Comparison of semantic- and syntactic garden paths in a self-paced reading task testing the SSIRH

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Characters = 28800

ABSTRACT

Music and language are two complex, syntax-based systems used for communication and much research has been dedicated to connecting the two. The Shared Syntactic Integration of Resources Hypothesis (SSIRH) claims that syntactic processing of music and language is a shared process as shown by EEG studies and studies of self-paced reading tasks of syntactic garden path sentences. Proponents of the theory have found that a syntactic bottleneck in reading time occurs when reading syntactic garden path sentences while hearing syntactic harmonic violations. A later study replicated this effect with semantic garden path sentences, suggesting that the bottleneck is purely attentional and not related to a shared syntactic system. The current study attempted to replicate both experiments in order to compare them within-subject, but found no evidence supporting the SSIRH, though this could be due to a small sample size. Future studies should aim for a higher sample size, try to integrate neuroimaging into this paradigm and account for musical expertise using the Gold-MSI index.

Keywords: “Music and Language”, SSIRH, “Garden path sentences”, “Self-paced reading task”, harmony

INTRODUCTION

Music and language are two very powerful and unique systems of communication that allow us to convey deep emotions and meaning in many different contexts. Behind both systems lie certain syntactic rules that allow us to structure words and notes to convey specific messages. Because of these similarities, some musicians like to think of and speak of music as a form of language. Researchers, namely Koelsch et al., (2005); Patel, (2003) and Slevc et al., (2009), have been invested in examining the link between music and language processing, arguing that some of these processes build on the same underlying neural mechanisms based on similarities in brain activity when processing music and language. Examining how music and language are connected in the brain could help us better understand how the brain processes and learns complex systems of meaning and uses them in practice. This link could also be used to develop therapeutic treatments for disorders impacting music and/or language processing. One still-developing example of such a treatment is Melodic Intonation Therapy (MIT), a form of speech therapy which helps patients with aphasia or apraxia regain the ability to speak through melodic repetitions of phrases sung while tapping the left index finger, though there is some debate as to whether MIT truly can be used to treat aphasia (Schlaug, 2016; Zhang et al., 2022; Zumbansen et al., 2014).

Amusia and aphasia

A common way to research the link between music and language processing is by studying patients with impairments in these areas to assess whether they are linked. **Amusia** is an impairment of one's ability to accurately perceive or produce music. Patients can be born with amusia (**congenital amusia**) or acquire it from strokes or other forms of brain damage (**acquired amusia**). In the brain, amusia manifests as damage or a lack of connection in the middle and superior temporal gyri (MTG and STG), the inferior frontal gyrus (IFG) and the surrounding areas (J. Sihvonen & Särkämö, 2022). **Aphasia** is a neurological condition affecting comprehension and production of language. There are two common types of aphasia: **Broca's aphasia**, which impacts a patients ability to repeat sentences and structure words and sentences in time with proper grammar and **Wernicke's aphasia**, which impacts understanding of and production of meaningful language. Both types of aphasia stem from damage around their respective areas – Broca's and Wernicke's areas – and often in the left hemisphere of the brain. Patients with Broca's aphasia can often still create meaningful sentences, but with poor grammar. Patients with Wernicke's aphasia on the other hand can't create or repeat meaningful sentences but speak very fluently without pauses. Importantly, aphasia impacts not only spoken or written language, but also non-verbal communication such as sign language (Damasio, 1992). Matching of environmental sounds to corresponding pictures is also impacted by aphasia (Saygın et al., 2003). Performance in this task specifically seemed to correlate with damage in Wernicke's area, possibly because of the semantic processing required to understand meaning of sounds and relate them to objects. Could this link extend to semantic processing of music as well?

