1 **Shared Structuring Resources Across Domains:**

2 **Double task effects from linguistic processing on the structural integration of pitch sequences**

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4 **Authors:** J. Van de Cavey*¹, E. Severens¹, R.J. Hartsuiker¹

5
6 **Affiliations:**

7 ¹ Department of Experimental Psychology, Ghent University

8 Henri Dunantlaan 2

9 Ghent, Belgium

10 Tel: +32 9 264 86 27

11 Fax: +32 9 264 6496

12
13 *Correspondence to: joris.vandecavey@ugent.be

Abstract:

Many studies have reported evidence suggesting that resources involved in linguistic structural processing might be domain-general by demonstrating interference from simultaneously presented non-linguistic stimuli on the processing of sentences (Slevc, Rosenberg, & Patel, 2009). However, the complexity of the analyzed linguistic processes often precludes the interpretation of such interference as being based on structural - rather than more general - processing resources (Perruchet & Poulin-Charronnat, 2013). We therefore used linguistic structure as a source of interference for another structural processing task, by asking participants to read sentences while processing experimentally manipulated pitch sequences. Half of the sentences contained a segment with either an “out-of-context” sentential violation or a “garden path” unexpectancy. Furthermore, the pitch sequences contained a cluster shift which did or did not align with the sentential unexpectancies. A two-tone recognition task followed each pitch sequence, providing an index of the strength with which this structural boundary was processed. When a “garden path” unexpectancy (requiring structural reintegration) accompanied the cluster shift, the structural boundary induced by this shift was processed more shallowly. No such effect occurred with non-reintegratable “out-of-context” sentential violations. Furthermore, the discussed interference effect can be isolated from general pitch recognition performance, supporting the interpretation of such interference as being based on overlapping structural processing resources (Kljajevic, 2010; Patel, 2003).

Keywords: Language, SSIRH, Syntax, Domain-general

INTRODUCTION

The organisation of discrete elements into a hierarchical structure is a necessary component in language comprehension. The syntactic rules of a language, governing the relation between words, allow for complex structures to be produced and interpreted. It is important to note that this function, though studied extensively in the domain of language, pertains to other domains as well. Music for example also involves a specific set of rules that govern the structuring of sequences and combinations of musical notes (Patel, 2003; 2008). Similarly to syntactic processing, our ability to process such musical structure seems to be based on mere exposure to the rule set, rather than formal training (Koelsch, 2005; Koelsch, Gunter, Friederici, & Schröger, 2000). The structural processing of sequences thus seems to have analogies between language and music.

In recent years, there has been an increase of interest in such findings of similarity between sequential processing of linguistic and non-linguistic materials. Several neurophysiological studies have shown large overlap in the brain areas and ERP components underlying linguistic and musical processing (Maess, Koelsch, Gunter, & Friederici, 2001; Patel, Gibson, Ratner, Besson, & Holcomb, 1998), suggesting that strongly aligned, if not overlapping, processes might be at work. This suggestion of overlap in structure processing across domains has been further developed by Patel (2003) who proposed the Shared Syntactic Integration Resource Hypothesis (SSIRH). Specifically, this model distinguishes between (a) the representational network, which stores long-term knowledge that guides the structural integration, and (b) the limited (neural) resources, which are dedicated to structural integration. The SSIRH claims that, whereas the representational networks are domain-specific, the resources that are needed for structural processing based on these representations may strongly overlap between domains (as presented in Figure 1).

[Figure 1 around here]

The SSIRH model makes predictions about situations where music (as a specific non-linguistic domain) and language are processed simultaneously. During such joint processing, structural integration processes in both domains would make a demand on a single, shared resource pool. Therefore, providing a structural integration difficulty simultaneously in both domains should lead to a depletion of resources, so that the structural processing in one domain would interfere with the structural processing in the other domain. This claim was tested by Slevc, Rosenberg, and Patel (2009) in a self-paced reading task. They found that during simultaneous processing, the presentation of harmonic unexpectancies increased the slowdown found during the reading of syntactic garden path unexpectancies. In contrast, harmonic unexpectancies did not modulate the effects of semantic unexpectancies in sentences. Slevc et al. interpreted these findings as direct evidence for the SSIRH's claim for shared structural integration resources. Furthermore, similar linguistic influences on music-related ERP measures have been found. For example, Steinbeis and Koelsch (2008) found a reduced early Right Anterior Negativity (eRAN, associated with processing structural difficulties in music) when a syntactic (but not a semantic) unexpectancy was presented in a sentence simultaneously with a harmonic unexpectancy.

Although these previous studies support the claims of the SSIRH (Patel, 2003), several questions remain to be addressed. For example, neurophysiological studies (Steinbeis & Koelsch, 2008) find influences from linguistic processing on musical processing, suggesting that the behavioral effects found by Slevc et al. (2009) might only reveal one side of a bidirectional influence. Such a claim follows the SSIRH, which predicts that the sharing of syntactic integration resources will lead to interference during simultaneous processing of music and language, both when participants are asked to respond to linguistic *and* to non-linguistic materials. However, research still needs to further address the possibility of interference effects on direct measures of structural integration in non-linguistic stimuli.

