EVIDENCE OF A DOMAIN-GENERAL SYNTAX RESOURCE
Understanding the P600 response to syntax violations in language and music.
by
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I declare that this thesis is my own account of my research and contains as its main content work which has not previously been submitted for a degree at any tertiary institution.

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Theodore Teow
An unresolved question in the literature relates to the extent to which language and music share syntax-related processing and how this is reflected in brain responses (e.g., certain event-related potential components of the electroencephalogram (ERP; EEG). Across three studies using neurologically healthy adult non-musicians, the goal was to examine the claims of the Shared Syntactic Integration Resource Hypothesis (SSIRH) and P600-as-P3 hypothesis: language and music share syntax-related processing, and that the relatively under-researched P600 component is the best index of this shared neural resource. Experiment 1 used a novel application of single-trial and subset EEG analyses to examine response-alignment across domains; similarities of response-alignment would suggest that the purported shared resource behaves the same way when employed in language and music processing. Participants ($N = 16$) listened to short sentences or chord progressions, and indicated via timed button-press the presence or absence of a syntax violation. P600 amplitudes were similar across domains, but response-alignment of the P600 occurred for language but not music. This suggests that music syntax errors recruit the P600-related shared resources in a quantitatively similar (ERP), yet qualitatively different (response-alignment) manner to language syntax errors. To explore the interactivity of unattended-on-attended syntax errors, the music and language stimuli were presented simultaneously in Experiment 2 ($N = 20$) and participants instructed to selectively...
attend to one domain only. P600 amplitude increased only to attended error conditions in either domain, and unattended error conditions elicited no P600 effect or RT impairment. Experiment 3 used the same methodology as Experiment 2 in a dual-attention task in order to examine combinatorial effects. Participants (N = 22) pressed one of three buttons to error-free, single-domain error, and dual-domain error conditions. P600 amplitude and RT increased for both single error conditions relative to controls, and further increased in the dual error conditions. Taken together, the P600 ERP component appears to index a similar cross-domain resource employed in syntax manipulations. Similar patterns of attention-dependence, combinatorial increases to dual errors, and of functional co-occurrences to RT verify the P600 as a correlate of processing cost in syntax error integration. However, some differences exist in the lack of response-alignment patterns in music versus language. Further research should determine if this shared resource represents a more general cognitive resource such as part of the P3 family, extending beyond syntax, or even language and music.
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Now faith is the substance of things hoped for, the evidence of things not seen. – Hebrews 11:1
LIST OF ORIGINAL PUBLICATIONS

This thesis is comprised of three individual experiments that are prepared as ‘stand-alone’ manuscripts, with the intention of submission for publication. The co-authors listed here contributed via their supervision of research and conceptual guidance. The doctoral candidate, as first author, was responsible for all aspects of experimental design, data collection and analysis, interpretation and write-up of the manuscripts.

These are as follows:


Theodore Teow  Dr. Bethanie Gouldthorp

Dr. Jon Prince  Dr. Urte Roeber
LIST OF PRESENTATIONS


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1. INTRODUCTION

1.1. Overview

Language and music represent two acoustically and structurally complex auditory stimuli that humans encounter on a daily basis, and are universal human abilities (Peretz, 2006). They are representative of the advanced cognitive abilities of our species, conveying semantic content and emotion through various means; for example, spoken or words, or a played musical instrument. To do so, language and music rely on structural rules called syntax, described as the “set of principles governing the combination of discrete structural elements (such as words or musical tones) into sequences” (Patel, 2003, p.674). This ordering of linguistic and musical elements enables encultured listeners to predict and process the sequences efficiently (Slevc & Okada, 2015; Tillmann, 2012). The possibility that these shared properties are associated with overlaps in their neural processing has received increasing scrutiny in the past two decades, beginning with the finding of similar brain responses to syntax errors across the two domains (Patel, Gibson, Ratner, Besson, & Holcomb, 1998). Investigating the language-music syntax interaction is the goal of the present thesis.

Before discussing the aforementioned similarity of syntax processes between language and music, it is important to define what syntax is in language and in music, and outline some relevant theory underlying syntax in either domain. Gibson’s Dependency Locality Theory (DLT; 2000, 1998) conceptualises syntax in language to be driven by a storage/predictive component that an individual uses to expect future words in syntactically correct forms (e.g., “this car”, not “this cars”), as well as an integrative component that continually updates itself to new incoming information. If, however, the new information is not in the expected form, the individual perceives a syntactic distance from the expected form that requires repair or integration into a coherent context. Perceived distance of the syntactic form of the incoming word is measured in terms of how far the word is from its expected form; for example, a
syntactic violation (“this cars”) would be harder to integrate than a non-violation. This is due to its linguistic distance relative to its expected form (“this car”). The main takeaway from the DLT is that there are increased costs to unexpected syntactic forms of words that, for example, can manifest in terms of reading time increases relative to a syntactically expected form (Slevc, Rosenberg, & Patel, 2009). This can take place in the structure of unusually encountered, but technically correct syntactic phrases such as the garden path task (Slevc et al., 2009), or that of a full morphosyntactic violation that is syntactically incorrect (Sassenhagen, Schlesewsky, & Bornkessel-Schlesewsky, 2014). Syntactic violations can appear in aspects of prosody (Soderstrom, Seidl, Nelson, & Jusczyk, 2003), gender agreement such as in German (Sassenhagen et al., 2014) and Spanish (Alarcón, 2009), and number agreement in English (Shen, Staub, & Sanders, 2013) and in Italian (Balconi & Pozzoli, 2005) among others. Number agreement is also a powerful structural rule that generates reliable syntax-related costs to brain response (Balconi & Pozzoli, 2005; Shen et al., 2013), with theoretical accounts such as the extended argument dependency model describing number agreement as a higher-level linguistic/syntactic aspect that can overpower the interpretation of a sentence (Bornkessel & Schlesewsky, 2006). For example, significant reinterpretation of an incoming sentence (“I cut the cakes beside the pizza that were brought by Jill”) is required to maintain the syntactic agreeableness of the sentence (i.e., Jill brought the cakes, not the pizza). In sentences with single objects, however, number agreement can create an unambiguous syntactic violation (such as “Jill began walking towards this cars”). In this fashion, number agreement can also present a cleaner manipulation of syntax that does not rely on lexical representations (Barber & Carreiras, 2005).