Theories for and against a link

Peretz & Coltheart, (2003) propose that the brain has two separate modules for speech and language, and that these modules are made up of even smaller and more specific sub-modules. They base this theory on cases where patients exclusively have either aphasia or amusia (Ayotte et al., 2002; Godefroy et al., 1995; Peretz et al., 1994). If processing of music and language are related, impairment of one function should impact the other. This evidence seemingly falsifies the idea that processing of music and language relies on shared neural resources, though one theory does attempt to consolidate the confusing set of differences and similarities between the two domains by dividing processing and representation up in the brain. Created by Patel, (2003), the Shared Syntactic Integration of Resources Hypothesis (SSIRH) proposes that although we represent music and language differently, syntactic processing of both systems uses a shared pool of cognitive resources. The SSIRH argues that, while representation of music and language are domain specific and take place in the posterior areas of the brain (with left- and right lateralization for language and music respectively), syntactic processing of both takes place in the frontal areas of the brain, specifically in the IFG. Patel proposes that congenital amusia arises due to a "developmental failure to form cognitive representations of musical pitch" (Patel, 2003, p. 679), and that acquired amusia stems from right-lateralized damage to areas like the STG that store long-term representations of things like harmonic relationships, which is why language processing is not affected. According to Patel, the SSIRH predicts that Broca's area is an important part of syntactic processing of music and language, and that Broca's aphasia should impact both – though he and others have since falsified this assumption (Chiappetta et al., 2022; Faroqi-Shah et al., 2020).

A review of neuroimaging studies found shared resource use between music and language in the left pars opercularis, the most posterior fold of the IFG and part of Broca's area, supporting the SSIRH (LaCroix et al., 2015). Event-related potential (ERP) studies of tasks requiring syntactic processing of music and language found that a positive ERP at 600 milliseconds is consistently elicited in tasks where subjects experience a syntactic incongruence in a sentence or chord sequence, suggesting that there is a shared processing of syntax happening in the brain at 600 ms. (Patel et al., 1998). Additionally, syntactic deviations in music and language respectively elicit a right- or left-anterior negative ERP (RAN and LAN), suggesting some domain specific syntactic processing. LANs elicited by syntactic violations in language are reduced by simultaneous violations of musical syntax, suggesting some shared processing of syntax, though the same isn't true for the RAN elicited by syntactic violations in music (Koelsch et al., 2005).

Behavioral experiments

If resources are shared for syntactic processing of both, a syntactic processing load in both domains should create a bottleneck. Slevc et al., (2009) tested this idea by presenting in-key and out-of-key chord sequences during a self-paced reading task. Subjects read a sentence split up into segments presented one at a time. Each sentence had an associated chord sequence, and one chord was played for each sentence segment shown. Most sentences were "fillers", but some were **garden path sentences** – sentences that trick the reader into reading them one way, only to be confused and forced to reevaluate the sentence e.g. "After the trial the attorney advised the defendant *was* likely to commit more crimes". The sentence seemingly ends at "*defendant*", but "*was*", continues the sentence, confuses the reader and forces them to reanalyze the syntax. At random, the critical segment in garden path sentences would be presented along with an out-of-key chord not matching the rest of the sequence, creating a second syntactic load. Slevc et al. found that subjects were slower to read the critical segment while hearing such a harmonic violation, suggesting that a bottleneck in syntactic processing was created. To make sure that reading time was affected by a genuine bottleneck in syntactic processing and not just a lack of attentional resources, Slevc et al. also included sentences with semantic violations of expectations e.g. "The boss warned the mailman to watch for angry *pigs* when delivering the mail". These sentences were unexpected like garden path sentences, but there was no observed effect on reading time of the critical segment ("*pigs*" in this case) when subjects heard a harmonic violation, suggesting that this bottleneck is specific to syntactic processing. Another experiment was done examining the effect of sudden timbre change rather than chord key. For the critical segment, a sudden timbre change made no impact on reading time, again implying the existence of a syntactic bottleneck (Slevc et al., 2009).

