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Music and language: Do they draw on similar syntactic working memory resources?

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Abstract

The cognitive processing similarities between music and language is an emerging field of study, with research finding evidence for shared processing pathways in the brain, especially in relation to syntax. This research combines theory from the shared syntactic integration resource hypothesis (SSIRH; Patel, 2008) and syntactic working memory (SWM) theory (Kljajevic, 2010), and suggests there will be shared processing costs when music and language concurrently access SWM. To examine this, word lists and complex sentences were paired with three music conditions: normal; syntactic manipulation (out-of-key chord); and a control condition with an instrument manipulation. As predicted, memory for sentences declined when paired with the syntactic manipulation compared to the other two music manipulations, but the same pattern did not occur in word lists. This suggests that both sentences and music with a syntactic irregularity are accessing SWM. Word lists, however, are thought to be primarily accessing the phonological loop, and therefore did not show effects of shared processing. Musicians performed differently from non-musicians, suggesting that the processing of musical and linguistic syntax differs with musical ability. Such results suggest a separation in processing between the phonological loop and SWM, and give evidence for shared processing mechanisms between music and language syntax.

Keywords

memory, musicians, phonological loop, shared syntactic integration resource hypothesis, syntax

The connection between music and language has a long history of research (Johansson, 2008; Mithen, 2009; Peretz, 2006), and whether music and language share similar cognitive processing resources is a matter of some debate (Patel, 2008; Peretz & Coltheart, 2003). Neuropsychological research questioned a connection between music and language processing because of the apparent double dissociation found between people with aphasia (Tzortzis,

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Goldblum, Dang, Forette, & Boller, 2000) and people with amusia (Ayotte, Peretz, & Hyde, 2002; Piccirilli, Sciarma, & Luzzi, 2000), leading to the conclusion that music and language were processed via separate systems in the brain (Peretz & Coltheart, 2003). With neuroimaging techniques, however, studies revealed that the syntactic structure of both music and language appeared to be processed in areas previously thought to be primarily used for language, such as Broca's area (Maess, Koelsch, Gunter, & Friederici, 2001; Sammler, Koelsch, & Friederici, 2011) and Brodmann's Area 47 (Levitin & Menon, 2003). Moreover, Patel, Gibson, Ratner, Besson, and Holcomb (1998) found that the P600 positivity – a brain signal produced when something unexpected occurs in language – was identical to the one produced when something syntactically unexpected occurs in music. Therefore both neuroimaging and behavioural evidence (Fedorenko, Patel, Casasanto, Winawer, & Gibson, 2009; Slevc, Rosenberg, & Patel, 2009) suggests an overlap in the cognitive processing of music and language, and thus reveals a tension between neuropsychological models of music and language processing, and neurophysiological/cognitive evidence for shared cognitive resources in music and language processing.

The aims of the current experiment are to show that music and language share similar cognitive processing mechanisms. In particular that they both draw on syntactic working memory (SWM) which is a form of memory dealing with the processing of syntax (Kljajevic, 2010). The theory behind this aim will be discussed.

An explanation for the contradiction in the literature has been offered by the shared syntactic integration resource hypothesis (SSIRH; Patel, 2003, 2008). This hypothesis integrates both neuropsychological and neuroimaging research by suggesting that there might be a distinction between two types of cognitive networks in language and music cognition – *representational* networks and *resource* networks. Representational networks can be viewed as domain-specific knowledge areas, where information about music and language are held separately in long-term memory. According to Patel (2003), these are the areas that show dissociation in brain damage, as one representational network can be damaged while the other remains intact. Resource networks, on the other hand, are the domain general processes by which this task-specific information is accessed and used in working memory. The SSIRH suggests that the overlap in music and language processing is therefore at the level of the resource networks. This would explain the apparent dissociation between aphasic and amusic individuals, and at the same time explain the apparent contradiction that neuroimaging data show similarities in music and language processing. The SSIRH predicts that there will be interference in tasks involving both linguistic and musical syntax, as they utilize the same processing resources and therefore draw on shared resource networks. This has indeed been found in a number of studies (Fedorenko et al., 2009; Koelsch, Gunter, Wittfoth, & Sammler, 2005; Slevc et al., 2009). Each of these studies accounted for possible effects of attention or semantics, and found significant results only with the combination of musical and linguistic syntactic information.

Syntax as a basic concept in both music and language is related to the rules that combine different elements into an overriding structure, or in language terms, our fundamental understanding of grammar (Patel, 2003). If a word is grammatically unexpected in a sentence, this puts strain on our syntactic expectancies (Patel, 2008). This can be seen in garden path sentences where our implicit expectations of where the sentence is leading are altered, and we have to re-evaluate the sentence. For example: 'While the band played the song pleased all the customers' (Roberts & Felser, 2011, pp. 325). When the word 'pleased' is read, the sentence has to be re-evaluated, taking into account the unexpected direction. This puts a strain on our processing capacity. More complex syntax can be seen in the difference between subject-extracted (see sentence 1 below) and object-extracted (see sentence 2 below) sentences (Fedorenko, Gibson, & Rohde, 2006).

1) The physician who consulted the cardiologist checked the files in his office.
2) The cardiologist who the physician consulted checked the files in his office.

The object-extracted sentence (2) is more syntactically complex, and has larger processing costs. This is because, instead of the local integration of 'the physician who consulted the cardiologist', a distant integration is necessary: 'the cardiologist who the physician consulted' (Patel, 2007). Music syntax is based on rules that involve harmonic expectancies and harmonic relations (Maess et al., 2001). Within a certain key, particular chords and notes are more likely to occur than others, depending on their harmonic distance from the tonic note. Out-of-key chords or notes are used in a number of studies of musical syntax, as it has been suggested that harmonically unexpected chords and notes have larger processing costs and correspond to more syntactically complex music (for an in-depth review see Patel, 2008).