Music appears to share a similar reliance on expected syntactic forms through the establishment of hierarchical tone-based relationships, where frequencies are organised into structures that generate predictions about incoming stimuli (Rohrmeier & Koelsch, 2012). For
Western music (e.g., classical, pop, rock, jazz, country, etc.), the tonal hierarchy, or musical key, contributes to crucial syntactic structure (Krumhansl, 2001) alongside other aspects of the pitch-time structure (see Lerdal & Jackendoff, 1983). Each musical key consists of seven notes that vary in terms of stability, which is highest for the tonic note. Each musical note is nested in a tonality, which comprises seven individual notes that harmonically relate to each other. For example, C major comprises the tonic note C, and also D, E, F, G, A, and B. These notes change when moving to B major to the tonic B, C sharp (♯), D♯, E, F♯, G♯, and A♯. The Tonal Pitch Space Theory (TPS, Lerdahl, 2001) outlines the relationships between musical notes, and how they relate to each other. Syntax violations can occur by inserting musical events that do not fit the surrounding context (Fedorenko, Patel, Casasanto, Winawer, & Gibson, 2009; Koelsch, Schmidt, & Kansok, 2002; Maidhof & Koelsch, 2011; Zioga, Luft, & Bhattacharya, 2016), which elicit characteristic brain responses (see Koelsch, 2011 for a review). These responses do not depend on formal musical training, as implicit learning via exposure is sufficient to generate predictions about upcoming events (Rohrmeier & Koelsch, 2012). Tonally-based musical expectations function similarly to linguistic cloze probabilities (Fogel, Rosenberg, Lehman, Kuperberg, & Patel, 2015). In violating these tonal rules, the brain produces exaggerated negative (Steinbeis & Koelsch, 2007) and positive (Zioga et al., 2016) electrophysiological responses as measured by electroencephalography (EEG).

There exists, therefore, a number of similarities between the theoretical accounts of language and music. The DLT and TPS both refer to linguistic and musical syntax, and the relationships between words or chords. Both lead to the generation of expectations on incoming stimuli based on structural constraints. Not only do both domains rely on domain-specific unique structural rules to efficiently predict and process incoming stimuli, the violations of these rules in both domains produce similar behavioural cost in comprehension accuracy (Fedorenko et al., 2009; Kunert, Willems, & Hagoort, 2016) or comprehension time (Slevc et
Additionally, early ERP components interact and attenuate one another in the presence of a simultaneous error (Koelsch, Gunter, Wittfoth, & Sammler, 2005), and late ERP components appear similar in latency, amplitude, and distribution (Patel et al., 1998). However, further research in the area has not validated the idea of a clear congruence of cognitive processes that drive syntax in language and music. Consequently, the extent to which language and music share neural circuitry has been in contention. Research investigating this topic has involved complex behavioural manipulations (e.g., Kunert, Willems, & Hagoort, 2016), lesion studies (e.g., Frisch, Kotz, Von Cramon, & Friederici, 2003; Kotz, Frisch, von Cramon, & Friederici, 2003), electrophysiological (e.g., Steinbeis & Koelsch, 2008a), and neuroimaging studies (see LaCroix, Diaz, & Rogalsky, 2015 for a review). Evidence from the functional magnetic resonance imaging (fMRI) literature in particular point to a broad overlap between domains with some functional dissociations (LaCroix et al., 2015), the findings of which are corroborated by experimental research in electrophysiology (Carrus, Koelsch, & Bhattacharya, 2011; Carrus, Pearce, & Bhattacharya, 2013; de Leeuw et al., 2018; Patel et al., 1998; Steinbeis & Koelsch, 2007). Findings from the area have produced differential hypotheses, including three overarching concepts. These are that: a) language structure is represented separately from music structure in the brain, but processed similarly and specifically to syntax (Patel, 2012; Patel et al., 1998; Tillmann, 2009); b) language interacts with music at the earliest stages of acoustic processing, and the language/music relationship lies on a continuum of complex sounds rather than as distinct concepts (Koelsch, 2011a); and c) language and music are processed as more complex versions of simpler stimuli, with domain-general processes related to task relevance and perceptive salience that underpin them rather than syntax or semantic-specific processes (Coulson, King, & Kutas, 1998; Sassenhagen & Bornkessel-Schlesewsky, 2015; Sassenhagen et al., 2014), with a concurrent variation in this group referring to cognitive control as the underlying process (Slevc & Okada, 2015; Tillmann, 2012).
Although the broad theoretical question of this thesis pertains to the nature of shared cognitive resources, the overarching methodological question lies in quantifying this interaction between language and music. There is not a consensus in the literature on the most suitable behavioural, electrophysiological, or functional imaging correlate of syntactic processing cost shared across domains. Such ambiguity of indexing the language-music interaction remains despite recent research that continues to support some level of cross-domain interaction at the behavioural level (Kunert et al., 2016; Perruchet & Poulin-Charronnat, 2013) and various interactions at the electrophysiological (Carrus et al., 2011, 2013; Steinbeis & Koelsch, 2007; Zioga et al., 2016) level. Specifically, is the proposed shared syntactic resource between language and music (Patel, 2012) identically recruited in both cases, and is there a way to best capture the cost of processing such syntax violations? By systematically examining EEG data collated from hundreds of trials, the present program of research will aim to understand how the relatively under-researched late positive P600 component responds to syntactic violation, applying novel analyses such as response-alignment (Sassenhagen et al., 2014) and a new point-of-deviance method of measuring brain responses to language syntax violations that appear to provide new comparisons between language grammatical number agreement and music tonal syntax, and compare syntax-related P600 effects with behavioural measurements of reaction times (RTs) and task accuracy. Doing so will produce a greater understanding of the sensitivity of P600 to syntax violations and its associated processing cost, thereby clarifying the role of P600 in indexing this processing cost at the electrophysiological level. As reviewed in section 1.3, it is proposed that the P600 is a suitable functional correlate of the syntax-related processing cost incurred when such violations are encountered. However, it is first necessary to review the techniques employed in the literature to date, which have typically focused on three types of data in quantifying the syntax-
processing costs associated with syntactic violations: behavioural, electrophysiological, and functional imaging.

1.2. Techniques Used in the Examination of Shared Processing in Language and Music

**Behavioural.** Behavioural techniques include RTs measured with button presses (Sassenhagen et al., 2014), sentence comprehension (Fedorenko et al., 2009), musical closure ratings (Kunert et al., 2016) and reading times for self-paced reading tasks (Slevc et al., 2009). Behavioural measures are the sum product of sensory and decision making processes, as well as motor actuation; as such they are a complex but crucial measure of the individual’s response to a stimulus. As such, the measurement of behavioural performance is an essential component of anchoring other data, including electrophysiological data, in changes to the performance of an individual.