Although the garden path paradigm seems compelling, Perruchet & Poulin-Charronnat, (2013) raised a critique of it by arguing that the increased reading time might stem from the design rather than the syntactic element of the sentences. Garden path sentences are ambiguous and force the reader to reanalyze the sentence. Semantic violations of a sentence like the one mentioned above don't make the reader reanalyze, they just surprise the reader. To examine whether reading time was truly affected by the syntactic processing aspect of sentences, Perruchet & Poulin-Charronat replicated the study of L. R. Slevc et al., (2009) and replaced the **syntactic** garden path sentences with **semantic** garden path sentences (see figure 1). They work similarly, but make the meaning of a word ambiguous rather than the sentence structure. In the example below, the reader is surprised by the word "*net*" and is forced to reinterpret the meaning of "*bank*" to be read as a "*river bank*" rather than a bank with money. In their study, they found a similar effect of semantic garden path sentences on reading time when readers were presented with an out-of-key chord. In interpreting their results, they argue that there is an interaction effect of harmonic violations and garden path sentences on reading time because garden path sentences are less confusing and demanding to read than sentences with a semantic violation like in Slevc et al., (2009), and that participants were too distracted in the semantic violation condition to be impacted by harmonic violations. To back up this claim, they cite Loui & Wessel, (2007), who found that nonmusicians don't pay attention to harmonic violations when distracted. This is a good argument, but it is problematic because L. R. Slevc et al., (2009) found no difference in effect between musicians and nonmusicians. If their argument was true, musicians would have also read sentences with semantic violations slower when hearing harmonic violations, though this is not the case. Additionally, Perruchet & Poulin-Charronnat found a markedly smaller effect on reading time with their semantic garden path sentences than Slevc et al., suggesting that effects are not comparable. Finally, they did no within-subjects analysis between syntactic and semantic garden path sentences, thus not respecting interpersonal variance and making it hard to compare results.

This study was done to compare the effect of syntactic and semantic garden path sentences on reading time when experiencing harmonic violations within-subjects to find out if the effect Slevc et al. observed was only due to the structure of garden path sentences. If the SSIRH is true, subjects should slow their reading time at the critical point of syntactic garden path sentences while experiencing a harmonic violation. For semantic garden path sentences, harmonic violations shouldn't impact reading time.