With a new focus on syntax, researchers have been reassessing aphasic patients and other individuals with language disorders to see if their processing of music syntax is also affected. Children with specific language impairment have been found to have comparable difficulties processing musical syntax (Jentschke, Koelsch, Sallat, & Friederici, 2008), and individuals with Broca's aphasia have demonstrated difficulties processing musical syntax in the form of harmonic expectancies (Patel, Iversen, & Hagoort, 2004; Patel, Iversen, Wassenaar, & Hagoort, 2008). These findings are consistent with predictions from the SSIRH that both language and music share a common syntactic processing network. Such research shows that damage to this network affects syntactic processing in both music and language syntax, while the domain-specific networks for both music and language remain intact.

The concept of a domain-general area in the brain specialized for syntax is consistent with recent models of working memory that propose a unique syntactic component, referred to as syntactic working memory (SWM; Fiebach, Schlesewsky, & Friederici, 2001). The SWM model has been conceptualized as a short-term memory mechanism specialized for syntax, where syntactic information is held while the rest of the sentence or musical sequence is processed via working memory (Kljajevic, 2010). This is believed to be where the overlap in resource networks occurs between musical and linguistic syntactic processing (Kljajevic, 2010).

The syntactic working memory model is proposed to be separate but related to the working memory model proposed by Baddeley and Hitch (1974), and later extended by Baddeley (2000), which includes the phonological loop, the visuospatial sketchpad, the central executive and an episodic buffer. The phonological loop is a construct that is thought to be comprised of two parts: a phonological store and an articulatory rehearsal process (Baddeley, 2000). The existence of the phonological loop has had strong support in the literature (e.g., Vallar & Baddeley, 1984); however, it has been found that it cannot completely account for the phenomenon of articulatory suppression (Baddeley, 2000).This indicates that there is another aspect of verbal working memory that is separate to the phonological loop. To account for this gap, Baddeley (2000) added the 'episodic buffer'. Baddeley outlines the episodic buffer as a temporary store of information that helps integrate information across the phonological loop, the central executive and the visuospatial sketchpad. Even with the addition of the episodic buffer, Baddeley (2000) doesn't specifically mention how syntax is processed. This indicates a gap in the model of working memory, and points towards a role for a SWM system.

Other models of working memory focus on both memory as conceptualized through working memory span tasks (e.g., remembering lists), as well as attentional processes that are important in directing working memory (Engle, 2002). Such models are more generally focused around the combination of working memory, attention, and intelligence via the prefrontal cortex (Kane & Engle, 2002). Such models concentrate less on specific structures such as the phonological loop, and focus on more general forms of executive attention. In the case of musical and linguistic syntactic information, it makes more sense that different types of syntactic stimuli would necessarily interfere with each other, as syntactic processing can be conceptualized in a domain-general way, not as specific structural areas in the brain specialized for linguistic and musical processing separately.

In line with domain-general approaches to working memory, a number of studies have shown support for the existence of a working memory system that deals specifically with syntactic processing. Early supporters of this idea, Caplan and Waters (1999), phrased the concept as a separate sentence interpretation resource and suggested there is a subset of verbal working memory which deals specifically with syntactic information used to interpret sentences. Their theory is drawn from evidence showing a double dissociation in brain damaged patients between syntactic processing and phonological (or verbal) working memory (Larkin & Burns, 1977; Martin, 1993). Such a double dissociation shows that syntactic processing can be selectively impaired while verbal working memory processes remain intact, suggesting that syntactic processing operates separately from other verbal working memory processes. On top of this, neuroimaging data have shown different levels of activation in the brain for word lists (which have little syntactic information) and complex sentences (which contain syntactic information; Stowe, Withaar, Wijers, Broere, & Paans, 2002). Stowe et al. suggest this is evidence for a separate syntactic processing area in the brain. Fiebach and colleagues (Fiebach et al., 2001; Fiebach, Schlesewsky, & Friederici, 2002; Fiebach, Schlesewsky, Lohmann, Cramon, & Friederici, 2005) have also shown evidence for a separate SWM system, using event related potentials (ERP) and functional magnetic resonance imaging (fMRI) to localize SWM in Broca's area. These experiments give strong support for the existence of SWM as a form of working memory separate from the phonological verbal working memory model, and furthermore help to provide evidence that SWM is localized in Broca's area.

Neuroimaging data have shown a connection between music and language syntax processing in the brain (e.g., Maess et al., 2001), and evidence suggests pathways in the brain specialized for the processing of syntax (e.g., Fiebach et al., 2001); however, the distinction between these resource networks and the general concept of verbal working memory (the phonological loop and episodic buffer) has not been made experimentally. The resource networks in the SSIRH would provide a reasonable theoretical framework for these findings by conceptualizing the shared syntactic processing resource between music and language as SWM. The next step is therefore to see if there is a behavioural distinction between SWM and the phonological loop, using the predictions of the SSIRH to determine if music and language both draw on SWM.

The current experiment will explore whether music and language syntax both draw on SWM by looking at the interaction of music with a syntactic violation paired with both word lists and complex sentences. The syntactically manipulated music is expected to interfere with the processing of the complex sentences, as they are both drawing on SWM. According to the SSIRH (Patel, 2003, 2008), this would lead to a decrease in accuracy in processing the complex sentences, because of the shared processing costs. Word lists, on the other hand, are predicted to only utilize the phonological loop and not tap into SWM. Therefore syntactically manipulated music should not have such an effect on word lists. There will also be an instrument control condition to see if the results obtained are purely syntactic or whether attention is a factor, and the effects of musical ability will be taken into account as a covariate. A unique part of this experiment is that the music stimuli has been specifically composed for this experiment to ensure no familiarity with the music, and it has been designed to be more ecologically valid than in past studies with a combination of chords and melody resembling a song, as opposed to block chords or one note melodies (e.g., Fedorenko et al., 2009; Slevc et al., 2009).