Earlier work by Slevc and colleagues (2009) utilised language syntax anomalies (so-called garden path sentences) alongside musical harmonic errors to measure the differences in a behavioural task. Syntactic expectancy was violated by changing the sentence structure. For example, “After the trial the attorney advised (that) the defendant *was* likely to commit more crimes.”; removing the word “that” would necessitate reinterpretation of the sentence. In the “that”-removed sentence, the expectation generated prior to the critical word “was” would be an outline of what the attorney told the defendant and not that the defendant would commit more crimes. These syntactic garden paths were accompanied by musical progressions that violated musical tonality through the rules outlined by a musical Circle of Fifths – chords that were played inside a given tonality (C Major) would sound congruent to each other, but aberrant chords (such as B Major) would produce expectation violations alongside their linguistic counterparts. Using a self-paced, phrase-by-phrase reading task, they measured the time taken by participants to read the phrases while ignoring music. The authors found that reading times were significantly higher when language syntax garden paths co-occurred with
a musical syntax violation as compared to a language syntax garden path violation alone, whereas language semantic violations of replacing a word with another in its word category (e.g., “The boss warned the mailman to watch for angry dogs/pigs when delivering the mail.”) did not interact with musical syntax violations. Lastly, timbral violations were introduced in a separate experiment that changed the critical-chord musical instrument from a piano to a pipe organ with no harmonic error; these produced no interactive effects with either language syntax or semantic manipulations. The authors took this to demonstrate the specific interaction of music and language syntax processing above that of simple deviance-related processing as shown in the lack of music syntax interaction with language semantic errors. Furthermore, musical timbre did not have the same interactive effects with language syntax or semantics, providing additional evidence that simple deviance-related effects were not an adequate explanation for the pattern of results. This pair of experiments as outlined by Slevc and colleagues (2009) highlighted a sensitivity of the observed effects to syntactic errors – delays in reading time were only accentuated when two syntactic demands were imposed on the participant. Follow-up work by Perruchet and Poulin-Charronnat (2013) used the same behavioural paradigm with music violations, but replaced the syntactic garden path sentences with semantic equivalents. These semantic garden paths (e.g., “The old man went to the bank/river bank to withdraw his net which was empty.”) violated actions committed to expected objects (e.g., in this case the bank would not reasonably contain an empty fishing net, but a river bank may do so). They found that there was a similar interaction of the semantic garden paths with music harmonic violations. Such a pattern of results suggests that there is a possible interaction between language and music domains when processing any structured stimuli overall, and not limited to syntax.

One particular experiment utilised music syntax violations presented at the same time as language syntax equivalents, semantic category-based violations, or an arithmetic task
This experiment measured a behavioural measure of music closure ratings, explained as the extent to which a participant judged a sequence to be musically resolved. These ratings were lower (less resolved) when language syntax violations were present at the same time. This was not observed with a semantic task or an arithmetic task, which was meant to parse out the distractive effects of a separate task and therefore attention-based effects. This finding demonstrates the specific effect of the language-music syntax interaction at the behavioural level – beyond the simple effects of attention or deviance-related processing alone. Further research could examine these behavioural effects using different techniques, such as using EEG to better understand the cortical responses to these syntactic errors. Doing so may better understand the neural response change associated with concurrent syntax errors. Nevertheless, these two experimental examples demonstrate the sensitivity of behavioural measures in capturing the effects of syntax processing costs, whether in the form of reading speed and accuracy, or of ratings of musical closure respectively. Both behavioural dependent variables (i.e., reading time, musical rating) demonstrate the real-world processing cost of individuals processing these errors. Further, these two tasks cover both directions of the behavioural cost incurred, one of the effect of music on language processing and the other of the effect of language on music processing. Each experiment focused on the selective-attention on either the language stimuli (Slevc et al., 2009) or on music (Kunert et al., 2016).

However, the tasks are substantially different from each other. The reading time paradigm allows for a timed response that is compared between conditions, producing an online measure of the ability to comprehend the language stimuli. It must be said that Slevc and colleagues’ (2009) task had contained an occasionally-occurring offline comprehension task that was more comparable to Kunert and colleagues’ (2016) task, but the language comprehension accuracies in Slevc and colleagues’ study showed near-ceiling accuracy scores that did not meaningfully differentiate between conditions; effects were more suitably captured.
within reading times and hinder efforts to compare across tasks. In contrast, Kunert and colleagues’ (2016) study focused on an offline measurement of musical closure, which relies on a rating system that does not capture the effects of timing. Participants may therefore have varied significantly with regard to the speed of their processing that do not directly compare to the ratings they finally entered. The issue is compounded by the fact that the specificity of reading time effects of language syntax with musical syntax was challenged in later research (Perruchet & Poulin-Charronnat, 2013; Slevc et al., 2009) versus a syntax-specific effect in the musical closure ratings (Kunert et al., 2016); the conflict of findings therefore adds to a sense that there is a lack of clarity on how best to capture the syntax effects, and how differently captured effects can be directly compared.

As task demand is an important factor in determining neural recruitment as evidenced by a recent review of hemodynamic studies in language and music syntax processing (LaCroix et al., 2015), the effects of syntax across both directions of music-on-language and language-on-music processing require consistent tasks to be directly compared (for examples, see Maidhof & Koelsch, 2011; Patel et al., 1998) instead of ignoring one domain while only examining the other (Slevc et al., 2009). Only focusing on the music-on-language effect, for example, may neglect the other direction and result in missing the comparisons that can be drawn with effects of language-on-music. In addition, another criticism of the behavioural measurements is that there are few ways to differentiate the point at which the processing cost is incurred. In order to produce an action, the brain first processes sensory information and determines a response through a separate ventral-parietal dual pathway (Goodale & Milner, 1992), which incurs significant response-related delays through motor neuron transmission (Wing & Kristofferson, 1973), and has structural, functional, and biochemically-induced differences across age and individuals (Seidler et al., 2010). Each point in the chain from perception, interpretation, and response add a stage at which eventual behavioural performance
may be affected, and may not precisely represent cognitive processing differences between
cognition and action. As such, there is a clear advantage for alternative techniques to
complement observed behavioural effects, such as EEG, in clarifying the neural extent to where
these processing costs originate in the cortex. In fact, the utility of EEG has been shown in
separating lower-level sensory encoding brain mechanisms from higher-level cognitive ones,
finding that the brain response to a task-relevant stimulus may happen ~80ms post- stimulus
onset, but that cortical activity doesn’t affect behavioural performance until 150ms post-
stimulus onset (VanRullen & Thorpe, 2001). One good example of the complementarity of
EEG is its use alongside behavioural measures to quantify response-related cortical processing
and its relationship to reaction time (Sassenhagen et al., 2014).

**Electrophysiological.** Electroencephalography (EEG) can be used to monitor moment-
by-moment variations in electrical activity generated by the brain. By pooling together the sum
activity of thousands of pyramidal cells that work in unison in the cortex, a net electrical and
magnetic dipole is created that can be measured at the scalp (Kappenman & Luck, 2011).
Collecting that data in a continuous fashion, it can be segmented according to time windows
(or epochs) around a given event. Using that information, a grand average ERP of the most
consistent scalp response to a given stimulus can be constructed. This produces a high signal-
to-noise of the resultant ERP waveform, as it averages out the trial-by-trial noise of non-
stimulus related processing (Luck, 2014). While these ERPs are not necessarily anchored in a
physical response, they can be functionally correlated with a specific manipulation of external
stimuli; a strong example of this is the P300, which occurs in the parietal region of electrodes
when a salient stimulus is presented (Polich, 2007). The P300 has been functionally correlated
to novelty processing (P3a) and task-relevant processing (Polich, 2007); these ERP
components and associated cognitive processes (and sub-components) are functionally
correlated with experimental findings that consistently demonstrate the component’s
enhancement or attenuation when a stimulus is changed. Such correlations help us understand what modulations in the component’s timing (i.e., latency) or strength (i.e., amplitude) mean and provide insight into how the brain’s neural populations react to changes in an external stimulus.