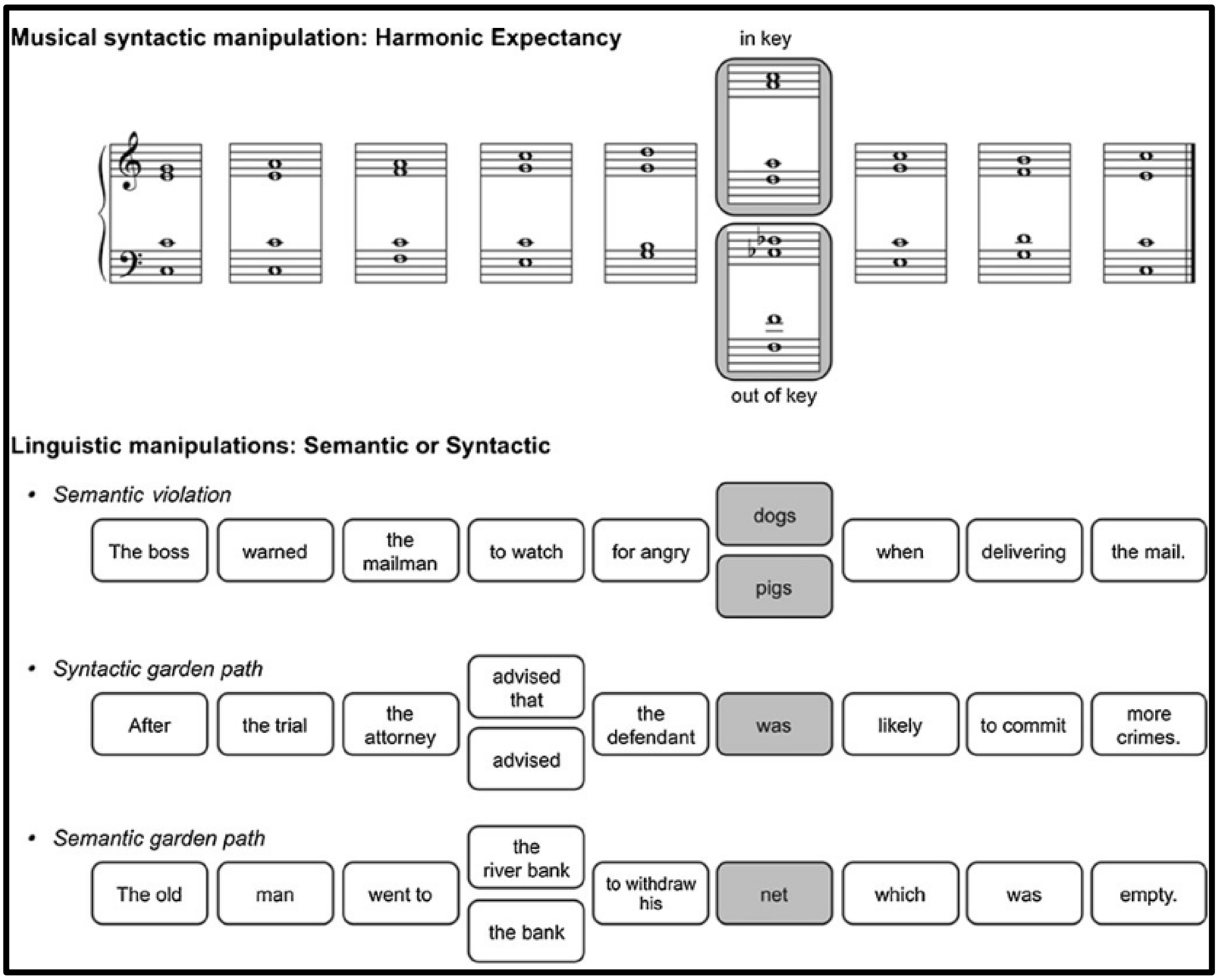

Figure 1: Examples of sentence-types and harmonic manipulations from Perruchet & Poulin-Charronnat (2013). They didn't use syntactic garden path sentences but compare them to semantic garden path sentences.

METHODS

Participants and sampling

Participants (N = 18) were convenience sampled from the royal library in Aarhus. All participants had normal or corrected-to-normal hearing and vision. Average Gold-MSI score was 61.59.

Ethics

All participants gave informed consent prior to participation and were able to withdraw consent throughout the experiment. No personal data was collected, and data was anonymized upon collection by using random IDs. Participants were blind to the condition and randomization of trials as well as the true purpose of the study until the end. They were simply informed that the purpose of the experiment was to examine reading comprehension, and that the chords did not matter. Participants were debriefed after the experiment.

Materials

During the experiment, subjects were presented with a sentence and a chord sequence, one sentence segment/chord at a time. After reading each sentence, subjects were asked to answer a yes/no question specific to that sentence.

Sentence stimuli

There were 48 sentences across 3 categories, 24 filler sentences, 12 syntactic garden path sentences and 12 semantic garden path sentences. Filler sentences were simple, short sentences. Four filler sentences were accompanied by harmonic violations. Fillers were included to keep subjects from guessing the purpose of the experiment. Syntactic and semantic garden path sentences each had two variations – expected and unexpected (see figure 2). Unexpected semantic garden path sentences used an early ambiguous word, which subjects later had to reinterpret. Expected semantic garden path sentences used a non-ambiguous word which aligned with the context of the rest of the sentence. Unexpected syntactic garden path sentences made the end of sentences ambiguous.