It is hypothesized that memory for complex sentences will be significantly lower in the syntactic manipulation music condition compared with the normal and instrumental violation conditions, and that type of music interference will not have a significant effect on memory for word lists. As word lists are expected to primarily utilize the phonological loop because of their lack of syntax (Baddeley, Lewis, & Vallar, 1984), and complex sentences are assumed to utilize both the phonological loop *and* have access to SWM (Fiebach et al., 2001), if the results are as hypothesized, this will suggest that music and language both draw on SWM and that this is separate to the phonological loop system. It will also provide further support for the SSIRH stating that music and language draw on similar resource networks in the brain, specifically SWM.

Method

Participants and design

Sixty-one participants were recruited through advertising at the Australian National University (ANU) and through social media. Participants' age ranged from 18–45, with a mean age of 22.6. Twenty-five participants classified themselves as musicians, and 36 classified themselves as non-musicians. All participants were native English speakers, and two were bilingual.

The experiment was as a 2×3 within subjects design, where a visually presented word list or a complex sentence was paired with three types of musical stimuli: (1) no manipulation; (2) syntactic manipulation; and (3) instrumental manipulation. The independent variable was music interference type, and the dependent variable was accuracy of recall of the word lists and sentences. The 40 sets of music (with a normal, syntactic and instrument manipulation in each set) were randomly allocated among word lists and sentences and randomized so that there was an equal number of each manipulation paired with the word lists and sentences. There were 120 pairings overall. These were re-randomized every eight participants to ensure the results were related to the music condition rather than the difficulty of the word list or sentence.

Apparatus and stimuli

All trials were run on a Dell desktop computer with a 15 inch monitor. Participants listened to music through Philips headphones with a frequency range of 14–20,000 Hz and sensitivity of 100dB. Volume was kept at a constant comfortable level across participants, and responses were recorded through an Olympus WS-6505 digital voice recorder.

Language stimuli were 60 word lists and 60 complex sentences. Word lists were derived from the Medical Research Council (MRC) Psycholinguistic Database (Coltheart, 1981) which is available freely online. Each word list was: five items long; monosyllabic; had a Brown Verbal Frequency rating between 1 and 250; a familiarity rating between 100 and 643; a concreteness range between 530 and 642; an imagability rating between 400 and 620; and a Colorado norms meaningfulness between 100 and 590. An example of a typical word list was: 'sand, bat, light, pear, mole'. The complex sentences (see Appendix 1) were based on object-extracted versions of sentences used by Fedorenko et al. (2006, 2009). Sentences were altered so that they were all between 10 and 16 words long, with a similar overall length between 50 and 68 characters. An example of a complex sentence was: 'The host who the contestant offended ruined the show for the audience'.

The music stimuli were composed specifically for the experiment using Sibelius 4. Acoustic guitar was the main instrument used, and the audio files were exported as MIDI (musical instrument digital interface) files, with a sound closely resembling an acoustic guitar. Forty individual pieces of music, each eight seconds in length, were created in the keys of C, G, D, E, and A, as these are common in mainstream Western music. Each piece of music differed in rhythm, chords and melody to eliminate familiarity and make them ecologically valid; however, each had a 4/4 time signature and the tempo was kept consistent at 100 beats per minute to lower variability. Each of the 40 pieces of music had three variations. The first version was the original piece of in-key music (e.g., Figure 1a). The second version involved a syntactic manipulation consisting of an out-of-key chord (e.g., Figure 1b), and the third version involved an instrumental manipulation (e.g., Figure 1c). All together there were 120 music files which were paired with the 120 word lists and sentences.

The syntactic manipulation in the music involved one out-of-key chord in the musical sequence. Out-of-key chords were determined by the circle of fifths (Figure 2). The out-of-key chords were composed of elements at least three places away from the key signature of the piece. The circled chords in Figure 2 show what is considered out-of-key in relation to a piece in C major. Out-of-key elements were combined into an out-of-key chord to violate harmonic expectations.

To control for the possibility that the syntactic manipulation merely drew attention away from memory rehearsal rather than interacting with the syntax in the sentences, an instrument manipulation control condition was included. To limit variability, the same chord that was manipulated in the syntactic manipulation was manipulated in the instrument condition, and

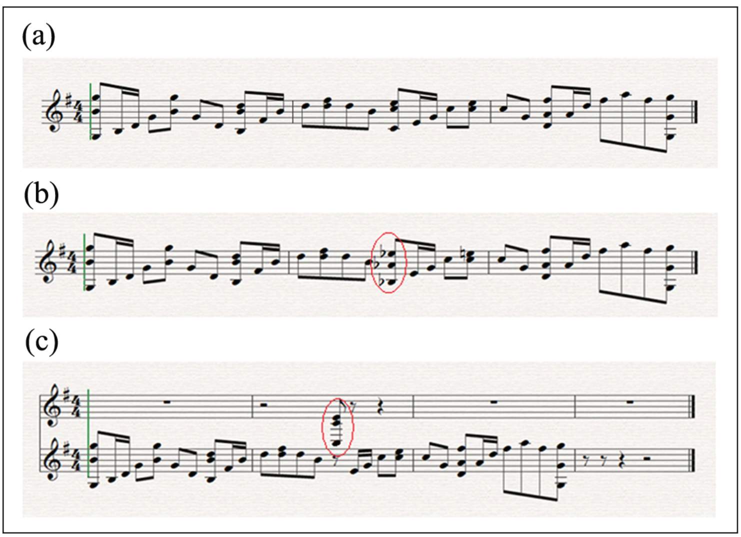

Figure 1. Examples of the three types of music stimuli: (a) normal in-key version; (b) syntactic manipulation, out-of-key chord circled; and (c) instrumental manipulation, circled chord played by flute.