EEG has the advantage of being relatively inexpensive to use and versatile in the ways in which data can be analysed, but primarily benefits from the direct measuring of electrical activity generated by cortical activity in response to external stimuli. Recording up to once every millisecond, electrical activity is measured at the scalp level by electrodes across the head. Systems range from single electrode systems to a full head 256-channel geodesic system and can be analysed as single channels (Maidhof & Koelsch, 2011) or entire regions of interest (Carrus et al., 2013). This gives tremendous flexibility in obtaining and segmenting EEG data along several types of analyses, in addition to the chief advantage of EEG – high temporal resolution. Data collected from EEG is rich and can be analysed using conventional ERP averaging techniques, as well as emerging techniques like low resolution electromagnetic tomography (Pascual-Marqui et al., 2018; Pascual-Marqui, Esslen, Kochi, & Lehmann, 2002; Pascual-Marqui, Michel, & Lehmann, 1994) and single-trial analyses (Marathe, Ries, & McDowell, 2013), which give differentiated yet equally valuable results. As it is a non-invasive, relatively affordable method of collecting electrophysiological alongside behavioural data, EEG and specifically the ERP have been used extensively in the examination of grammatical processing in language (Molinaro, Barber, & Carreiras, 2011). Commonly observed components for language syntax errors include the left anterior negativity (LAN), which is a negative electrical response that occurs around 300-400ms post stimulus onset (Carrus et al., 2013; Steinbeis & Koelsch, 2007, 2008), as well as the early LAN (also known as the ELAN), which occurs in specific subsets of grammatical errors (for a review, see Gouvea et al., 2010). A later component known as the P600 (Osterhout & Holcomb, 1992, 1993) is a
modality-independent (Osterhout & Holcomb, 1993) positive electrical response centred in the parietal midline 600ms after the onset of a syntax violating stimulus. Similar to the cognitive processes postulated in language processing, processing musical violations requires additional neural resources, observable using EEG (Besson, Schön, Moreno, Santos, & Magne, 2007; Carrión & Bly, 2008). Commonly elicited syntax ERP responses include the early right anterior negativity (Bonfiglio et al., 2015) which occurs 150-350ms after error onset, as well as the late positive component (Besson & Macar, 1987), which is a parietally-centred ERP component that occurs 600ms after onset.

Two early examples of EEG studies on music and language processing demonstrate the advantage of measuring cortical scalp amplitudes, and in particular the ERP waveform. Using 15 musically educated participants and a computer task, Patel and colleagues (1998) auditorily separately played sentences and music progressions through headphones. Language errors were of a semantic (word category) or syntactic (phrase structure) nature, and music had deviants in the form of a nearby (harmonic structure) or further out-of-key deviant. After the language or music progression was presented and a delayed time period, participants assessed the acceptability of the progression with one of two buttons (“acceptable” or “unacceptable”). In doing so, the authors found the predicted robust parietal P600s to language and music syntax errors relative to error-free control trials, where errors were behaviourally judged as much less acceptable compared to controls. ERPs were examined across the whole scalp as well, with a similar latency of the P600 peak, amplitude change, and topographical distribution across language and music. Taken together, these findings provided initial evidence that language and music showed similarities of brain response to syntax errors.

Subsequent work by Koelsch and colleagues (2005) focused on earlier components – the early right anterior negativity to music syntax errors, or ERAN, and the left anterior negativity to language syntax errors, the LAN. These are considered the earliest syntax-related
components in the ERP, and represent an automatic processing of syntax regardless of attention. Participants were presented with simultaneous language and music violations while they focused on a linguistic error detection task. This task elicited a LAN to language syntax errors. Additionally, the authors found that music syntax errors generated an ERAN even when being ignored. Furthermore, they found that the ERAN’s occurrence coincided with an attenuation of the LAN to concurrent language syntax errors, even when the ERAN and LAN are observed in opposite scalp positions corresponding to the left and right hemispheres. The interactivity of syntax processes at the ERAN and LAN was argued to imply a shared relationship between the resources underpinning syntax between language and music (Koelsch et al., 2005). Despite a lack of attention paid to one domain, a simultaneously-presented music syntax error resulted in an interactive attenuation of the language brain response.

By utilising the advantages of millisecond-by-millisecond recordings in the EEG data, these researchers measured strong similarities (Patel et al., 1998) and interactions (Koelsch et al., 2005) between language and music electrophysiological responses. However, there are limitations to EEG. Being a non-invasive scalp recording technique, measured amplitudes at the scalp are the result of summated brain activity. This is propagated through cerebrospinal fluid, subcortical regions, the cortex, protective lipid layers called the meninges, skull sections, the scalp and hair, and then through any air barriers between the scalp and electrode. As such, it is commonly argued that it is the cortex that EEG is best able to measure, rather than that of subcortical structures such as the thalamus (Luck, 2014). Furthermore, electrical dipoles such as found in neural activity radiate outward in ever-increasing arcs and can often lead to unclear spatial origins; this challenge of observed EEG having infinite possible origin points is called the inverse problem, where finding the inverse (the spatial origin) of an EEG signal is extremely difficult (Pascual-Marqui, 1999). This means that scalp-level measurements of amplitude change may not directly correspond to that region being the source of the measured activity.
Additionally, the grand averaging technique used in ERP waveforms removes trial-by-trial noise, but may average out the dynamics of task habituation (Ravden & Polich, 1999) and may obscure transient functional connections (Hutka, Bidelman, & Moreno, 2013). Additionally, the use of stimulus-alignment in the vast majority of ERP studies may obscure response-aligned components, which are often dissipated in the stimulus-alignment of the ERP; response-aligned components are more diffuse when stimulus-aligned, with lower amplitude and a less focal peak (Sassenhagen et al., 2014). Dipole estimation is mathematically inferred using algorithms such as LORETA (Pascual-Marqui et al., 2002), but may have several dipole solutions that requires either a theory-based judgment call, or converging evidence from more spatially precise techniques such as fMRI. Lastly, the co-occurrence of EEG/ERP effects with functional performance such as in RT or task accuracy is crucial. Lacking this information, it would be impossible to link amplitude change in an ERP component with any meaningful construct. Therefore, the establishment of functional co-occurrence of EEG components relies heavily on collecting behavioural data. This helps provide construct validity for the changes seen in ERP component amplitude.