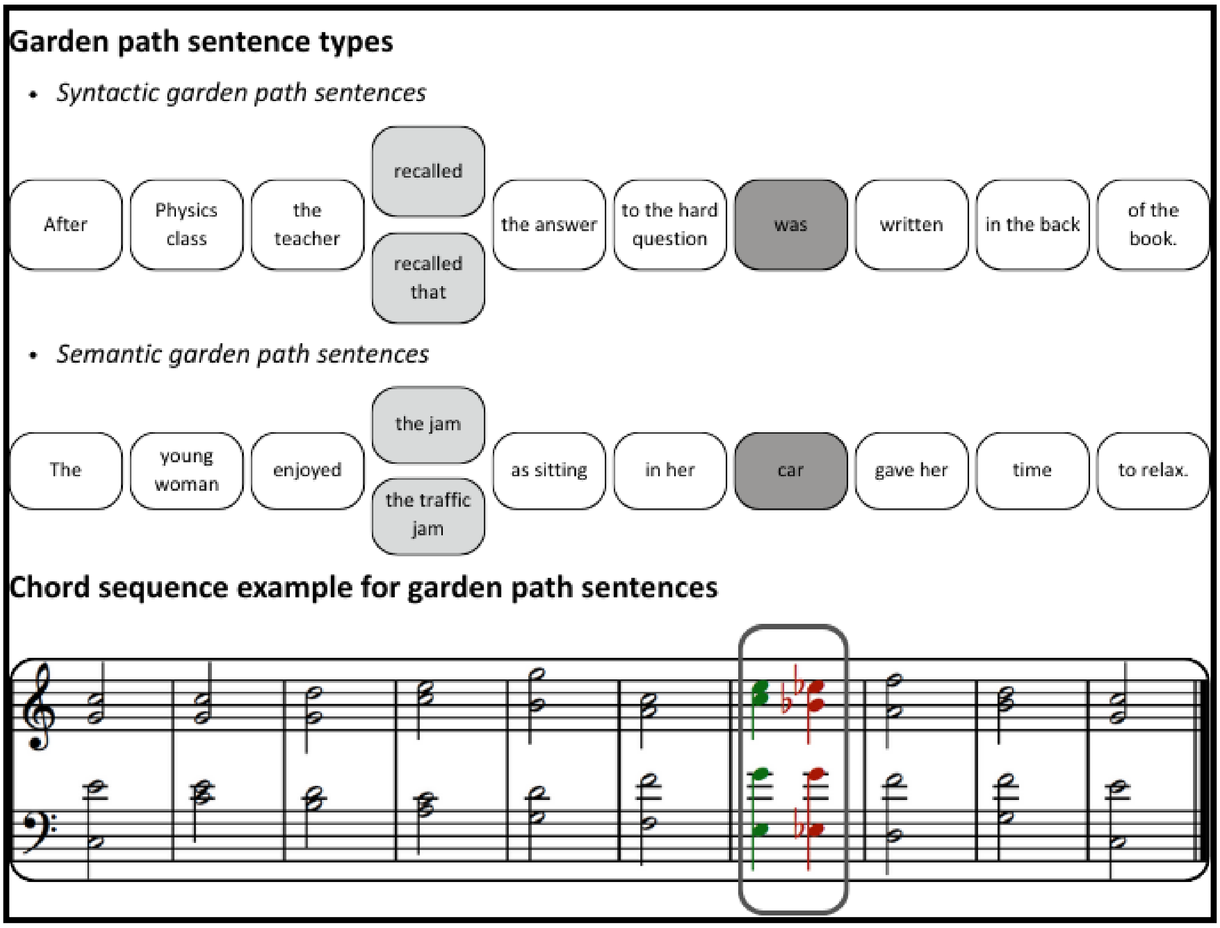

Figure 2: Experiment trial example. Blocks of text are presented one at a time along with a chord in the shown chord sequence. Critical words marked by dark grey were either unexpected or expected given the context (respectively upper and lower segments marked by light grey). Chords presented along with the critical word were either in-key (green notes) or out-of-key (red notes).

Expected syntactic garden path sentences made it clear that there is some continuation in the sentence. Filler sentences and syntactic garden path sentences were all identical to those used in Slevc et al., (2009). One semantic garden path sentence was identical to the english example used in Perruchet & Poulin-Charronnat, (2013). The rest were written based off it[1].

Questions

Yes/no questions were presented after each sentence. Sentences were made individually based off each sentence. These were **not** based on earlier studies. These questions were included to make sure that participants paid attention to the sentences and did not just read without processing the sentence

Musical stimuli

All 36 chord sequences were identical to those used in Slevc et al., (2009) for both filler sentences and syntactic garden path sentences. Semantic garden path sentences were matched in length to syntactic garden path sentences so that the same 12 chord sequences could be used, making it easier to compare the interactive effect of sentence types and music. Each of the 12 chord sequences had an out-of-key version. Chords were put together by playing mp3 files of piano notes in PsychoPy. Mp3 files were downloaded from a reddit post made by a user who'd made them for an art project (SingleInfinity, 2015).

Musical expertise questionnaire

The questionnaire used to assess musical expertise was Goldsmiths Musical Sophistication Index (Gold-MSI) questionnaire. This questionnaire was used as it is short, simple and predicts performance in listening tasks (Müllensiefen et al., 2014).

Stimuli, data and code availability

Stimuli, data and code used for this study is freely available at: https://github.com/EskilSkrammerMig/Perception-Action-exam-code-and-stimuli.

Procedure

Each experiment was conducted in public at the royal library in Aarhus using a laptop running Windows 11 while wearing semi-open headphones connected to the laptop.

