condition did not differ significantly from the rate of low-attachment continuations in the music low attachment conditions (M= 0.7, SD= 0.18); t_1 (19)=-1.053, p = 0.3, t_2 (29)=-1.814, p = 0.245, and the musical low attachment pause conditions (M= 0.7, SD= 0.18); t_1 (19)=-0.305, p = 0.764, t_2 (29)=-0.254, p = 0.8.

Overall, if we collapse the musical high attachment and the musical high attachment pause conditions, and the musical low attachment and the musical low attachment pause conditions, we get the pattern shown in Fig 9:

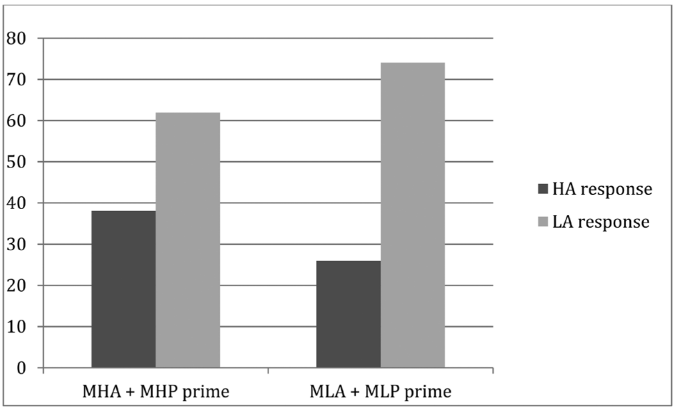


Figure 9. Overall priming effect

The high versus low primes were significant predictors for the type of sentence completions. Specifically there were 48 per cent more low attachment responses after a low attachment prime (MLA + MLP), whereas this number fell to 23.84 per cent after a high attachment prime (MHA + MHP). In other words, there was a 24.2 per cent priming effect (see Figure 11). The results are 10 per cent more than van de Cavey and Hartsuiker's (2016) results for musical priming in Dutch.

Musical bility and target completions

There was also an inverse patterning seen in the case of musical ability which the participants were asked to self-assess. Overall, participants with lower musical ability produced a higher proportion of high attachment completions than participants with higher musical ability (see Figures 10 and 11). There were five participants in each of the groups and the high musical ability group self-assess on a scale of 1-5 (1- less proficient, 5- highly proficient) at 4-5. The low musical ability group self-assesses at 1-2. Statistical analyses have not yet been conducted on this data, due to the small size of the group.

General Discussion

We found that the low-attachment bias normally seen in English is completely absent in the musical high attachment pause condition (MHP), and also not reliable in the musical high attachment condition (MHA). Overall, there was a main effect of musical attachment height. Low-attachment musical primes resulted in a higher rate of low attachment relative clause continuations than did high-attachment musical primes. In other words, the structure of the musical primes had an effect on people's linguistic completions.

The results of this experiment provide striking evidence for the domain general level of abstraction in the representation of hierarchical structural information. This challenges domain-specific theories that use local structures to account for syntactic priming. The results also challenge domain specific theories of syntactic processing. One possibility is the shared resource hypothesis (SSIRH) where there is a considerable overlap between resource networks. Put in other words, both language and music draw from a similar pool of limited processing resources to process incoming linguistic (syntactic) elements. A key prediction of the SSIRH is that syntactic integration in language should be more difficult when these limited integration resources are taxed by the concurrent processing of

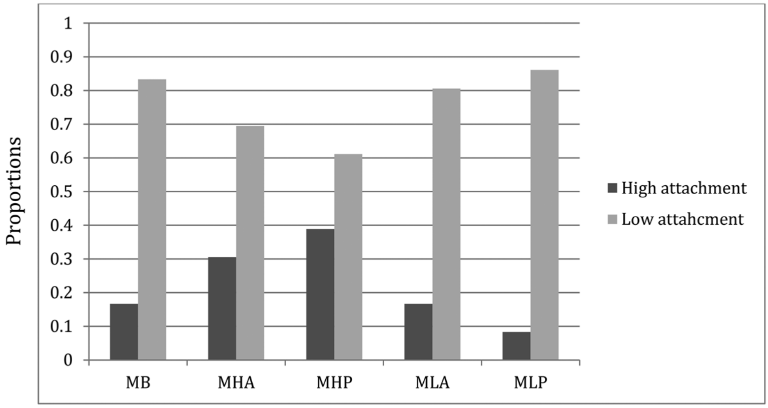


Figure 10: Target sentence completions by high musical ability participants (self-assessed as 4 on a scale of 1-5).