**fMRI.** Neuroimaging techniques provide another methodological approach to examining brain responses to the processing of language-music syntax. While there are other techniques included in the neuroimaging literature, such as positron emission tomography (PET; Aine, 1995) and diffusion tensor imaging (DTI; O’Donnell & Westin, 2011), a commonly employed alternative technique is functional magnetic resonance imaging (see LaCroix et al., 2015 for a review). fMRI uses functional measures of blood oxygen level differences (BOLD) as estimated by the amount of deoxygenation of haemoglobin in a given region; more deoxygenation is related to oxygen being consumed by nearby neurons, which correlates to activity and energy consumption (i.e., neuronal activity) in that specific brain region. The BOLD signal is measured as a change statistic on a magnetic resonance imaging
(MRI) template, and averaged brain responses are compiled for each stimulus category. fMRI possesses a high spatial resolution (measured in cubic millimetres, or voxels), aggregating net activity across that region. This allows for brain activity to be minutely averaged as the stimulus is presented, isolating key areas of activation as BOLD signals the neural hubs of activity. In fact, a review of 80 music and 91 language fMRI studies of healthy adults’ peak functional activations revealed cross-domain similarities in the left pars opercularis, which is a substructure within Broca’s Area (LaCroix et al., 2015). However, LaCroix and colleagues’ results were activation estimates based on a meta-analysis, which needed to be verified through experimental testing. One such study demonstrated the role of specific areas in the brain correlated with language and music processing, which led to discovery of a shared language and music dorsal-ventral dual-stream system centred around the left inferior frontal gyrus (IFG), which includes the aforementioned pars opercularis along with pars triangularis that has connectivity to temporo-parietal regions (Musso et al., 2015). Later language research also showed that the brain recruits specific resources in the prefrontal regions and the anterior insula to comprehend language, but there are large areas of similar activations in language error and control trials; these reside in bilateral frontal, temporal and inferior parietal lobes (Tune, Schlesewsky, Nagels, Small, & Bornkessel-Schlesewsky, 2016). Pragmatic (or semantic) and morpho-syntactic language errors are processed using similar neural networks, but with differentiated responses. For example, compared to control trials, pragmatic errors showed increased BOLD response in left temporal and inferior frontal regions, but a decreased response in right medial parietal cortex, whereas morpho-syntactic errors showed increased activity in bilateral medial and lateral parietal regions, and a decreased response in left temporal and inferior frontal regions (Kuperberg et al., 2003). Music syntax errors of harmony, in contrast, can differentially recruit the right IFG, the precuneus (a superior parietal region), and a substructure of the basal ganglia known as the putamen (Musso et al., 2015). fMRI is able to
clarify networks of cortical and subcortical activation to a high level of spatial specificity, without needing the invasive procedures of radioactive dye injection such as used in PET.

However, one of the limitations of fMRI lies in its indirect inference that BOLD activity correlates perfectly with cortical activity. This relationship depends on the idea that cognitive demand generates increased glucose demand, which blood then provides in greater measure to areas of need. This indirect measurement leads to the problem of not being able to confirm that BOLD changes are due to cognitive demand. One specific concern is that of the auditory environment under which fMRI research is conducted, which comprises loud whirring, repetitive pulsing buzzing, and beeping – the sporadic onset of these sounds confounds the auditory environment so crucial to music perception, which could generate transient increases of BOLD activity as part of the perception of these sounds alone (Peelle, 2014). However, researchers can now utilise active noise controlling headphones, new low-noise fMRI sequences, and novel methods of collecting silent portions of the MRI sequence to help attenuate the effects of this auditory confound (Peelle, 2014). Despite this, it is worth noting that behavioural measures and EEG do not necessarily struggle with the auditory confound that MRI inherently faces. Perhaps more crucially, fMRI is unable to measure the temporally slow BOLD responses to the same precision that EEG measures transient cortical activations. Typical fMRI data therefore comprises of changes that take up to two seconds to measure for well-controlled experiments with specific, limited physical responses (Kim, Richter, &UGHURBIL, 1997). While echo-planar imaging (EPI) is a popular MRI technique that allows for the reduction of inter-scan intervals to 100 milliseconds or less (Poustchi-Amin, Mirowitz, Brown, Mckinstry, & Li, 2001), the temporally imprecise hemodynamic responses to stimulus manipulations still constitute a challenge that is physiologically limited.

**Summary of techniques.** Given that each measurement technique has its limitations and strengths, there is a need to produce research that uses multiple techniques, as no one
technique is able to address contemporary research questions (Aine, 1995). The use of complementary behavioural, electrophysiological, and/or neuroimaging techniques will help answer specific questions more comprehensively. However, depending on the question asked, the optimum combination of techniques may vary. When investigating the temporal dynamics of brain responses to syntax processing, the combination of a highly temporally precise electrophysiological technique like EEG with the crucial cognitive demand of a behavioural task is the most appropriate combination. By using behavioural measures with EEG, we can observe how RT and task accuracy may vary with ERP latency, amplitude, and scalp distribution. While a spatially precise technique like fMRI would be useful to understand the cortical and subcortical dynamics of that brain response, its temporal limitations mean it is unable to add substantially to the discussion of the moment-by-moment brain/behaviour relationship.

1.3. Review of Literature and Current Understanding

Shared Syntax Integration Resource Hypothesis. In order to make sense of the similarities of P600 in language and music, Patel (2003, 2012) proposed what is now known as the Shared Syntax Integration Resource Hypothesis (SSIRH). The SSIRH claims that similarities in response to language and music syntax are contingent on distinct and shared processing resources, with the idea of understanding the extent to which processing overlap occurs. The SSIRH claims that there are representational processes that remain distinct, while the subsequent cognitive operations on language and music syntactic representations is shared across domains. The language-based DLT (Gibson, 2000), outlined earlier, predicts the relative costs of syntactic errors (Dröge, Fleischer, Schlesewsky, & Bornkessel-Schlesewsky, 2016) based on the difficulty of reactivating prior words in order to integrate the error into its preceding context. Syntactic errors may comprise either an anomaly of expected structure, such as in a garden-path type sentence that require a reinterpretation of the sentential context (Slevc
et al., 2009), or of a syntactic violation that cannot be integrated as they are into a preceding sentence (Shen et al., 2013). In both language and music, a predicted syntactic form incurs a cost when violated, which is expressed as a processing penalty (Fogel et al., 2015; Gibson, 2006; Rohrmeier & Koelsch, 2012).

As such, the SSIRH sets out the concepts of representational specificity and processing specificity (Patel, 2012). It states that there are differentiated representations in the brain for language and music, otherwise known as representational specificity. Representational specificity refers to the storing of linguistic information in the abstract concept of the lexicon (Goswami, 2000), as well as the prior knowledge of specific musical phrases in the musical lexicon (Peretz et al., 2009; Peretz & Coltheart, 2003). These representations are then processed in a similar way, leading to the concept of processing specificity (Patel, 2012) – shared syntax-specific cognitive resources are recruited to operate on the syntax knowledge in either knowledge or music, and may result in the observed similarities of brain activity for language and music processing. The SSIRH does not specify whether the representative or processing resources are distinct in the sense of anatomically separate regions of the brain, or perhaps were differentiated functions of an anatomically identical region, nor does it limit the neural networks underlying language or music to a specific region per se. Regions of language and music may therefore extend to full cross-cortical networks instead of being limited to a set of highly focalised locations.