Pre-trials

The entire experiment was run in PsychoPy and coded using Python (Peirce et al., 2019; Van Rossum & Drake, 2009). In the experiment, subjects first answered an online Gold-MSI questionnaire (*LongGold Battery Demo*, 2025), they then had to read three screens with text: one explaining the (not entirely true) purpose and scope of the experiment, one explaining the terms of participating – to continue subjects had to consent to these terms. Finally, a third screen was presented describing the procedure of each trial. Before beginning the trials, subjects had one trial sentence and comprehension question to get a feel for the experiment.

Reading trials

In each trial, subjects read sentences one segment at a time while hearing a chord sequence one chord at a time, just like in L. R. Slevc et al., (2009). Subjects continued on to the next segment by pressing space. After each sentence, a yes/no comprehension question was asked to ensure that participants spent time understanding sentences and syntactically

[1] Thanks to Slevc, Perruchet and Poulin-Charronat for sharing their materials for this study.

processing them. After answering, a screen displayed whether they were right or wrong and prompted them to continue to the next sentence by pressing space.

Participants read a total of 48 sentences:

- 24 filler sentences
- 6 unexpected syntactic garden path sentences
- 6 expected syntactic garden path sentences
- 6 unexpected semantic garden path sentences
- 6 expected semantic garden path sentences

After reading all the sentences, a screen appeared, thanking subjects for participating, and the experiment ended.

Randomization and counterbalancing

The combinations of unexpected and expected sentences were counterbalanced across participants. There were four different combinations of sentences given to subjects in order so that the first subject gets the first combination, second gets the second combination. This pattern repeated every four subjects. Order of sentences was shuffled. Whether a garden path sentence was accompanied by an out-of-key chord or not at the critical segment was randomized by applying 1 of 20 random permutations of three 1s and 0s to each set of 6 garden path sentences. This way, each condition always had half of its sentences accompanied by an out-of-key chord. Permutations and random lists were made using the *random* and *itertools* Python packages (Van Rossum, 2023).

Analysis

Analysis was done in R (R Core Team, 2024). All reading times below 50 milliseconds or above 2500 milliseconds were removed. Additionally, all reading times more than 2.5 standard deviations from a given participants mean reading time were also removed, removing a total of 3.16% of data. For analysis, reading times were log-10-transformed. Number of characters per segment were scaled and 0-centered.

The core analysis was one examining the effect of sentence type, condition and harmonic violations on reading time. This effect was estimated using a linear mixed-effects model with reading time as the dependent variable and the fixed effects of three factors interacting with two levels each: garden path type (syntactic/semantic), garden path condition (expected/unexpected) and music condition (in-key/out-of-key). Amount of characters were added as a fixed effect with no interaction to account for variance of reading time based on amount of characters in a given segment. Random intercepts were added for participants to account for variability within subjects. Three separate models were made across each segment type: before, during and after the critical segment. Models were run using the *lme4* package (Bates et al., 2015). Formulas were written like so:

$$lmer(logrt \sim characters + \; music\_condition \; * garden\_path\_cond \\ * garden\_path\_type \; + (1|participant\_id)$$

The *afex* package (Singmann et al., 2024) was used to do F-tests of models. Degrees of freedom were estimated using Kenward-Roger (KR) approximation (Kenward & Roger, 1997). Assumptions of heteroscedasticity and normality of residuals were visually inspected using scatterplots, histograms and qq-plots of residuals and predicted values.

RESULTS

There was no significant three-way interaction effect of garden path type, condition and music condition on reading time for pre-critical segments ($F(1,393.05) = 0.01$, $p = .925$), critical segments ($F(1,397.07) = 0.46$, $p = .497$), and post-critical segments ($F(1,399.07) = 0.16$, $p = .688$). There was a consistent significant effect of characters on reading time for all three segments (not reported since it isn't important to the study). A significant effect of garden path type was also present for post-critical segments ($F(1,399.02) = 5.85$, $p = < .05$). No other significant effects on reading time were discovered, although there were subtle patterns in the data, like in figure 3, where there seems to be a three-way interaction effect separating reading time for semantic and syntactic garden path sentences for out-of-key unexpected post-critical segments.