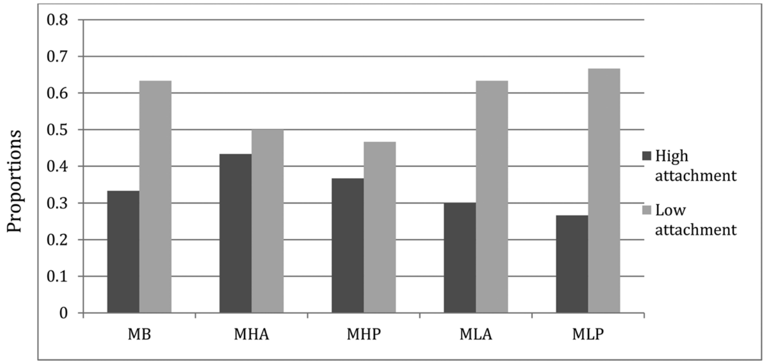


Figure 11: Target sentence completions by low musical ability participants (self-assessed as 1 or 2 on a scale of 1-5).

musical syntax (and vice versa). This is seen in the slowdown with RTs while the participants processed targets. Although there was a considerable slowdown with all of the targets, the slowdown was least when the participant gave an LA response (1389ms on an average) and it was highest when the participant completed the sentence fragment with a HA response (1870ms).

We built on van de Cavey and Hartsuiker (2016) by showing that the priming effect can actually be strengthened by using stimuli that sound more music-like. Our piano-generated melodies produced an overall priming effect of 24.2 per cent, a 10 per cent increase from van de Cavey's findings. We, however, could not find a main effect with the pause versus no pause condition, suggesting that musical cues are sufficient to get the priming effect without the additional pause cue that one might expect to matter.

An interesting thing to note is the difference in responses between self-assessed high-music ability participants and the self-assessed low music ability participants. The latter group (self-assessing at 1 or 2) performed considerably better than the high music ability group in completing HA completions (based on graphs only). This is contrary to our expectation. However, it has been seen in previous research that self-reported "years of musical training" may be a relatively imprecise measure of musical expertise (Slevc et al. 2009).

A potential possible confound with the pause condition could be that the place which we manipulated the pause was kept uniform across the two conditions, it was always after Zone 2 (the domain which is harmonically distant) and before Zone 3 (the domain which is harmonically similar to either Zone 1 or Zone 2). A better design could be to manipulate the pause after Zone 1 in the low attachment condition because this is the where the attachment is happening. This is currently being run as a follow-up study. (Menon and Iseminger, 2017; Menon and Coleher, in prep.)

Note

1. If considerable neural resources overlap in the activation of stored syntactic representations then this should lead to commonalities in structures built up for musical sequences and sentences. This then leads us to the big question of what does priming truly entail, (i) If there is priming, it could suggest that the representations are shared, or (ii) the processes of building up the representations and the mechanisms involved in using those representations are shared. We could have priming because the representations are the same even if the ways of using/activating those representations are different, or we could have priming because although the actual representations are different, there is something abstractly similar in how we process the representations. Or it could be that there is no clear distinction between the notion of representation and using that representation. We will not attempt to answer this bigger question in this paper, though see Wang et al (under revisions).

References

Antović, M. 2009. "Towards the Semantics of Music: The 20th century. *Language & History*, 52(1): 119-129.

Besson, M and D. Schön 2001. "Comparison Between Music and Language". *Annals of the*

New York Academy of Sciences 930 (June): 232-58.

Bharucha, J.J. 1984. "Event Hierarchies, Tonal Hierarchies and Assimilation: A Reply to Deutsch and Dowling." *Journal of Experimental Psychology*, General, 113, 421-5

Bock, J. K. 1986. "Syntactic Persistence in Language Production". *Cognitive Psychology*, *18*, 355–387.

Bock, J. K. and H. Loebell. 1990. Framing sentences. *Cognition, 35*, 1–39.

Dehaene, S., E. Spelke, P. Pinel, R. Stanescu and S. Tsivkin. 1999. "Sources of Mathematical Thinking: Behavioural and Brain-Imaging Evidence". *Science, 284*, 970–974.

Desmet, T. and M. Declercq. 2006. "Cross-Linguistic Priming of Syntactic Hierarchical Configuration Information". *Journal of Memory and Language, 54*, 610–632.