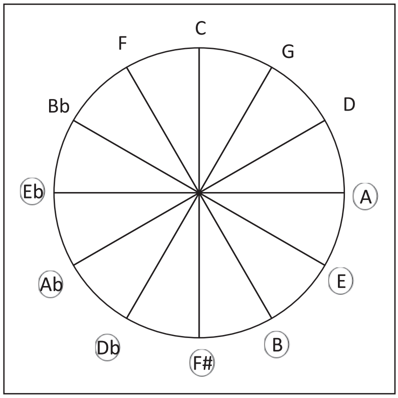

Figure 2. Circle of fifths. Elements three places or more away from the original key are considered out-of-key. In the case of C major, the circled chords would be out-of-key.

was played by a flute instead of an acoustic guitar (Figure 1c). Piano, organ and flute were thought to be of a similar level of distraction as the syntactic chords, and preliminary testing where participants rated level of distraction on a five-point scale showed that the flute was found to distract participants at approximately the same level as the out-of-key chord, compared to the piano and organ which were less salient and more salient respectively. This suggests that results are more likely related to the syntactic manipulation and not attention costs.

Procedures

The experiment was given ethical approval by the ANU ethics committee, and after being given an information sheet about the nature of the study, participants gave their consent to participate. Participants were asked to rate themselves as: non-musician; music loving non-musician; amateur musician; serious amateur musician; semi-professional musician; or professional musician. Participants were then given instructions on how the experiment would run and given three practice trials of music and language stimuli not used in the experiment proper to become accustomed to the procedure.

For each trial, the fixation point and music would simultaneously start. After three seconds either a word list or sentence would appear on the screen for five seconds, then a blank screen would appear and the music would stop (Figure 3). Participants were then instructed to verbally recall as much as they could remember of the word list or sentence, before pressing the space bar to continue to the next trial. Participants' responses were recorded using a digital voice recorder, which was positioned on the desk in front of them for the duration of the experiment. There were 120 trials, and participants were advised that they could take a break at any time by not pressing the space bar to initiate the next trial after they had responded. To counter for fatigue effects, the presentation of word lists and sentences were randomized for each participant. The syntactic and instrument anomalies occurred within the five seconds during which the words were presented on the screen. Other than this there was no synchronization of music with words. Participants averaged 26.4 minutes to complete the task, with individual times ranging from 23–33 minutes.

Results

Accuracy of recall for both sentences and word lists was scored based on a model previously used by Brewer, Sampaio, and Barlow (2005), who dealt with a similar level of sentence difficulty in

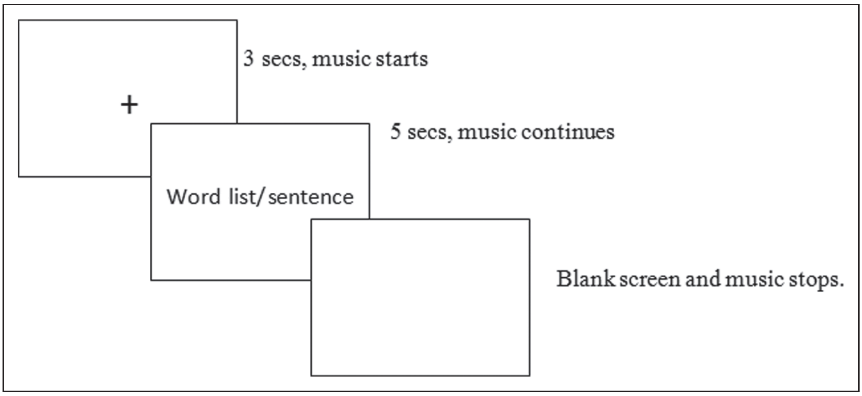

Figure 3. Schematic of presentation of stimuli in experiment. Music starts with a fixation point, continues with presentation of word list or sentence, and stops with blank screen where participants recall word list or sentence out loud into tape recorder.

Table 1. Scoring of word lists and sentences.

	Word lists	Sentences
Correct	All correct, right order	All correct, right order. Very small differences, e.g., that/who
Most	All correct, order different	All correct, order swapped, omissions of redundant info, addition of implied info
Partial error	Three or more correct	Missing important words, addition of information not implied by original sentence, non-synonymous word shifts
Error	Two or less correct	Minority of sentence remembered. Wrong words and order.
Omit	No recall	No recall

a similar sample. A word list or sentence could receive scores of: correct; most; partial error; error; or omit. The definitions of these are shown in Table 1. Accuracy was then scored for coding purposes as correct = 5, most = 4, partial error = 3, error = 2, omit = 1. This means that the lower the score, the lower the accuracy, and scores closest to 5 are the most accurate.

Main effects

A 2×3 repeated measures analysis of variance (ANOVA) was conducted with stimuli type (word list, sentence) × music interference type (normal, syntactic, instrument). Main effects of music interference type: $F(2, 120) = 3.417$, $p = .036$, $\eta^2 = .054$ and stimuli type: $F(1, 60) = 16.461$, $p = .000$, $\eta^2 = .215$ were found to be significant, as was the interaction effect: $F(2, 120) = 10.270$, $p = .000$, $\eta^2 = .146$. The graphed data show a clear effect of syntactic manipulation on sentence accuracy compared to word list accuracy (Figure 4). The syntactic manipulation led to highest levels of recall in the word list condition, and the lowest levels of recall in the sentence condition. The significant main effects of stimuli type and music interference type, as well as the interaction between the two, support the hypothesis that the combination of music and language syntax leads to lower accuracy of recall.