1 Also, previous research has, either neurophysiologically (Steinbeis & Koelsch, 2008) or
2 behaviorally (Slevc et al., 2009), measured structural processing by investigating the additional effect of
3 processing difficulties in one domain on unexpectancy resolution in the other domain. It might be
4 worthwhile to investigate whether such interference can also be found when the processed materials
5 contain no such unexpectancies. Do we find interference only when measuring reintegration processes or
6 also when measuring the processing of structurally sound materials? In our study, we investigated the
7 processing of structural unexpectancies in the linguistic domain upon the integrational processing of
8 *structurally robust* pitch sequences.

9 Furthermore, Perruchet and Poulin-Charronnat (2013) showed that previous findings of
10 interference between the processing of harmonically unexpected chords and simultaneously presented
11 syntactic “garden path” disambiguation (e.g. “After the trial the attorney advised (*that*) the defendant was
12 likely to commit more crimes”, Slevc et al., 2009), could be replicated using a semantic “garden path”
13 unexpectancy (e.g. “The old man went to the (*river*) bank to withdraw his net which was empty”). This
14 finding has two implications. First, the finding of such an interaction between music and semantic
15 reintegration suggests that the reintegration process, more so than the syntactic rules on which it is based,
16 drives the previously found interference effects. This suggests a more broad interpretation of “structural
17 integration mechanisms” as described by Patel (1998, p. 39: “*For language, I mean the linking of the
18 current input word to past dependents in a string of words, with the assumption that this integration is
19 more costly when dependencies are more distant, when they must reactivate dispreferred structures, or
20 when they are simply impossible.*”). This recent topic of debate thus suggests that further research might
21 benefit from using “dependency processing” as a central concept *across* syntax and semantics (in contrast
22 to the narrow definition of “syntactic” processing resources by the SSIRH, Patel, 2003). Indeed, several
23 recent theories investigating structural processing across domains (such as the Syntactic Working Memory
24 account, Kljajevic, 2010) proposed an overlap in *dependency processing resources*, required for
25 processing (syntactic or thematic) dependencies between elements. Importantly, also in the current study,

we interpret both the SSIRH (Patel, 2003) and the SWM (Kljajevic, 2010) as models suggesting an overlap in resources involved in processing the dependencies of integrational structures .

Second, the finding of interference between harmonic incongruency processing and semantic garden path disambiguation also raises some concerns about the theoretical interpretation of previous studies (e.g., Slevc et al., 2009). Given Perruchet and Poulin-Charronnat's findings, it seems that cross-domain interference during unexpectancy processing can be found for both semantic and syntactic garden paths, but not for semantic violations. Therefore, it seems that such interference depends on the processes involved in dealing with the unexpectancy (i.e., garden path unexpectancy versus simple violations), and not the unexpectancy being semantic or syntactic in nature. This shift in interpretation has led to the suggestion of a possible confound with attention (Perruchet & Poulin-Charronnat); if it is the "complexity" of the unexpectancy (read: the amount of implied structural reprocessing) that distinguishes whether interference is found, then maybe more general attentional resources could play a large role. Such attentional accounts need further investigation.

To address the abovementioned research questions, we have elaborated upon the paradigm of Slevc et al. (2009), contrasting the effect of "garden path" sentence unexpectancies that instigate a reconstruction of the abstract hierarchical representation (e.g., "I see the criminals robbed BY the police", as contrasted to a highly frequent baseline structure involving the second noun phrase as a patient, (e.g., "I see the criminals follow the woman") with the effects of sentence unexpectancies in which the critical word is "out-of-context" and thus does not involve a manipulation on the level of dependency relationships within the sentence (e.g., "I see the criminals DOVE by the police").

Similar to Slevc et al. (2009), these sentences will be provided simultaneously with rule-governed auditory sequences. In contrast to earlier studies however, we will use the structural processing of these auditory sequences as a dependent measure, allowing us to investigate possible interference effects on basic non-linguistic integrational processing. Importantly, these auditory sequences themselves contained no unexpectancies, allowing us to measure the integrational processing of structurally robust materials.

Also, we should note that we have used tone progressions in the present study, as opposed to the chord sequences used in previous studies (Slevc et al., 2009). This change was made to simplify the non-linguistic structure to a simple pitch sequence structure, which allowed for the integrational processing measure we explain below.

Measuring structural integration through recognition

To create a measure of structural integration processing in a non-linguistic domain, we have adapted the probe recognition task used by Tan, Aiello, and Bever (1981). Tan et al. provided subjects with a melody, which they were required to listen to attentively. During a subsequent two-tone probe recognition task, participants judged whether the two probe tones were present in the preceding melody (in the same order). Importantly, Tan et al. included a harmonic boundary in the melody, so that upon processing its harmonic structure, the melody would be perceived as two-phrased (see Figure 2).