Gibson, E. 1998. Linguistic Complexity: Locality of Syntactic Dependencies. *Cognition*, 68, 1-76.

Gibson, E. 2000. "The Dependency Locality Theory: A Distance-Based Theory of Linguistic Complexity". Edited by Y. Miyashita, A. Marantaz, and W. O'Neil, *Image, Language, Brain.* Cambridge, MA: MIT Press. 95-126

Hartshorne, J.K and J. Snedecker. 2012. "Verb Argument Structure Predicts Implicit Causality: The Advantages of Finer-Grained Semantics". *Language and Cognitive Processes, iFirst,* 1-35.

Hartsuiker, R. J., H. H. J. Kolk and Ph. Huiskamp. 1999. "Priming Word Order in Sentence Production". *Quarterly Journal of Experimental Psychology,* 52A, 129-147.

Hartsuiker, R. J. and C. Westenberg. 2000. "Word Order Priming in Written and Spoken Sentence Production". *Cognition,* 75, ***B***27-B39.

Huron, D. (2006). *Sweet Anticipation: Music and the Psychology of Expectation.* Cambridge, MA: MIT Press

Jackendoff, R. and F. Lerdahl. 2006. "The Capacity for Music: What is It, and What's Special about It?" *Cognition,* 100, 33-72.

Jentschke, S., S. Koelsch, S. Sallat and A. Friederici. 2008. Children with Specific Language Impairment Also Show Impairment of Music-Syntactic Processing". *Journal of Cognitive Neuroscience,* 20(11):1940-1951.

Kaiser, E. 2009. "Effects of Anaphoric Dependencies and Semantic Representations on Pronoun Interpretation". Edited by S.L. Devi, A. Branco and R. Mitkov, *Anaphora Processing and Applications (Selected papers from the 7th Discourse Anaphora and Anaphor Resolution Colloquium),* Heidelberg: Springer. 121-130.

Katz, J. and D. Pesetsky. 2011. *The Identity Thesis of Music.* Ms. Institut Jean-Nicod and MIT.

Koelsch, S., T. C. Gunter, A. D. Friederici and E. Schröger. 2000. "Brain Indices of Music Processing: 'Non-Musicians' are Musical". *Journal of Cognitive Neuroscience,* 12, 520-541.

Koelsch S., T.C. Gunter, M. Wittforth and D. Sammler. 2005. "Interaction between Syntax Processing in Language and Music: An ERP Study". *Journal of Cognitive Neuroscience,* 17, 1565-1577.

Koelsch, S. 2009. "Music-Syntactic Processing and Auditory Memory: Similarities and Differences between ERAN and MMN. *Psychophysiology,* 46, 179–190.

Krumhansl, C.L. 1979. "The Psychological Representation of Musical Pitch in a Tonal Context. *Cognitive Psychology*, 11, 346-374.

Lau, E., C. Stroud, S. Plesch, and C. Phillips. 2006. The Role of Structural Prediction in Rapid Syntactic Analysis". *Brain & Language*, 98, 74-88.

Loncke, M., S.M.J. Van Laere, and T. Desmet. 2011. "Cross-Structural Priming : Prepositional Phrase Attachment Primes Relative Clause Attachment". *Experimental Psychology*,58, 227-234.

MacDonald, M. C. 1993. "The Interaction of Lexical and Syntactic Ambiguity". *Journal of Memory and Language*, 32, 692-715.

Maess, B., S. Koelsch, T. Gunter and A.D. Friederici. 2001. "Musical Syntax is Processed in Broca's Area: An MEG study". *Nature Neuroscience*, 4, 540-545.

Marslen-Wilson, W. D. 1975. "Sentence Perception as an Interactive Parallel Process". *Science*, 189, 226-228.

Menon, M. and D. Coleher. (in prep). Evidence for Syntactic Transfer from Langauge to Music. Poster to be presented at *AMLaP2018*, Berlin.

Menon, M. and K. Iseminger. 2017. Music Primes Relative Clause Completion in English. Poster presented at the *Society for Music Perception and Cognition Meeting 2017.* USCD, San Diego.

Patel, A.D. 2003. "Language, Music, Syntax, and the Brain". *Nature Neuroscience*, 6, 674-681.

Patel, A.D. 2008. *Music, Language, and the Brain.* New York: Oxford Univ. Press.

Patel, A. 2012. "Language, Music, and the Brain: A Resource Sharing Framework". Edited by P. Rebuschat, M. Rohrmeier, J. Hawkins, and I. Cross *Language and Music as Cognitive Systems* Oxford: Oxford University Press. 204-223.