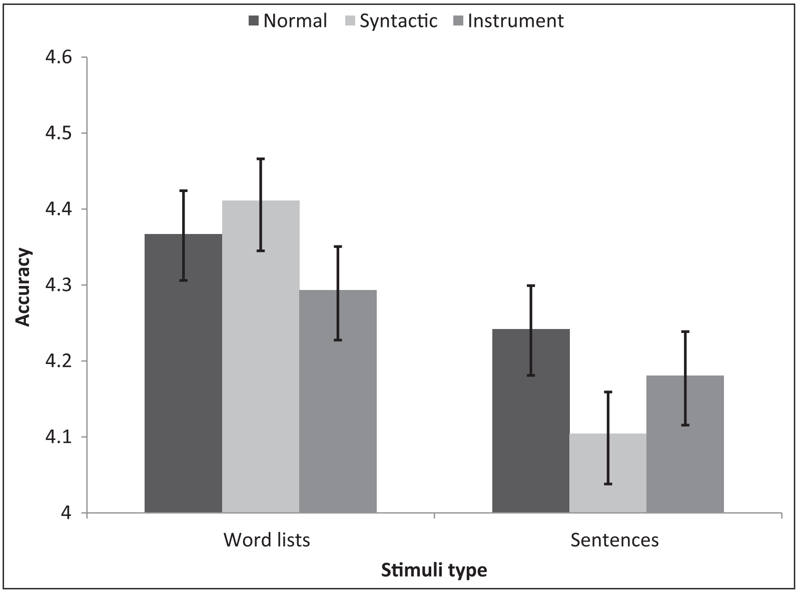

Figure 4. Graph of the effects of music interference type on level of accuracy by stimuli type. Data were scored so that a score of 1 = no recall and a score of 5 = correct. Error bars indicate one standard error either side of the mean.

Pairwise comparisons

The current experiment tested the hypothesis that memory for complex sentences would decline when paired with a syntactic manipulation in music compared to no musical manipulation and an instrument manipulation, whereas memory for word lists would not be similarly affected. To test this hypothesis, six pairwise planned comparisons were conducted.

Sentences. Within the sentence condition, the hypothesis suggests that the syntactic interference will lead to lower accuracy of recall compared to the normal and instrument conditions. Pairwise comparisons were therefore run between the normal and syntactic conditions, normal and instrument conditions, and syntactic and instrument conditions for sentences. Significant differences were found between sentence-normal and sentence-syntactic: $t(60) = -4.240$, $p = .000$, and sentence-syntactic and sentence-instrument: $t(60) = 2.200$, $p = .032$, while the difference between sentence-normal and sentence-instrument: $t(60) = -1.567$, $p = .122$ was non-significant.

Word lists. The hypothesis further suggested that there would not be significant differences between the three music conditions when paired with word lists. Therefore pairwise comparisons were run for the differences between the normal and syntactic conditions, normal and instrument conditions and syntactic and instrument conditions for word lists. The difference in means between the normal and syntactic conditions was non-significant: $t(60) = 1.208$, $p = .232$; and the difference between the normal and instrument conditions was of borderline significance: $t(60) = -2.021$, $p = .048$. Surprisingly the difference between the syntactic and instrument conditions was significant: $t(60) = -3.331$, $p = .001$.

Musical ability

To see whether musical ability affected the results, a repeated measures analysis of covariance was run. Participants were categorized as a non-musician if they rated themselves as non-musician or music-loving non-musician, and were classified as a musician if they chose amateur, serious amateur, semi-professional or professional musician. The vast majority of musicians classified themselves as amateur, and no participant classified themselves as a professional musician.

With the inclusion of musical ability as a covariate, the previously significant main effects of stimuli type and music interference became non-significant: $F(1, 59) = 1.299$, $p = .259$; and $F(2, 118) = 0.238$, $p = .788$ respectively. The only significant interaction was stimuli type × musical ability: $F(1, 59) = 7.259$, $p = .009$, $\eta^2 = .110$, reflecting the differences between musicians and non-musicians in the normal and instrument conditions (Figure 5 and Figure 6). As it appears that the covariate of musical ability accounted for the previous significant effects, these groups were looked at separately.

A repeated measures ANOVA was run using the data of the 35 self-reported non-musicians. Both the stimuli type and music interference effects were non-significant: $F(1, 35) = 1.927$, $p = .174$ and $F(2, 70) = 1.840$, $p = .166$ respectively; however, the interaction effect was significant: $F(2, 70) = 6.009$, $p = .004$, $\eta^2 = .147$, reflecting the effect of the syntactic manipulation between word lists and sentences.

A repeated measures ANOVA using the data of the 26 self-reported musicians found the effect of stimuli type to be significant: $F(1, 24) = 36.040$, $p = .000$, $\eta^2 = .6$, as well as the stimuli type and music interference interaction: $F(2, 48) = 4.872$, $p = .012$, $\eta^2 = .169$. The main effect of interference was not significant: $F(2, 48) = 1.524$, $p = .228$.

To see if there was a difference between musicians and non-musicians in the effect of music interference on memory for word lists and sentences individually, one way ANOVAs were run. One ANOVA looked at word list normal, syntactic and instrument, and another looked at sentence normal, syntactic and instrument for both musicians and non-musicians. Interestingly, the ANOVAs

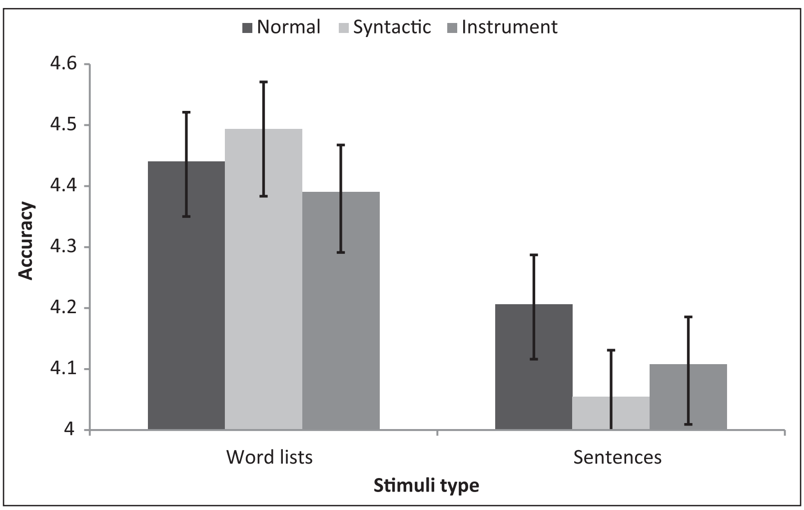

Figure 5. Musicians' accuracy by stimuli type and music interference. Error bars indicate one standard error either side of the mean.