[Figure 2 about here]

Tan et al. (1981) observed that participants found it significantly harder to accurately recognize the probe tone pair if these tones were separated by such a harmonic boundary. Moreover, this recognition effect was stronger with participants who had more musical experience aiding them in detecting this harmonic shift (around 7.5 % for non-musicians, versus around 28 % for musicians). Tan et al. argued that the difference in performance on the “between probes” (i.e., recognition probes consisting of the tones spanning the harmonic boundary) versus the “within probes” (i.e., recognition probes consisting of tones within a harmonic phrase), was due to the participants having a parsed representation of the melody. This “within probe” advantage on the recognition task would occur since, upon processing the harmonic boundary in the melody, the representation of the melody would have an increased sequentiality of tones

1 within a same harmonic phrase (sampled in “within probes”), and it would have a decreased sequentiality
2 of the tones spanning a harmonic boundary (sampled in “between probes”). In other words, the authors
3 argued that the “within probe” advantage on the recognition task is a result of structural integration of the
4 melody, leading to a parsed representation of the melody. We denote this effect as the boundary
5 processing effect (BPE); when comparing pitch sequences that are structurally processed to pitch
6 sequences that are not structurally processed, the recognition of “between probes” (spanning pitch
7 boundaries) will be decreased and the recognition of “within probes” (within pitch boundaries) will be
8 increased, leading to a “within probe” advantage.

9 In this paper, we used non-linguistic pitch sequences, which also included structural boundaries.
10 Though these pitch sequences are not “musical”, or created based on tonal harmony (a requirement to
11 ensure that the structuring effort was not dependent on musical knowledge), they contained boundaries
12 based on easily acquired grouping rules. The reason for this choice is that we wanted to avoid any
13 influence of explicitly acquired knowledge (e.g., music theory) during the processing of the pitch
14 sequences. Regardless of these differences, we still expect a BPE when comparing pitch sequences with a
15 processed boundary to pitch sequences where this boundary was not processed. To be able to replicate the
16 BPE in our task, we needed to allow for good recognition performance. This is why, instead of the chord
17 sequences provided in earlier experiments (e.g., Slevc et al., 2009; Perruchet & Poulin-Charronnat, 2013),
18 we opted for simple tone sequences.

20 **Current study**

21 In this study, we addressed the claim that structural processing of both linguistic and non-
22 linguistic materials might draw on the same pool of resources (SSIRH, Patel, 2003). In contrast to
23 previous research (Slevc et al., 2009), which has focused on a linguistic measure of interference, we aimed
24 to test whether there is interference from linguistic syntax upon non-linguistic processing. Based on the

SSIRH (Patel, 2003), we predicted that providing structural integration difficulties in language and non-linguistic pitch sequences simultaneously should lead to interference. Such interference should occur only when a linguistic unexpectancy is provided simultaneously with the structural shift in the pitch sequence, and when this linguistic unexpectancy triggers a reintegration of the sentential structure (garden path unexpectancies, but not unexpectancies that are “out-of-context” to the sequence and thus do not trigger dependency processing, Perruchet & Poulin-Charronnat, 2013; Slevc et al., 2009). This predicts a BPE (i.e., better performance on “within probe” recognition and worse performance on “between probe” recognition) in the conditions where we expect intact processing of the boundary (all no overlap conditions, and the overlap conditions using sentences containing an “out-of-context” violation), compared to the condition where we expect poor boundary processing (the overlap condition where the sentence contained a “garden path” unexpectancy). Thus, we expect a three-way interaction between probe type (within vs. between), overlap (overlap vs. no overlap), and sentence type (“out-of-context” vs. “garden path” unexpectancies), reflecting a decreased “within probe” advantage when there is an overlap between the sentence manipulation and the structural boundary in the pitch sequences, but only when the sentence manipulation is a garden path unexpectancy.

METHOD

Participants

We recruited 40 participants from the student pool of Ghent University (average age = 18, age range 17-21, 4 men, 36 women), who participated for course credits. We ran participants until the predetermined sample size of 40 was reached. Because of the limited availability of participants during

certain periods of the year, there was a time gap of about half a year between testing the first and the second group of 20 people. Grouping based on testing moment was included as a control variable in our design, but yielded no statistical differences. No participants were removed. Participants were not selected on the basis of their musical abilities, given that the pitch sequences did not consist of tonal compositions based on Western Tonal Harmony. However, after obtaining informed consent for the experiment, we measured the number of years spent on formal musical training (which ranged from 0 to 11 years, mean of 2.65 years), and included that variable in our analyses, so as to control for possible explicit tracking of pitch tones (which might be possible for people with high musical training).

Materials

All procedures, materials, programs, raw and processed data, and analyses are freely accessible at the Open Science Framework (<http://openscienceframework.org/profile/v49bp>).

We presented three sentence types in Dutch, namely control sentences, sentences containing a garden path unexpectancy, and sentences containing an “out-of-context” unexpectancy (i.e., a word category violation, where a noun replaces a verb). The stimulus list consisted of 96 sentences, preceded by 4 practice sentences. Each sentence contained eight segments. Half of the sentences were control sentences (48), which always had the following surface structure: “Imperative verb | noun phrase | complementizer | noun phrase | passive participle | auxiliary | preposition | noun phrase”. An example sentence is “Zeg | de arts | dat | zijn zoon | ontvangen | wordt | in | de hal” (meaning “*tell / the doctor / that / his son / received / is / in / the hallway*”, word-by-word translation, or “*tell the doctor that his son is received in the hallway*”)¹. We used a fixed sentence structure for all control sentences in order to create a strong expectation for the passive voice in the complement clause of garden path sentences as well.