Patel, A.D., E. Gibson, J. Ratner, M. Besson, and P. Holcomb. 1998. "Processing Syntactic Relations in Language and Music: An Event-Related Potential Study". *Journal of Cognitive Neuroscience*, 10, 717-733.

Peretz, I. 2003. "Brain Specialization for Music: New Evidence from Congenital Amusia. Edited by I. Peretz and R. Zatorre, *The Cognitive Neuroscience of Music.* Oxford: Oxford University Press, 192-203

Peretz, I. and M. Coltheart. 2003. "Modularity of Music Processing". *Nature Neuroscience* , vol. 6(7), 688-691

Pickering, M. J., and H. P. Branigan. 1998. "The Representation of Verbs: Evidence from Syntactic Priming in Language Production". *Journal of Memory and Language*, *39*, 633–651.

Pickering, M .J. and V. S. Ferreira. 2008. "Structural Priming: A Critical Review". *Psychological Bulletin*, 134, 427-459.

Pickering, M. J., H. P. Branigan and J. F. McLean. 2002. "Constituent Structure is Formulated in One Stage. *Journal of Memory & Language,* 46, 586-605.

Rohde, H. 2008. *Coherence-Driven Effects in Sentence and Discourse Processing.* San Diego: University of California.

Rohde, H., R. Levy and A. Kehler. 2011. "Anticipating Explanations in Relative Clause Processing". *Cognition*, 118: 339-358.

Scheepers, C. 2003. Syntactic Priming of Relative Clause Attachments: Persistence of Structural Configuration in Sentence Production. *Cognition*, 89, 179-205.

Scheepers, C., P. Sturt and C.J. Martin. 2011. "Structural Priming Across Cognitive Domains: from Simple Arithmetic to Relative-Clause Attachment". *Psychological Science*, 22, 1319-1326.

Slevc, L. R., J. C. Rosenberg and A. D. Patel. 2009. "Making Psycholinguistics Musical: Self-Paced Reading Time Evidence for Shared Processing of Linguistic and Musical Syntax". *Psychonomic Bulletin and Review*, 16, 374-381.

Thompson, W.F., and L. L. Cuddy. 1992. "Perceived Key Movement in Four-Voice Harmony and Single Voices". *Music Perception*, 9, 427-438.

Tillmann, B., J .J. Bharucha and E. Bigand. 2000. "Implicit Learning of Tonality: A Self- Organizing Approach". *Psychological Review*, 107, 885-913.

Van de Cavey, J. and Robert Hartsuiker. 2016. "Is there a Domain-General Cognitive Structuring System? Evidence from Structural Priming across Music, Math, Action Descriptions, and Language". *Cognition*, 146, 172-184.

Wang, Hao Felix, Mythili Menon and Elsi Kaiser. (under revisions). "Statistical Structures in Artificial Language Primes Relative Clause Attachment". *Journal of Experimental Psychology: Learning, Memory, and Cognition.*

Appendix 1

List of Targets

1. Anna studied with the chef of the aristocrats who
2. John lived next to the teacher of the second graders who
3. Jenny joked with the maid of the executives who
4. Nick stood near the captain of the sailors who
5. Angela gossiped with the secretary of the lawyers who
6. Bob greeted the leader of the activists who
7. Laura knows the manager of the cashiers who
8. Zack recognized the daughter of the shopkeepers who
9. Sarah jogs with the uncle of the toddlers who
10. Adam resembled the representative of the employees who
11. Tina met the gardeners of the millionaire who
12. Justin carpools with the cousins of the accountant who
13. Emily waited with the nieces of the florist who
14. Joe ran into the brothers of the athlete who
15. Jessica worked with the doctors of the supermodel who
16. Brian visited the associates of the businessman who
17. Melissa babysits the children of the musician who
18. Frank talked to the servants of the dictator who
19. Tracy chatted with the bodyguards of the celebrity who
20. Kevin counted the fans of the singer who
21. James appreciated the servant of the anchorists who
22. William watched the student of the teachers who
23. Lisa saw the accountant of the chefs who
24. Sandra toiled with the farmer of the landlords who
25. Ron read to the kids of the boxer who
26. George went with the sisters of the comedian who
27. Nancy took the babies of the friend who
28. Carol studied the sons of the doctor who
29. Mathew recommended the psychiatrist of the sopranos who
30. Ivana alerts the refugees of the mother who