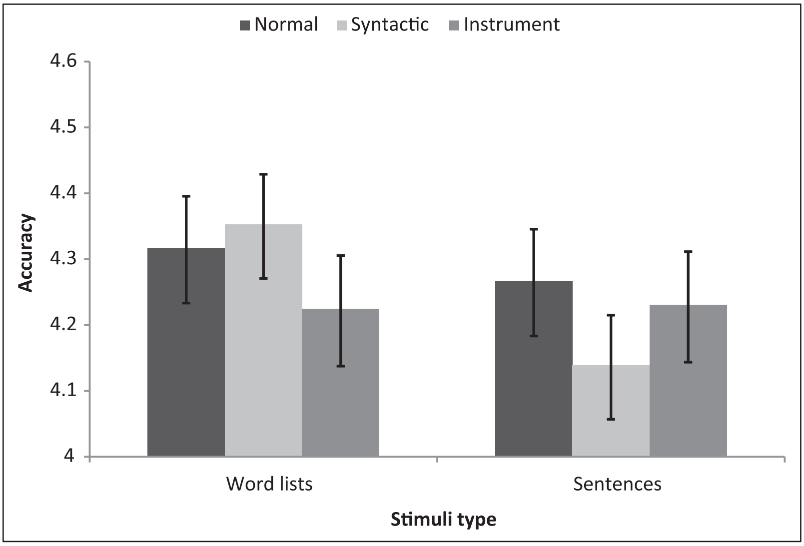

Figure 6. Non-musicians' accuracy by stimuli type and music interference. Error bars indicate one standard error either side of the mean.

showed borderline significant effects of music interference within word lists: $F(2, 70) = 3.218$, $p = .046$; and significant effects of music interference within sentences: $F(2, 70) = 4.774$, $p = .011$ for non-musicians, but non-significant effects of music interference on memory for the word lists: $F(2, 48) = 2.388$, $p = .103$; and borderline significant results for the sentences: $F(2, 48) = 3.098$, $p = .054$ for musicians. This suggests that the different types of music interference are having more of an effect *within condition* for non-musicians, whereas the musicians appeared to be performing more consistently across music type within condition, but differently between conditions.

Discussion

This research aimed to show that both music and language draw on similar syntactic working memory (SWM) resources. Predictions from the shared syntactic integration resource hypothesis (SSIRH) were used which suggest that music and language draw on similar cognitive processing resources, and that processing costs will be seen when both music and language syntax are processed concurrently. To discriminate between SWM and the phonological loop, visually presented word lists and sentences were paired with three music conditions: normal; syntactic (out-of-key chord within sequence); and instrumental (flute played on one chord instead of guitar). Word lists were assumed to utilize the phonological loop, as they do not contain complex syntax (Baddeley, et al., 1984), while complex sentences were assumed to utilize both the phonological loop *and* have access to SWM (Fiebach et al., 2001). It was hypothesized that memory for complex sentences would decline when paired with syntactically complex music due to costs of shared processing between music and language syntax in SWM, and that this would not occur in word lists because word lists do not draw on SWM resources.

The results support the hypothesis, with memory for complex sentences decreasing significantly when paired with the music syntactic condition compared to the music normal condition. The same pattern was not found in word lists, showing that the syntactic music manipulation had different effects on word lists and sentences. This may be due to word lists primarily accessing the phonological loop, while complex sentences are accessing both the phonological loop and SWM. Effects of shared processing are therefore seen when the sentences are paired with the syntactic manipulation in music, as syntactically irregular music is thought to also access SWM (Kljajevic, 2010). The instrument manipulation control condition was included to ensure that effects of the syntactic violation in music were not purely to do with the diversion of attention to the syntactic manipulation. In line with the hypothesis, it was found that the difference between the music normal and music instrument conditions in the complex sentences was non-significant, whereas the difference between the music normal and music syntactic conditions paired with complex sentences was significant. The difference between the music syntactic and music instrument was also significant. This suggests that the music syntactic condition interacted with the sentences in a way that was not purely attentional.

Connecting the shared syntactic integration resource hypothesis and syntactic working memory

The current experiment extends the SSIRH, suggesting that the shared resource networks between music and language are likely to include SWM. SWM theory (e.g., Fiebach et al., 2001; Kljajevic, 2010) has been developing separately from the SSIRH, with researchers finding strong evidence of a role for SWM separate from the verbal working memory model that has been popular in the literature (Baddeley, 2000). Research into the similarities between music and language processing show that areas thought to be specifically used in language syntax processing are being activated with musical irregularities (Koelsch et al., 2002; Maess et al., 2001), and a recent connection of SWM and the SSIRH (Kljajevic, 2010) shows a theoretical path where the two can be integrated; however, this had not previously been done experimentally. By using predictions of the SSIRH and SWM theory, this experiment has used music and language to show a distinction between complex sentences (assumed to be processed via both the phonological loop *and* SWM) and word lists (assumed to be processed via the phonological loop) when paired with syntactically manipulated music. Such a result supports the predictions of the SSIRH by showing evidence for costs of shared processing between music and language syntax, and further suggests that these shared resources could include SWM.

As SWM is a newer concept than the phonological loop and the verbal working memory system proposed by Baddeley and Hitch (1974), it has not been as extensively researched. The current findings therefore help to provide further evidence for an SWM system as an addition to the verbal working memory system that is well known in the literature (Baddeley, 2000). Such research can also start to incorporate SWM into more domain-general theories of working memory, attention and intelligence (Kane & Engle, 2002). SWM is not mentioned specifically in such models; however, it could be considered a form of online processing where information is integrated across modalities (Nairne, 2002). The importance of SWM as evidenced through the interaction of musical and linguistic syntax can help shed light on such online processing connections. For example, other studies are investigating the possibility that there is a connection between music, language and action (Fadiga, Craighero, & D'Ausilio, 2009; Overy & Avanzini, 2009). The difficulty in isolating SWM is partially due to syntactic processing activating a number of different brain areas, all of which are not used exclusively in the processing of syntax (Kaan & Swaab, 2002). Future research should look at uncovering the networks involved in SWM so that we are able to better understand the connections between SWM, music, and language.