Evidence for a domain-specificity comes primarily from lesion studies. For example, Patel (Patel, 2012) outlined a clinical case of a man, G.L., who acquired amusia after a series of strokes that damaged regions in his temporal lobe, which resulted in him losing the ability to discern musical key. While healthy controls may be able to recognise notes within a coherent musical context and identify in-key notes as a better musical fit than out-of-key notes, G.L. was unable to do so, instead relying on a pitch distance heuristic. He did not have a memory
advantage to melodies that lay in a specific key. Despite this neurological damage and subsequent musical impairment, he did not have more general auditory memory disadvantages, and did not suffer from aphasia. G.L.’s case highlights the specificity of a music-only impairment that happened post-stroke, which implies that there are music-specialised representative networks that were damaged without impact on more general functions. Further lesion research has outlined the importance of even subcortical resources, such as the basal ganglia, in the generation of ERP components such as the P600 (Frisch et al., 2003; Kotz et al., 2003), which is a reliably elicited component to a syntactic anomaly or violation (Hagoort & Brown, 2000; Van Petten & Luka, 2012). In the two studies mentioned (Frisch et al., 2003; Kotz et al., 2003), P600 was absent while P300 (Frisch et al., 2003) and N400 (Kotz et al., 2003) were present in patients with temporo-parietal lesions.

However, despite the apparent specialisation of music-specific neural structures, there is a large body of evidence that suggests a large overlap of neural activity as evidenced by electrophysiology and neuroimaging, as well as of behavioural cost as evidenced by processing speed and task accuracy. For example, simultaneously presented language and music progressions produced combinatory reading time increases when syntactic errors were presented in both domains at the same time, effects which were higher than that of a single language error (Slevc et al., 2009). This study demonstrated the cost of processing language and music syntax anomalies at the same time, above the effect of semantic or timbral deviants. Such findings led to the conclusion that there is a shared syntax resource across domains that is taxed simultaneously in unique ways. Further research in the area has supported the idea of shared resources, as evidenced by a behavioural cost to task performance accuracy (Fedorenko et al., 2009), or the reported agreeability of a syntactically errant musical progression (Kunert et al., 2016) or reaction time performance to a lexical decision task to sentence stimuli (Hoch, Poulin-Charronnat, & Tillmann, 2011) in the presence of simultaneous language and music.
errors. Electrophysiological research has shown similar strong effects of syntax on the subsequent brain response, whether language is presented in an auditory or visual modality (Hagoort & Brown, 2000), or even with trained musicians simply mimicking a silent video of erroneously played piano chord progressions (Sammler, Novembre, Koelsch, & Keller, 2013).

Additionally, there is evidence of strong interactive effects of syntax in simultaneously presented language and music, with early components of the ERP interacting with each other (Carrus et al., 2013; Koelsch et al., 2005; Maidhof & Koelsch, 2011; Steinbeis & Koelsch, 2008b). In most of these cases, the focus was cast on language as the principal domain of interest, with the language error LAN component attenuated in the presence of an unattended musical syntax error (Carrus et al., 2013; Koelsch et al., 2005; Steinbeis & Koelsch, 2008b). Only one study examined the language-on-music effect using EEG, with a selective-attention design equally weighting language-on-music and music-on-language effects (Maidhof & Koelsch, 2011). The later P600 component has not been examined in this way before, but early evidence points to a similarity of language and music syntax error responses in the late ERP (Besson et al., 1998; Patel et al., 1998). Language-elicited P600 has displayed a reliance on attention (Batterink & Neville, 2013) and task demand (Schacht, Sommer, Shmuilovich, Martínez, & Martín-Loeches, 2014), and of response-alignment similar to the P3 family (Sassenhagen et al., 2014) – the P600 in music also shares attention-dependence (Brattico, Tervaniemi, Näätänen, & Peretz, 2006). The existing literature points to similar brain responses across language and music. Musical manipulations that involve timbral and tonal information demonstrate similar frequency-based power change in processing syntactic anomalies to language equivalents (Brilmayer, Sassenhagen, Bornkessel-Schlesewsky, & Schlesewsky, 2017), and low-frequency based responses across language and music display similarities in the time-frequency decomposition of EEG data (Carrus et al., 2011). Furthermore, strong overlapping cortical activations and some functional dissociations were detected across over
170 fMRI studies in language and music (LaCroix et al., 2015), with attend-to-syntax tasks shown to correlate to higher activation overlap across domains. If attended syntax tasks tend to promote cortical recruitment overlap across domains, and if P600 relies on attention, the P600 is an ERP component of primary interest to examine overlap between language and music.

Furthermore, there is strong evidence of cross-training and expertise effects in language and music. Musicians perform better than non-musicians at music tasks (Ungan et al., 2013), show an ERAN to musical syntactic errors more readily than non-musicians (Sun, Liu, Zhou, & Jiang, 2018), modulate language processing as a result of their expertise (Asaridou & McQueen, 2013), while also showing an enhanced ability to perform more accurately than non-musicians in a challenging dual-attention language-music task (Roncaglia-Denissen, Bouwer, & Honing, 2018). Similar advantages are seen in auditory pitch acuity and of working memory capacity for tone language speakers as in musicians over non-musician English speakers (Bidelman, Hutka, & Moreno, 2013). Reviews on the transference between musical expertise on language suggest that the effect may be either driven by acoustic processing (Asaridou & McQueen, 2013) or the transfer of training effects (Besson, Chobert, & Marie, 2011), improved cognitive control to constitute a unique musician advantage (Slevc & Okada, 2015), or perhaps the experience-based reinforcement of shared subcortical and cortical networks that influence behaviour (Asaridou & McQueen, 2013).

The evidence outlined above of separate and apparent similarity between language and music lie in shared patterns of behavioural and electrophysiological cost. This is apparent in the interactivity of components at the early ERP when language and music errors are presented simultaneously, the behavioural cost of task performance and speed when simultaneous language and music errors occur, and the cross-domain transference of expertise in language and music. As such, the SSIRH is regarded as the premier explanation regarding the language-music interaction. That said, notable opposition has also accumulated in response to the SSIRH,
with some researchers finding no difference between semantic and syntactic behavioural cost (Perruchet & Poulin-Charronnat, 2013), a distinct harmonic parser that operates independently of higher-level language syntax (Fedorenko, McDermott, Norman-Haignere, & Kanwisher, 2012), and somewhat mixed results depending on the syntactic/semantic aspect of language in comparison with music (for a review, see Besson & Schön, 2001). There is even some evidence of a non-syntactic semantic P600 effect (Kuperberg, 2007), which challenges the syntax-specificity effects correlated with the ERP component. Furthermore, there are documented P600 effects to arithmetic violations (Núñez-Peña & Escera, 2007; Núñez-Peña & Honrubia-Serrano, 2004), alongside proportion-based P600 amplitude changes with rare deviations being more strongly reacted to (Coulson, King, & Kutas, 1998; Osterhout, McKinnon, Bersick, & Corey, 1996), of a higher lexical knowledge of the given language increasing P600 amplitude versus a language of lower lexical knowledge (Fitzroy & Sanders, 2013), and of individual differences affecting whether the P600 appears at all, or if other components such as the N400 take its place (Tanner & Van Hell, 2014).