¹ Note that in Dutch, an auxiliary verb can follow the past participle (e.g. “dat de bal gestolen was” would be an appropriate Dutch translation of “that the ball was stolen”). Following control sentences, the participant would

The other half of the sentences consisted of experimental sentences (48), which contained linguistic unexpectancies. Of these experimental sentences, 50% contained an “out-of-context” violation, which took place either at the third or sixth sentence segment and which did not allow for any possible revision. For example, a sentence with a violation at the sixth segment would be “Vraag | de directeur | of | de dossiers | opgehaald | plek | door | de secretaris” (meaning “ask | the director | if | the files | fetched | PLACE |by |the secretary”, word-by-word translation).

The other 50% of the experimental sentences contained a “garden path” ambiguity, with the disambiguating word either at the third or the sixth sentence segment. An example of disambiguation at the sixth segment would be “Vraag |de agent| of | de inbreker |onderschept |welke | berichten |er zijn” (meaning “Ask |the policeman | whether |the burglar | caught |WHICH |messages |there were”, word-by-word translation). The correct reading of the sentence has a different structure from the control sentences, but we assumed that the participants would often initially adopt the garden-path reading of a passive voice in the complement clause (i.e. “the burglar caught” would be expected to be followed by “was”, making “the burglar” the patient of the verb), both because of the verb’s semantics (i.e., a burglar is likely to get caught) and in light of the high frequency of a passive voice in the complement clause in the experiment overall. Importantly, once the infelicity of the initial reading is detected, a reconstruction of the sentential structure is possible, which leads to a comprehensible sentence.

The pitch sequences consisted of 8 pitches, which were created out of sine waves and had a fixed duration of 230 ms, separated by 70 ms silences. Their frequencies ranged from 196.00 to 698.46 Hz and corresponded to 18 pitches: G³, Ab³, A³, B³, C⁴, Db⁴, Eb⁴, E⁴, F⁴, and the same set repeated one octave higher. To create experimentally manipulated structural boundaries, we applied a novel grouping rule on pitch sequences, thus being able to create and break a simple expectancy pattern that could be easily

expect the use of a passive voice (e.g. “that the girl investigated....was”). A garden path manipulation could then be to contrast these expectations for a passive voice (e.g. “that the burglar caught... was) by having an active voice in the complement clause (e.g. “that the burglar caught....the message”).

acquired. We subdivided the pitches that could be played into three clusters: notes A-B-E, notes Ab-Eb-Db, and notes C-F-G (See Figure 3).²

[Figure 3 about here]

Whereas the first tone was randomly selected out of all 18 possibilities, the following tones were randomly chosen to be one of the two closest neighbors (in frequency) above or below the preceding tone, *selected within the same cluster*. Importantly, there was no other structure in the sequences, except for this cluster grouping. Therefore, it was expected that their underlying structure would be easily acquired regardless of formal music knowledge. An illustration can be found in Figure 4. For every trial, a pitch sequence was randomly created with the abovementioned characteristics.

[Figure 4 about here]

Importantly, a cluster shift was included in all pitch sequences. This cluster shift encompassed that a pitch was taken randomly from all pitch possibilities outside the pitch cluster of the preceding pitch. For example “A B A | G C F G C” includes a cluster shift from the third to the fourth pitch, where there is a shift from the “ABE” to the “CFG” cluster. The position of this cluster shift occurred either on the 3rd-4th pitch (50%) or the 6th-7th pitch (50%), and was manipulated to investigate the effects of overlap with the sentence irregularities presented at the 3rd or 6th sentence segment. We chose to align the linguistic unexpectancy with the pitch preceding the cluster shift, given the fast presentation time of each segment

² Please note the clustering presented in Figure 3. We grouped tones into pitch clusters on The Circle of Fifths, separating each cluster by maximally one tone. When regarding the Circle of Fifths as an overview of harmonic closeness, we can thus see that within-cluster transitions (e.g., G to F) can be similar in harmonic closeness as compared to between-cluster transitions (e.g., F to Eb). The clustering further did not follow harmonic composition.

(370 ms), so that the cluster shift would be detectable within 400 ms after the linguistic unexpectancy presentation, which should create overlap (see procedure).

For the recognition probes, the “between probes” (1/3 of trials) were selected to be the two tones spanning the shift in the preceding pitch sequences. The “within probes” (1/3 of trials) were selected randomly from all possible segments of 2 sequentially presented pitches in the preceding pitch sequence that did not span the cluster shift. The “foil probes” (1/3 of trials) were incorrect recognition probes, and consisted of a random combination of two pitches that *were* presented in the preceding sequence, yet not in that sequential order.