The current experiment supports and extends similar work by Fedorenko et al. (2009) and Slevc et al. (2009), using stimuli that are more ecologically valid, and looking at SWM through the behavioural differences seen between memory for word lists and complex sentences. Fedorenko et al. (2009) looked at comprehension accuracy of subject-extracted and object-extracted sentences paired with a sung melody with one note per word. While it was found that comprehension accuracy decreased when the last note sung was out-of-key, supporting the SSIRH, the merging of musical and linguistic stimuli and the use of a control condition where the last note was sung louder, could be questioned. Slevc et al. (2009) looked at reading times of garden path sentences combined with one chord every three beats (Slevc et al., 2009), finding that reading times increased when an out-of-key chord was paired with a grammatically unexpected word, but not when an out-of-key chord was paired with a semantically unexpected word or syntactically unexpected words were paired with a change in instrument. While reading time measures reflect how fast a sentence is processed, they do not give us insight into recall for the sentences, and this is one area where the current study adds to the literature. On top of this, the music stimuli used by both Fedorenko et al. and Slevc et al. were very simple. As neuroimaging research has shown a difference between the processing of chords and melodies (Koelsch & Jentschke, 2010), and using one note or chord per word or every three beats does not reflect complexities involved in most musical pieces, the current study extends results with more ecologically valid music stimuli, as well as memory for overall recall when musical and linguistic syntax are competing for resources.

This research focused on syntactic differences between word lists and sentences; however, the grammatical connections within sentences add an element of semantics or meaning that word lists lack. The semantic similarities between music and language are more difficult to extract than syntactic similarities, largely due to the nature of semantics in music being unclear. fMRI studies have however shown distinct but related processing pathways in the brain for semantic and syntactic information (Friederici, Ruschemeyer, Hahne, & Fiebach, 2003; Uchiyama et al., 2008), and Koelsch et al. (2004) suggest that both music and language can prime word meaning. Similar studies to the present one have controlled for semantic irregularities when paired with syntactically manipulated music, and found little interference costs (Slevc et al., 2009), suggesting that, when focusing on SWM in complex sentences and syntactically manipulated music, the syntactic manipulation is the variable of most interest. The complex sentences presented in this study were all semantically congruous to avoid any issues of semantics becoming entangled with syntax.

Differences between musicians and non-musicians

A major finding of this research was the difference in memory for musicians and non-musicians in relation to whether the stimuli type was a word list or a sentence. While both groups showed a significant interaction effect led by the syntactic manipulation, musicians' accuracy was significantly affected in each condition by whether the stimulus was a word list or a sentence, whereas this was not the case for non-musicians. More interestingly, musicians had the highest accuracy recall in each condition for word lists, but the lowest accuracy recall in each condition for sentences. The higher accuracy recall in word lists for musicians could be explained by the fact that musicians have been shown to have superior rehearsal mechanisms for verbal working memory compared to non-musicians, meaning they are able to rehearse the word lists more efficiently and therefore remember them more accurately (Franklin et al., 2008). While this superior rehearsal mechanism theory explains the higher performance of musicians in word lists, it does not explain why musicians had the poorest accuracy for each music condition when paired with sentences, and this is what is of interest. Besson, Chobert, and Marie (2011) suggest that musicians are more sensitive to speech sounds, and that there is a transfer of training between music and language. This could plausibly lead to interference when music and language are processed together, leading to a lower recall in sentences when paired with the musical stimuli.

The difference between musicians and non-musicians may also be due to the connection between attention and working memory. The links between attention and working memory are well researched (Awh, Vogel, & Oh, 2006; Engle, 2002), and it has been shown that musicians are more likely to pay attention and notice changes in music stimuli compared to non-musicians (Wolpert, 2000). This would lead to a higher level of distraction for musicians when listening to the music, and less attention may be allocated to working memory. In terms of the results, it may be that such distraction is only shown behaviourally in the sentence condition as the sentences involved a higher processing capacity.

There are a few considerations to be taken into account when looking at this experiment. The breakdown of musicians and non-musicians in this experiment was not very sensitive and was a self-report measure. As musical ability was added as a covariate, and not as a major aim of the study, it was a suitable, easily administered measure; however, upon looking at the results, it may be worth testing the differences in recall for word lists and sentences between musicians and non-musicians with a stronger, more accurate measure, such as the Advanced Measures of Music Audiation (AMMA; available online at http://www.giamusic.com/products/P-3372.cfm#). Another consideration is that language stimuli were presented visually. This leads to participants processing two lots of information across modalities. Research looking at integration of information across modalities suggests that attentional processes can favour one modality over the other and can lead to changes in memory encoding (Johnson & Zatorre, 2005). This should be taken into account when comparing similar studies where linguistic information is presented as auditory stimuli.

The finding that musicians had the highest recall for each music condition when paired with word lists, but the lowest recall for each music condition when paired with sentences, suggests that the change is related to the syntax, semantics or another aspect that is added with a sentence compared to a word list. While the syntactic music manipulation affected musicians the most with sentences, the accuracy of recall in both the normal and instrument conditions also significantly declined when paired with sentences. It appears that there is a mechanism that differs between musicians and non-musicians, causing music to interfere more with sentences than word lists for musicians. Jentschke and Koelsch (2009) found that children with musical training appear to have better developed neural networks for processing syntax. It could be that, in this experiment, the syntax in the music and language interacted more for musicians compared to non-musicians because musicians have better developed syntax processing networks. This fits well with studies showing cognitive differences between musicians and non-musicians (Francois & Schon, 2011; Marques, Moreno, Castro, & Besson, 2007; Rodrigues, Loureiro, & Caramelli, 2010; Slevc & Miyaki, 2006), especially in relation to enhanced verbal memory (Brandler & Rammsayer, 2003; Helmbold, Rammsayer, & Altenmüller, 2005; Ho, Cheung, & Chan, 2003; Jakobson, Lewycky, Kilgour, & Stoesz, 2008; Kilgour, Jakobson, & Cuddy, 2000).