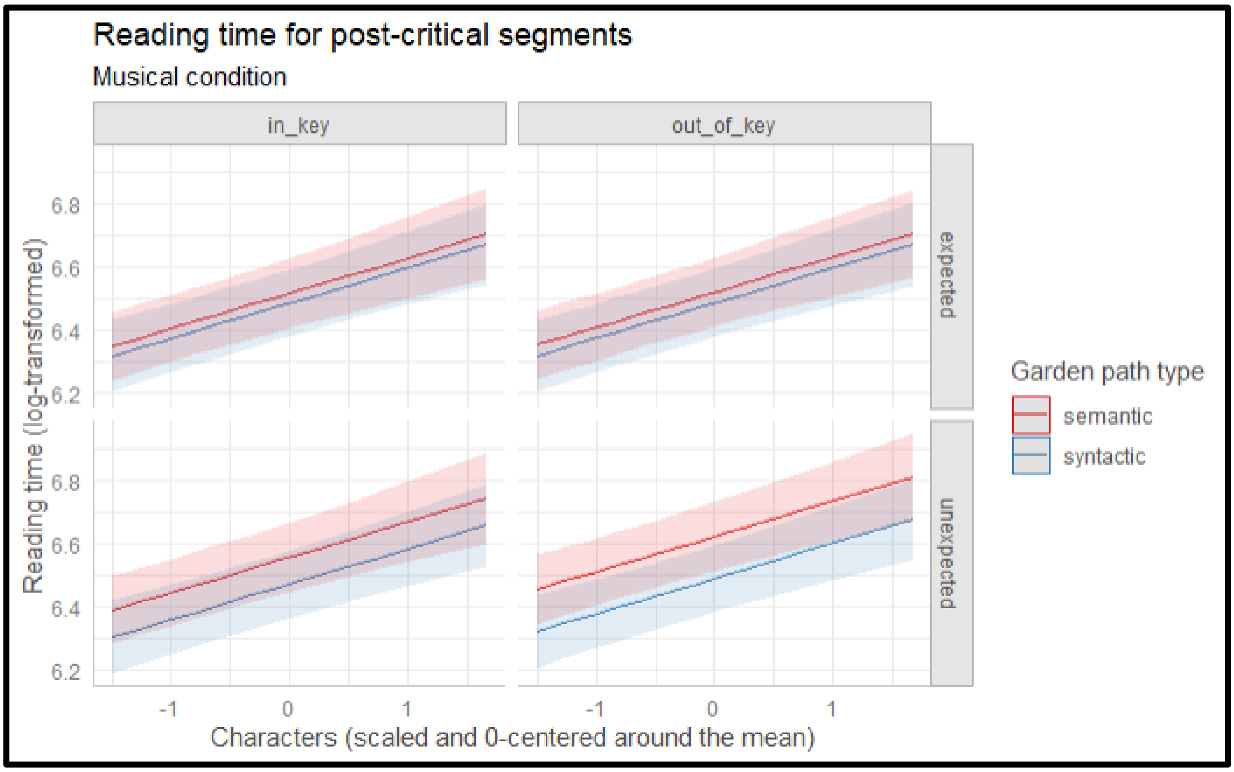

Figure 3: Log-transformed reading time across conditions as a function of scaled characters pr. segment. Boxes are split up by musical- and garden path condition.

Follow-up analyses

A follow-up analysis of post-critical segments for only semantic garden path sentences was done using the formula: *lmer(logrt ~ characters + music_condition * garden_path_cond + (1|participant_id)).* An F-test of this model using KR approximation revealed a significant effect of garden path condition on reading time ($F(1,191.10) = 3.94$, $p < .05$), but not for music condition ($F(1,191.09) = 0.87$, $p = .352$) nor the interaction effect between music- and garden path condition ($F(1,191.10) = 0.76$, $p = .384$).