Procedure

Participants received task instructions and then performed four practice trials to familiarize themselves with the experiment. The practice sentences had a different structure from the control and experimental trials. After practice, participants performed 96 trials, with each trial consisting of a simultaneous presentation of pitch sequences and sentence segments, followed by a pitch recognition task (Figure 5). The presentation of the trials was randomized. To indicate the start of a trial, a fixation cross was presented for 500ms. After this, the eight sentence segments were presented in Arial 12 font against a black background, for 370 ms, separated by 200 ms breaks. The onset of pitches was aligned with the onset of the sentence segments. After presentation of the complete sentence and pitch sequence, the participants heard a two pitch fragment. They judged whether this two-pitch fragment had occurred in the previously heard pitch sequence by clicking left or right for “correct” or “incorrect”, respectively. After this judgment, a fixation cross appeared and the next trial started. However, to ensure attentive reading, a button appeared instead of the fixation cross on eight random trials. Participants were instructed to then write down the previously read sentence on the back of their music questionnaire, before clicking the button to continue; they performed this reproduction task accurately in 79% of the cases. Furthermore,

1 participants received 20 easy comprehension prompts randomly dispersed across trials, as to heighten the
2 attention towards sentence processing. No trials were removed.

3
4 [Figure 5 about here]
5

6 **Design and Analyses**

7 The experiment had a 2 (“overlap” / “no overlap” between unexpectedness and pitch cluster
8 boundary) X 3 (“control” / “garden path” unexpectedness / “out-of-context” violation) X 3 (recognition of
9 “between probe”/ “within probe”/ “foil probe”) design. All variables were manipulated within-
10 participants. There were four trials per condition. We ran lmer analyses, treating years of formal training,
11 sentence condition, critical overlap (between linguistic unexpectedness and pitch boundary), and probe
12 condition as predictive variables for recognition performance (which was the binomial dependent
13 variable). Furthermore, we also included the trial number as a covariate measure.

14 The analyses were run on R (version 3.1.2), using the lme4 package (version lme4_1.1-7). To
15 achieve the optimum lmer model, random slopes for all independent variables were tested incrementally
16 for subjects and items, starting from the “random intercepts”-only model. The best model fit was obtained
17 with “overlap” and “recognition” probe as independent variables. This model was run with the settings for
18 a binomial dependent measure, and included a random intercept across participants and items, and a
19 random slope for the recognition probe across participants. P-values were determined based on the z-
20 values within the glmer model.

22 **RESULTS**

23

Table 1 provides an overview of the recognition performance of all probe types across the different sentence conditions. Overall accuracy on the probe recognition task was 63%. There were 68% correct recognitions for “between probes”, 74 % correct recognitions for “within probes”, but only 48% correct rejections for foils. The d' scores were 0.59 for the within-phrase probes and 0.41 for the between-phrase probes, respectively. According to the best fit model reported above, there were more correct responses to the “within probes” and “between probes” (i.e., hits) on average, than to the foils (i.e., correct rejections): ($\beta = -0.77482$, $z = -5.856$, $p < .001$). The low number of correct rejections of foils likely results from ordering errors, as foils consisted of pitches that were presented in the pitch sequence but in the reversed order. The difference in “within probe” and “between probe” performance was also significant ($\beta = -0.2534$, $z = -3.113$, $p < .01$), which clearly demonstrates that in general, phrase boundaries were processed. Regarding the trial progression, a small, non-significant increase in correct probe recognition (between and within-probes) as compared to foil performance could be observed.

[Table 1 about here]

Importantly, there was a significant interaction between how much the “within probe” performance differed from the “between probe” performance and whether or not a sentential unexpectancy was presented simultaneously with the structural shift in the music. In line with a BPE, the advantage for “within probes” over “between probes” was stronger when there was no overlap between the pitch boundary and an unexpected sentence segment ($\beta = 0.2305$, $z = 2.526$, $p = .012$). There was no significant difference in “foil” probe performance when contrasting “overlap” to “no overlap” conditions.

Although “sentence type” in general did not significantly improve the fit of the lmer model, it remains important to our theoretical hypothesis to look at the three-way interaction between overlap condition (“overlap”/ “no overlap”), probe type (“within”/ “between”/ “foil”) and sentence condition

(“control” / “out of context” violation / “garden path” unexpectancy). Therefore, we ran the lmer model including sentence type as an independent variable. This model showed the general “within probe” advantage ($\beta = -0.249$, $z = -2.419$, $p = .016$). However, the three way interaction between probe type, overlap and sentence type did not approach significance ($\beta = 0.321$, $z = 1.423$, $p = .155$). Nevertheless, it is important to acknowledge that the overlap*condition interaction includes 5 out of 6 cells in which no difference in the “within probe” advantage is expected or found. Though it is perfectly in line with our hypotheses to only find a decreased “within probe” advantage in the “garden path /overlap” conditions, this imbalance between critical and control conditions may have seriously reduced the power of the three-way interaction. In fact, using simple contrasts, we do find that the “within probe” advantage is significantly smaller for the “garden path/overlap” condition as compared to all five other conditions: “overlap/control” ($\beta = 0.35022$, $z = 2.215$, $p = .027$), “overlap/out of context” ($\beta = 0.4112$, $z = 2.269$, $p = .023$), “no overlap/control” ($\beta = 0.507$, $z = 3.195$, $p = .001$), “no overlap /garden path” ($\beta = 0.4917$, $z = 2.593$, $p = .009$), “no overlap /out of context” ($\beta = 0.56203$, $z = 2.992$, $p = .027$). Furthermore, the “within probe” advantage was not significantly different when comparing any of the other conditions with each other. Given that the data pattern thus follows our expected pattern and that the “garden path/overlap” condition shows significant differences in the “within probe” advantage as compared to all other conditions, we decided to further split up the data to investigate these effects.