While there were a number of differences between musicians and non-musicians in this study, both musicians and non-musicians showed an effect of the syntactic music manipulation on sentences compared to word lists, suggesting that the syntax in the music interacts with the syntax in the sentences even for non-musicians. Though studies have shown that out-of-key chords are more salient for musicians compared to non-musicians (Koelsch, Jentschke, Sammler, & Mietchen, 2007) and that the cognitive response to syntactically unexpected notes is higher for musicians compared to non-musicians (Besson & Faita, 1995), the syntactically manipulated music still led to poorer sentence recall for non-musicians. To help explain this finding, research has found evidence to suggest an inherent system of music syntax processing in both musicians and non-musicians (Koelsch, Gunter, Friederici, & Schroger, 2000; Koelsch et al., 2007). This inherent system of music syntax processing would explain why the syntactic music condition showed an interaction effect for non-musicians as well as musicians.

Conclusions

This research suggests a role for SWM within an SSIRH framework, and supports a number of studies of both the SSIRH and SWM (Fiebach et al., 2001; Patel, 2008; Slevc et al., 2009). While it is clear there appears to be a connection between music and language (Maess, 2001; Patel, 2008), this connection is multi-layered and is still being uncovered. With many neuroimaging studies it is difficult to isolate effects of processing different stimuli due to the interconnectedness within the human brain. The behavioural nature of the current study shows clear effects of the syntactic condition on memory for sentences compared to word lists, and shows a difference between musicians and non-musicians; however, isolating where these effects are occurring in the brain is somewhat difficult. This is the challenge for future researchers in trying to uncover more of the brain mechanisms involved in the processing of music and language. In illuminating both the shared and distinct neural resources used in music and language processing, this information can be useful in helping both aphasic and amusic individuals in rehabilitation, and can be utilized in music therapy.

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Appendix 1

Complex sentences

1. The boy that the dean called to his office had a small voice full of anger.
2. The parents who the babysitter liked planned a trip to Queensland.
3. The chairman who the banker informed gave a million for the start up.
4. The cellist who the violinist chose played a piece from the symphony.
5. The policeman who was hurt by the burglar reloaded the revolver quickly.
6. The tiler who was punched by the electrician quit the job a week later.
7. The banker who advised the accountant calculated the costs of the project.
8. The artist who was approached by the buyer signed the contract for a year.
9. The professor that the student trusted answered the question about the lab.
10. The dealer who the mobster attacked organized some crimes in New York.
11. The cop who was overheard by the investigator closed the case with an arrest.
12. The starlet who the actor respected forgot to say the lines during the scene.
13. The lawyer who the defendant misled blamed the system for the conviction.
14. The princess who the count adored brought the best gift to the reception.
15. The socialite that the bachelor pursued owned a small company in the area.
16. The secretary who the councilman kissed covered the expenses for the party.
17. The host who the contestant offended ruined the show for the audience
18. The teacher who the scholar addressed offered the proof at the conference.
19. The leader who the diplomat insulted ended the negotiations on the spot.
20. The nun who the priest thanked founded the shelter opposite the church.
21. The governor who the queen queried proposed some changes to the plan.
22. The expert who the farmer questioned promoted the product at the fair.
23. The manager who the official harassed questioned the official documents.
24. The director who the clerk disliked typed the letter to the government.
25. The band who recommended the guitarist recorded the song for the album.
26. The cashier who the salesman resented mislabelled the products in the paper.
27. The cook who the waiter invited to the meal tasted the sauce for the meat.
28. The doctor who the medic assisted borrowed the instrument for the surgery.
29. The pilot who the passenger befriended enjoyed the flight across the Atlantic.
30. The mascot who was bothered by the fans attended the game at the college.
31. The producer who was criticized by the manager offered to fix the problem.
32. The protestor who was hated by the dictator gave a speech about the war.
33. The criminal that was discovered by the inspector turned out to be crazy.
34. The student that the girl tutored did better than expected in the exam.
35. The minister that the councilman liked had a desk overlooking the forest.
36. The host that the guest kissed brought a homemade cake to the party.
37. The thief that the crook had warned fled the town early the next morning.
38. The king that the knight had helped sent a runner to deliver the present.
39. The guard that the thief saw looked like he had a gun in his holster.

40. The policeman that the investigator met wrote a book detailing the case.
41. The coach that the nurse blamed looked over the file of the gymnast.
42. The queen who knew the count owned an impressive castle by the lake.
43. The coach that the scout punched ended up in a fight with the manager.
44. The dog that the cat had fought licked its wounds over in the corner.
45. The shark that the whale wounded won the fight over who got the food.
46. The chef that the waitress loved quit the underpaid job at the house.
47. The cop that the criminal scared crossed the street at the traffic lights.
48. The nurse that the man phoned forgot to take his pills into the office.
49. The cook that the priest forgot to pay deposited the cheque at the bank.
50. The guard that the dean overheard made a call about the matter at hand.
51. The bride that the friend teased told an outrageous joke about the past.
52. The wolf that the fox chased hurt its paw on the pavement on the way.
53. The aunt that was charmed by the groom raised a toast to his parents.
54. The monk that was blessed by the nun lit all the candles on the table.
55. The judge that the barrister thanked exited the room without a smile.
56. The guest that was pleased by the king poured the wine from the jug.
57. The cake that was squashed by the fruit made a large mess in the bag.
58. The pigeon that was scared by the eagle made a loop through the air.
59. The truck that was pulled by the car had a scratch on the back door.
60. The pipe that was bent by the rod had a hole through the middle.