The accumulation of contraindications of the SSIRH help provide insight into the complexity of interactions that occur in the brain, which may not be as cleanly explained across domains as the SSIRH suggests. As a first theoretical perspective linking language and music in terms of syntax, the SSIRH has generated much interest in understanding how these two areas intersect and interact; previously parallel lines of research in language and music must now be framed in the light of the other. More importantly, other theoretical perspectives regarding language and music have emerged, such as the a shared processing system of language and music (Tillmann, 2012), a shared resource model based on cognitive control (Slevc & Okada, 2015; Slevc, Reitman, & Okada, 2013), and a recent revision of the P600-as-P3 hypothesis (Sassenhagen et al., 2014).
**Shared Processing System.** Instead of the syntax-specific shared resource of the SSIRH, Tillman (2012) posits a model of stimulus processing that underlies language and music. This goes beyond syntax to include other aspects of stimulus processing as well, including semantic and other structured stimuli (Tillmann, 2012), and focuses on the brain’s use of existing cortical resources to structurally integrate language and music stimuli. Similar to other models such as the neurocognitive model by Koelsch (2011a), Tillmann posits the use of more general resources that span across domains – elements of stage-by-stage processing are shared as language and music are processed. This means that the main difference of Tillmann’s (2012) perspective from the SSIRH is that of lacking syntax-specificity – for example, language and music share structural integration resources of single element (word or chord) processing that generalise to semantic information as well. However, while the neurocognitive model of music (and language) perception focuses on processing stages analogous across domains, such as acoustic analysis, interval analyses, syntax structure building, reanalysis and repair, and semantic interpretation, Tillmann suggests a model of language and music processing that posits generic, lower-level processes such as short term memory, prediction, and the updating of a mental model being employed to process more complex stimuli in language and music. Musical progressions produce expectations of tempo and pitch that can be repaired and updated with incoming stimuli. Such expectations help to increase processing speed, and reduce errors by facilitating likely upcoming events based on formal and implicit training (Tillmann, 2012). Due to the generalist approach to language and music in this perspective, the effects of non-syntactic linguistic interactions with musical syntax are supportive of, not challenging to, shared resources across domains. Linguistic-semantic garden path sentences interacting with musical-syntactic manipulations (Hoch et al., 2011; Perruchet & Poulin-Charronnat, 2013) therefore do not challenge Tillmann’s (2012)
shared processing resource in the same way as the SSIRH, as the SSIRH is proposed to be syntax-specific.

Furthermore, recent work on similar expectation-based violations of content and structure seem to generate similar electrophysiological responses in observed actions, which do not have a linguistic or musical nature (Maffongelli et al., 2015), and numerical sequence errors (Núñez-Peña & Escera, 2007; Núñez-Peña & Honrubia-Serrano, 2004). In fact, the P600 component can be reinterpreted in this perspective to be an index of linear distance from an expected result (Núñez-Peña & Escera, 2007), not the measure of structural reintegration or processing. Such a theoretical perspective would thus challenge the syntax-specificity as claimed in the SSIRH, and would suggest a generalised resource for prediction violation instead of syntax processing. Previous evidence of the lack of language-semantic and music-syntactic interactions (Slevc et al., 2009) may also not be due to the syntax-specificity of language and music interactions, but rather the semantic errors were not challenging enough to require significant processing. This is evidenced by stronger linguistic semantic manipulations interacting with musical syntax (Perruchet & Poulin-Charronnat, 2013).

Tillmann (2012) also argues for music as a prime template for helping organise stimuli in a regular fashion (van Atteveldt et al., 2015), and thereby reduce confounds of acoustic differences on stimulus processing and the interactions between domains. In fact, there is some evidence to show that regularly presented language facilitates cortical response in the P600 component (Otterbein, Abel, Heinemann, Kaiser, & Schmidt-Kassow, 2012; Schmidt-Kassow & Kotz, 2008, 2009). Comparing regularly presented language and music may therefore be an effective way to compare cross-domain differences in syntax processing after accounting for the facilitatory effects of regular rhythm, as the acoustic and semantic complexity of music (Koelsch, 2011b) make close comparisons to language. Tillmann’s review of the literature highlights the conflicting nature of extant literature – it is not simply that syntax has a special
effect on brain and behaviour, but that other aspects of language and music interact as well. Moreover, physical action and numerical sequencing influence electrophysiology in a similar way to language and music. While not fully replacing the SSIRH due to strong evidence for a uniquely strong effect for syntax (Carrus et al., 2013; Kunert et al., 2016; Steinbeis & Koelsch, 2007), Tillman’s proposal of shared processing systems that are not syntax-specific is one possible alternative perspective. However, a more general perspective on the language-music interaction has the opportunity to link these neural functions to well-established mechanisms beyond language or music. This is something that the more recent cognitive control model aims to do (Slevc & Okada, 2015).

Cognitive Control. Following the observation that syntax-specificity is not as reliably demonstrated as first conceptualised, Slevc and Okada (Slevc & Okada, 2015) agree with the SSIRH’s basic tenet of a shared syntax resource between language and music, but like Tillmann (2012) also disagree with the syntax-specificity of this resource. Instead, they argue that there is a domain-general, non-syntax-specific resource of cognitive control that underlies processing of language and music syntax, and may comprise resources that extend beyond language and music altogether. The authors describe an integration and prediction model that first forms a syntactic context. The brain generates predictions of future events in the environment based on prior patterns of events; for example, regular, rhythmic beats in the environment would engender an expectation of future rhythmic beats in the same pattern. In language, this might take place in the form of a syntactic context formed through a sentence. Such expectation-based processing is akin to the more general concept of predictive coding, an established model of brain sensory and cognitive function that describes the matching of internally generated predictions to external stimulation (Bar, 2009). As Bar and colleagues (2009) argue, the brain discerns patterns in incoming stimuli, and creates an expectancy for future stimuli based off that existing framework. New information either confirms or refutes
the framework, and that drives either amendment of the existing framework or reinforcement of the framework. This bidirectional process allows for new experiences or stimuli to be processed in the light of previous stimuli, even if the previous stimuli may not be completely related to the new stimulus. The decision making process of processing stimuli produces attentional and cognitive demands, which accrue cost when the expected stimulus is replaced with a violating stimulus such as seen in a syntactic error (Slevc & Okada, 2015). Rauss and Pourtois (2013) further developed the prediction model by emphasising the multi-layered predictive capabilities of the brain. They argue that simpler sensory regularity and, for example, complex syntactic expectation are not alike, and that the brain uses levels of cortical hierarchy to process these differences with specialised areas of the brain. As such, violations of a different nature may well be processed by different cortical regions, which focus on expectations of a specific nature.