Within the “no overlap” data there was a significant “within probe” advantage ($\beta = -0.263$, $z = -2.584$, $p = .01$). Furthermore, there was a significantly lower performance for foil probes ($\beta = -0.741$, $z = -4.885$, $p < 0.001$) as compared to “within probes” and “between probes”. However, no significant interaction with sentence type was present, as expected.

Within the “overlap” data, we found a significantly lower performance for foil probes ($\beta = -0.661$, $z = -4.462$, $p < .001$). Importantly, we also found an interaction between sentence type and probe type ($\beta = 0.343$, $z = 2.188$, $p = .029$). More specifically, sentences containing a garden path unexpectancy had a poorer performance on “within probe” recognition and a higher performance on “between probe” trials as

1 compared to the other sentence conditions in our “overlap” data, resulting in a strongly decreased “within
2 probe” advantage to the point of a small “within probe” disadvantage.

3 Figure 6 illustrates the differential recognition performance, specifically in the condition where a
4 structural shift in the pitch sequence co-occurred with a garden path unexpectancy in the sentence (see
5 Table 1) .

6 [Figure 6 about here]

7
8 It is important to note that, although we did hypothesize a BPE when comparing all other
9 conditions to the “overlap/garden path condition”, we did not a priori hypothesize that there would be a
10 “within probe” *disadvantage* in the “overlap/garden path condition” (see Figure 7). Rather, based on the
11 assumption that the pitch sequence would not be structurally integrated, a similar performance for “within
12 probes” and “between probes” performance might have been expected. Given that the “within probe”
13 disadvantage was not expected and is not significant by conventional standards (although admittedly close
14 to it, $\beta = 0.271$, $z=1.903$, $p = 0.06$), we will refrain from extensive speculation about any reasons for it. As
15 illustrated in Figure 7, there might be a slight “baseline” preference in our stimuli, so that when there is no
16 structural processing at all, there is a slight “between probe” advantage. For the goals of the current paper,
17 it is more important to have established a BPE in those conditions where we expected it.

18
19 [Figure 7 about here]

20
21 Finally, it is important to acknowledge that the amount of formal musical training of the
22 participants did not significantly affect recognition performance, as can be expected given the novelty of
23 our experimentally manipulated pitch sequences. This lack of an expertise effect suggests that the

structures could not easily be recognized in an explicit manner. Table 2 shows how the amount of formal training of the participants relates to the performance on the recognition task. Though there is a slight indication for the “within probe” advantage to increase alongside years of formal musical training, this is far from significant.

[Table 2 around here]

DISCUSSION

The goal of the current study was to provide a new test of the hypothesis that there is an overlap in resources for structure processing across domains (Kljajevic, 2010; Slevc et al., 2009). Whereas previous research has mostly directly investigated this claim by addressing the interference of non-linguistic manipulations on syntactic processing in language, some doubt has been cast on whether the nature of the interference is syntactic (Perruchet & Poulin-Charronnat, 2013). Therefore, we developed a novel paradigm in which the influence of sentential syntax processing on the structuring of basic pitch sequences was investigated.

Using a dual task paradigm, we provided sentences containing reintegratable and non-reintegratable unexpectancies simultaneously with pitch sequences that entailed a cluster shift. We found a BPE (which is an indication for stronger structural processing of the pitch sequence) when comparing sentences containing no unexpectancy or an “out-of-context” unexpectancy simultaneously with the pitch boundary to sentences containing a “garden path” unexpectancy simultaneously with the pitch boundary. The BPE thus indicates that, specifically when the pitch boundary was matched to a sentential unexpectancy *that required structural reintegration*, there was a weaker structural processing of this pitch boundary.

1 These findings provide suggestive evidence in favor of models such as the Shared Syntactic
2 Integration Resource Hypothesis (Patel, 2003), which suggests that the integrational resources that are
3 required in the structural processing of linguistic and non-linguistic materials are shared between the two
4 domains. As we found suggestive evidence in favor of interference between structural processing in
5 linguistic and non-linguistic domains on the basis of syntactic garden paths, yet not word category
6 violations, this does suggest an interpretation beyond syntactic processing resources to structural
7 reintegration resources. This is in line with the recent findings by Perruchet and Poulin-Charronnat (2013),
8 where interference effects found were also dependent on whether or not the sentential unexpectancies
9 invoked structural reintegration.

10 We admit that the finding of a small numerical “within probe” disadvantage in the condition
11 where no structural processing was argued to occur, is rather unexpected. As this difference did not reach
12 significance, it may be reflect nothing more than noise in our data. However, assuming there is really such
13 a within probe disadvantage, how can we explain a baseline level where, without structural processing,
14 there is a better performance for “between probes” versus “within probes” performance, when the
15 structure of the pitch sequence is not processed? One might argue that the “between phrase” tones have a
16 higher saliency than the “within phrase” tones, even if the pitch sequence is not structurally processed. A
17 reason for this might be that these “between phrase” transitions draw more attentional resources based on
18 the pitch cluster transition between the novel and preceding tone. After all, an implicit learning of the
19 pitch clusters would lead participants to expect a within-cluster continuation of the preceding tone. Such
20 an explanation would thus make a distinction between the levels of structural detection and structural
21 reintegration of the pitch boundary, which might pose an interesting subject for future research.