Power analysis

Post-hoc power analyses were run to evaluate the chance of discovering significant changes in reading time. The *simr* package (Green & MacLeod, 2016) was used to simulate data and estimate power for the sample size of 18 and an assigned effect size of 10 log-10 units corresponding to about a 10% change in reading time, which is similar in size to the 76 ms mean difference in reading time (with a mean of 657 ms) between in-key expected garden path sentences and out-of-key unexpected garden path sentences in Slevc et al., (2009). The power for the given effect was estimated using a likelihood ratio test between a null-model with only main effects and a full-model with the three-way interaction effect. Data was simulated using 100 Monte Carlo simulations based on the reading times for the critical segment of sentences. For the three-way interaction model, simulations suggested that the model has a power of 60.8% (95% CI [57.7, 63.8]) with an α of 0.05. To reach 80% power given the effect size, 29 participants would be needed. To reach 80% power for a more conservative effect size of 5 log-10 units, or about a 5% change in reading time, 63 participants would be needed. If the dataset is representative of the underlying population and if the set effect size is realistic, this could suggest that the current study and model is underpowered.

DISCUSSION AND FURTHER RESEARCH

No significant three-way interaction effect of sentence condition, type and harmonic violation on reading time was found contrary to the predictions of the SSIRH. Counter to the evidence of both Perruchet & Poulin-Charronnat, (2013) and Slevc et al., (2009), none of the results from the study suggest a robust effect of garden path sentences and harmonic violations on reading time, though small patterns – like the difference in reading time between unexpected syntactic and semantic garden path sentences during and following harmonic violations – are present and might become clearer given a larger sample size of 30-60 subjects. Despite the lack of three-way interaction, semantic and syntactic garden path sentences do seem to interact differently across musical condition and segments. Subjects' reading times for the post-critical segments are impacted by semantic- and not syntactic garden path manipulation, suggesting that unexpected semantic garden path sentences require more processing and surprise the reader more after the fact. If the garden path design is the driving force of the impact on reading time as Perruchet & Poulin-Charronnat, (2013) suggest, there shouldn't be a difference between garden path types since characters account for difference in segment length and its impact on reading time although this doesn't exclude other differences from affecting reading times. Sentences aren't created on a scale where reading or conceptual difficulty is scored, and so there might be a range of differences affecting reading time that the model can't pick up.

It wasn't possible to estimate the interaction of musical experience with the three-way interaction due to too few samples. This effect is important, because Perruchet & Poulin-Charronat claim that the lack of interaction effect between semantic and harmonic violations on reading time in Slevc's 2009 study could be due to non-musicians' difficulty with attending to harmonic violations when distracted (Loui & Wessel, 2007; Perruchet & Poulin-Charronnat, 2013, p. 315). If this is the case, musically trained people should be able to attend to harmonic violations. In Slevc et al., (2009), no difference was found between non-musicians and people with self-reported musical training. This threshold for musicians is problematic because musical training can be defined very broadly, and because people practice very differently. The Gold-MSI index questionnaire offers a more thorough overview of musical experience regardless of whether or not someone is a musician and correlates with performance in listening tasks, making it a well-suited measure of musical expertise for a harmonic violation task (Müllensiefen et al., 2014). Future studies with greater sample sizes and opportunity for more complex models could incorporate this index either as a random categorical effect and index people into groups of expertise to examine whether there are groups of musically trained people who react differently to the garden path paradigm. The index could also be accounted for as a continuous fixed interaction effect. If attention to harmonic violations during a distraction (such as an unexpected garden path sentence) depends on musical training, surely there should be an interaction effect of garden path condition, music condition and Gold MSI index score.

Neuroscience and behavioral studies

A promising way to test the SSIRH is through neuroimaging during behavioral experiments such as this one. If semantic and syntactic garden path sentences work similarly as Perruchet & Poulin-Charronnat suggest, they should both elicit a P600 as in (Patel et al., 1998). Similarly, a study could test whether syntactic and semantic garden paths elicit a LAN and whether this LAN is reduced by a simultaneous harmonic violation as seen in (Koelsch et al., 2005). If the SSIRH is true, the LAN and P600 should only occur for syntactic garden paths.

As it stands, the SSIRH seems uncertain, though more research is needed to ascertain whether integration of syntax really is shared across music and language or if linguistic and musical systems are fully modular. The current study found no evidence backing the SSIRH, though this could be due to a lack of statistical power. Future studies should aim to have bigger sample sizes due to the relatively small effect of reading time and to mix behavioral experiments with neuroimaging methods to connect neural substrates to syntax and interactions of syntax in music and language. Understanding the link between these systems could help us develop speech therapy solutions and better understand how the brain processes and utilizes abstract systems of information such as music and language.

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