22 **Accounts of resource interference**

23 Importantly, our demonstration of cross-domain interference in structural processing has
24 theoretical implications that go beyond the confirmation of a prediction from the SSIRH (Patel, 2003). In

1 particular, the findings are relevant for a recent debate concerning the resources underlying previously
2 found interference effects (Perruchet & Poulin-Charronnat, 2013; Slevc et al., 2009). As mentioned in the
3 introduction, Perruchet and Poulin-Charronnat recently conducted an experiment with a version of Slevc
4 et al.'s paradigm, using semantic garden path sentences as opposed to simple semantic violations (e.g.,
5 "*the old man went to the bank to withdraw his NET which was empty*"). Slevc et al. reported that musical
6 unexpectancies increased the effect of syntactic garden path unexpectancies on reading times, but did not
7 modulate the effect of semantic violations. However, Perruchet and Poulin-Charronnat did find a
8 modulation of a semantic effect, namely of semantic garden path unexpectancies (where a reintegration is
9 possible). It thus seems that the type of linguistic unexpectancy (garden path configuration as opposed to
10 a violation) determines the occurrence of music-to-language interference rather than the linguistic level of
11 the unexpectancy (syntax vs. semantics, Koelsch, 2005, Rohrmeier & Koelsch, 2012), which might
12 suggest a broad interpretation of Patel's definition of "structural integration resources" as being
13 dependency-based processing resources for instance.

14 However, based on their finding of modulation effects on semantic garden path sentences,
15 Perruchet and Poulin-Charronnat (2013) have suggested that attentional aspects of the task might be
16 implied. Perruchet and Poulin-Charronnat reasoned that the amount of attentional resources spent on the
17 musical part of the interference study varies as a function of the structural expectancy of the materials.
18 They suggest that the musical unexpectancies might have different consequences for garden path
19 sentences than for sentences with sentential unexpectancies because of differences in the attentional
20 constraints of the sentential unexpectancies in both conditions. Whereas garden path unexpectancies are
21 resolved as soon as the right integrational structure is found, the violations cannot be resolved. Therefore,
22 it can be argued that garden path unexpectancies require moderate amounts of attentional resources and
23 can thus be hindered by the depletion of attentional resources towards structural unexpectancies. Full
24 sentential violations, on the other hand, have a much stronger demand towards the attentional resources,
25 and thus force the participant to disregard the musical task demands.

1 This claim of an attentional basis for overlapping resources proved difficult to assess in previous
2 research, given that it has only used linguistic or electrophysiological measures of structural integration.
3 On these general measures, the hypotheses of attentional demands and structural integration demands are
4 difficult to disentangle (e.g., both predict longer reading times). However, this is not the case in the novel
5 dependent measure used here. As mentioned above, the structural integration effect in the pitch
6 recognition task is expressed as a memory effect: if a shift is processed more strongly, the sequence of the
7 tones spanning this shift is remembered less well, and vice versa. In other words, if we observe a decrease
8 in the BPE (as we find upon simultaneous presentation of a garden path unexpectancy with the pitch
9 cluster shift), it must be noted that this decrease is in part due to a better performance for “between
10 phrase” tones in this condition as compared to the control conditions. In other words, upon the joint
11 presentation of the garden path unexpectancy with a pitch cluster shift, the pitches spanning the shift are
12 recognized *better* ($\beta = 0.492$, $z=2.112$, $p=0.034$). Of course, this clearly contrasts with the attentional
13 hypothesis, which would state that the sequence of tones presented simultaneously with the garden path
14 unexpectancy will be attended *less*, and thus also recognized *less well*, as compared control conditions.
15 This is clear from Table 1, where our data show an increased instead of a decreased performance on
16 “between probe” recognition in this condition.

17 Therefore, the findings reported above do not only provide first evidence for cross-domain
18 interference in structural integration resources involved in “default” structural integration, but furthermore
19 argue against the account of such interference being attentional in nature. While the experimental nature
20 of the pitch clustering allowed for a more controlled task environment, we believe future work would
21 make an important contribution to the research domain if it applied the abovementioned procedure to more
22 naturalistic, harmonically organized pitch sequences, specifically investigating the domain of harmonic
23 musical processing. For now however, the study suggests that measuring the structural processing of non-
24 linguistic auditory sequences is both possible, and reveals interference effects with simultaneous sentential
25 processing.

CONCLUSION

This study provides the first evidence for interference from the simultaneous processing of linguistic structure upon the structural processing of structured pitch sequences. Thereby, it uniquely provides evidence for models suggesting an overlap in structural processing resources (SSIRH, Patel, 2003; SWM, Kljajevic, 2010) by using a measure of “default” structural processing in non-linguistic materials. Additionally, this measure further allows us to address a recent point of discussion concerning such “shared resource”-models, namely the attentional account as provided by Perruchet and Poulin-Charronnat (2013). Though earlier findings of interference between domains can be accounted for as an effect of depletion of attentional rather than integrational resources, the findings reported in this study enable us to discriminate between the two, providing clear evidence in favor of overlapping integrational measures. Therefore, we suggest that the findings reported in our, as well as in previous (Perruchet & Poulin-Charronnat, 2013; Slevc. et al, 2009) studies, suggest shared *integrational* resources.

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Figures:

Figure 1: Overview of the SSIRH as adapted from Fedorenko, Patel, Winawer & Gibson (2009)

Figure 2: Example of the harmonic integration measure, adapted from Tan et al. (1981). The line in the melody represents the position of the harmonic boundary. Following the tone in the left circle (just like any other tone), participants form harmonic expectations concerning the pitches that might follow. When a pitch boundary is reached, this leads to a closure of the first musical segment. Therefore, the person will register a separation between this and the following tone, creating two separated segments in the melody. Because of this harmonic “shift”, the sequence of the two tones tagged in circles (“between phrase”-probes) will be recognized less well as compared to any other two sequential tones (“within phrase”-probes).

Figure 3: Overview of the pitch clusters

Figure 4: Overview of the pitch sequence construction. On top of the figure, an overview of the pitch sequence creation is being presented. Tones were selected so that each following tone was either the closest neighbor above or below the preceding tone. For example, F_4 could be either followed by C_4 or G_5 , whereas for example E_5 could only be followed by B_5 . Auditory representations of both examples can be found online on <http://openscienceframework.org/profile/v49bp>

Figure 5: Overview of the experimental procedure. The screen with the blue button was only provided on 8 random trials, indicating that participants were to write down the sentence before continuing.

Figure 6: Graphic representation of the differences in within versus between probe performance, referred to as the “within probe” advantage, in the several sentence conditions, when the sentential unexpectancies do or do not overlap. As suggested through the 95% confidence intervals plotted for every condition, there is a significantly lower “within probe” advantage only when a linguistic overlap that requires reintegration overlaps with the pitch boundary.

Figure 7: Graphic representation of the BPE and the expected and found results. Based on Tan et al.'s finding (1981) that “within probes” are recognized better as sequentially occurring than “between probes” (1), it has been argued that this pattern of results might stem from an increase of “within probe” performance (2) and a decrease of “between probe” performance (3) following a more parsed representation of the tone sequence, due to structural processing. Given this pattern of decrease and increase (which we call the BPE), we would also expect that all conditions where we did not attempt to induce an interference in structural processing resources (4) would have a higher “within probe” performance and a lower “between probe” performance, compared to our “overlap/garden path” condition (5), where we did induce an interference in structural processing resources across domains. Interestingly, where we would have expected this trend to go no further than an even performance on both kinds of probes (6), we find that, when structural processing resources are depleted, we observe a “between probe” advantage. This seems to suggest (7) that “between probes” might, in situations where relatively little structural processing takes place, actually be recognized better than “within probes.”

1 **Tables**

2

Probe condition	Control	“Out-of-context” Violation Overlap	“Out-of-context” Violation No Overlap	“Garden path” Unexpectancy Overlap	“Garden Path” Unexpectancy No Overlap
Within	<u>73.74%</u>	<u>73.75%</u>	<u>79.37%</u>	<u>67.50%</u>	<u>78.75%</u>
	75.32%	75.34%	81.01%	68.90%	80.33%
	(6.51%)	(8.58%)	(7.82%)	(9.16%)	(7.90%)
Between	<u>66.40%</u>	<u>66.88%</u>	<u>68.13%</u>	<u>76.25%</u>	<u>70.00%</u>
	68.57%	69.07%	70.36%	78.79%	72.39%
	(7.98%)	(9.89%)	(9.76%)	(8.70%)	(9.57%)
Foil	<u>47.34%</u>	<u>50.00%</u>	<u>50.63%</u>	<u>50.00%</u>	<u>47.50%</u>
	47.11%	49.90%	50.53%	49.88%	47.29%
	(6.79%)	(9.08%)	(9.11%)	(9.09%)	(8.98%)

3

Table 1: Overview of the numerical differences in recognition performance across recognition probe, sentence condition, and

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unexpectancy/boundary overlap. In italics, the respective percentages are displayed as modeled by the best fit model, for which the distances to

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the 95% confidence boundaries are mentioned between brackets.

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7

Years of Formal Training	0	2	4	6	8	10
Within	73.54%	75.32%	77.02%	78.63%	80.16%	81.61%
	(5.63%)	(4.46%)	(4.55%)	(5.62%)	(7.14%)	(8.81%)
Between	70.91%	70.70%	70.49%	70.28%	70.07%	69.85%
	(7.39%)	(6.08%)	(6.40%)	(8.20%)	(10.88%)	(14.01%)
Foil	47.83%	48.15%	48.46%	48.77%	49.09%	49.41%
	(5.46%)	(4.55%)	(4.76%)	(5.97%)	(7.70%)	(9.86%)

8

Table 2: Overview of the probe recognition performance by years of formal training, as modeled using the best model fit. For each

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averaged percentage, the distance to the 95% confidence interval is listed in brackets.

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