Using this information and approaching the language-music interaction using existing literature of the mechanisms driving stimulus-related processing, Slevc and Okada (2015) disambiguate their postulated cognitive control perspective from traditional attentional models of domain-general resources (Tillmann, 2012). Being more specific regarding the neural underpinnings of shared language-music brain response, they posit a well-established set of cognitive recovery/repair mechanisms based off non-linguistic research: conflict resolution, and reinterpretation. Such mechanisms are suggested to be merely (and slightly) differently recruited in music compared to language (Slevc & Okada, 2015). As such, differentiated neural network recruitment in language and music is a plausible explanation for the differences of activation seen, for example, within Broca’s area (LaCroix et al., 2015; Musso et al., 2015), while maintaining that it is a general set of cognitive resources used with strong overlap across domains. Furthermore, the cognitive control hypothesis does account for the findings of linguistic syntax violations interacting with musical syntax violations. The observed interaction
is attributable to the brain reducing available cognitive resources to a given violation in the presence of a concurrent violation of a similar nature. In this instance, syntax violations would require extensive revision and integration into its previous context, whereas a timbral violation’s surprising but cognitively easy to integrate nature would not interact as much with a syntactic violation (Slevc & Okada, 2015). The relative difficulty of task-related integration is therefore the basis of difference between findings in the literature, and explains the differences in findings seen in semantic versus syntactic language manipulations (Slevc et al., 2009). As outlined earlier, a syntactic garden path manipulation (“…the attorney advised (that) the defendant was…”) produced difficult complications to the sentence and required extensive reprocessing of the sentence. Semantically unexpected word category violations were not as resource-intensive, as the effect of the deviance was limited to the localised word context. Such a lack of findings in semantic errors was subsequently challenged when semantic garden paths (similar in cognitive demand to the syntactic equivalents) resulted in interactions with musical syntax (Perruchet & Poulin-Charronnat, 2013). Furthermore, the cognitive control perspective adds explanatory power in the sense that an attended timbral task may not elicit the same amount of reinterpretative resources, and therefore reduce the extent of overlap between language and music (Maidhof & Koelsch, 2011), instead highlight the areas of distinct (and automatic) processing.

The cognitive control perspective focuses on the regulatory role of higher representational processes resolving conflicts in incoming stimuli. In doing so, they highlight the role of active processing of stimuli over passive or unattended listening (Slevc & Okada, 2015); in fact, they state that active processing “may be a prerequisite for the involvement of control processes” (Slevc & Okada, 2015, p. 641). This suggests that active processing tasks are best able to capture the interactive effects of a shared language and music resource, above what can be seen with passive or unattended tasks; however, there has been only one
bidirectional selective attention task between language and music (Maidhof & Koelsch, 2011), and the task was to attend to timbre and not syntax. This may have had implications on how little observed interactivity was present in their dataset, and highlights the need for attended syntax manipulations in the literature. Future work could therefore add to the literature by utilising active tasks in processing language or music, examining their interaction under those conditions, and thereby fill in the gaps of existing research.

In the view of this more mechanistic account of the language-music interaction, one potential advancement of this idea is to extend these neural responses in more general brain responses, and ground them in neuroanatomically viable networks. Such a model is a recent iteration of the P600-as-P3 hypothesis (Coulson et al., 1998), combined with the locus coeruleus-norepinephrine system (LC-NE system; Nieuwenhuis, Aston-Jones, & Cohen, 2005) as described in the next section.

**P600-as-P3 hypothesis revisited.** Developing the idea of more generalist modelling of the syntax brain response, as well as grounding it in a neuroanatomically plausible network, the P600-as-P3 hypothesis has experienced a resurgence in the literature. As the most reliably elicited component in syntactic manipulations (Molinaro et al., 2011), the P600 is a useful index of electrophysiological response to syntax manipulation across domains (Patel et al., 1998) and modalities (Hagoort & Brown, 2000). This is despite the fact that P600 is not strictly elicited only with syntax manipulations (Kuperberg, 2007). First coined by Coulson, King, and Kutas (Coulson et al., 1998), the researchers ran an experiment that examined the P600 alongside P3b from the P3 family of ERP components. Participants were visually shown individual words that formed a sentence. Morphosyntactic violations were interspersed in blocks of sentences, which were introduced to provide P600-eliciting conditions (Coulson et al., 1998). In order to separately manipulate probability effects, and thereby affect P3b-like conditions, the researchers also modified the probability of syntax violations by block – less
common errors in a block were hypothesised to increase P3b amplitude, if it is P3b-like activation taking place in the ERP. The late positivity in their experiment was modulated by grammaticality (syntactically correct or not) and stimulus probability (Coulson et al., 1998). This means that P3b- and P600-like activations were present in the late positivity to syntax violations, and suggests that the P600 shares characteristics of the P3b. Consequently, they concluded that:

“…the late positivity elicited by syntactically anomalous stimuli cannot be viewed as a direct manifestation of a domain-specific parser, but rather a member of the P300 family of components (P3b and perhaps the slow wave) elicited by encountering the relatively rare linguistic event of ungrammaticality.” (Coulson et al., 1998)

Following some research that suggested the P600 was not simply a P3 (Frisch et al., 2003), the P600-as-P3 hypothesis did not receive much further attention in the literature until recently (Sassenhagen et al., 2014). Using the hypothesis to predict response-alignment in language P600 (as in P3), these researchers presented visual morphosyntactic errors to participants and measured RT alongside EEG data. Participants were required to respond with a button press if they decided that a given sentence was syntactically acceptable, or if an error was present (Sassenhagen et al., 2014). Using a number of single-trial analyses and primarily subset analyses, they established that as RT increased, P600 latency increased. Given that the P3 demonstrates response-alignment, and that the P600 was predicted to show the same response-alignment if it was similar to the P3, P600 response-alignment provided supportive evidence of the P600-as-P3 hypothesis. Subsequent research in this area incorporated theoretical predictions based on the relationship of P3 with the LC-NE system (Nieuwenhuis et al., 2005), which suggests that the P3 is generated by a system in the brain that also modulates arousal (Corbetta, Patel, & Shulman, 2008) centred on the locus coeruleus. As such,
norepinephrine-related activation should also produce changes in physiology (such as galvanic skin response) as the P3 is elicited. Using this information, a P600-eliciting language task was compared alongside a facial detection P3 task and found to show the same pattern of response-alignment in both cases (Sassenhagen & Bornkessel-Schlesewsky, 2015), with the predicted galvanic skin response to P600 showing response-alignment as well. This led to a validation of the predictions based off the P600-as-P3 hypothesis, while incorporating new elements of neuroanatomically plausible neural system generation in the LC-NE system.

Subsequent work in the area has focused on the P600 and its relationship to the P3 under different types of analyses. In particular, the use of the time-frequency decomposition has allowed for novel comparisons of EEG data, such as in recent work investigating the P600-as-P3 hypothesis (Brilmayer et al., 2017). Using timbral and tonal music manipulations to physically match the timbral and tonal differences seen in language stimuli, participants reacted to manipulations of sequential position as well as stimulus type, and position. They found that the P3- and P600-eliciting conditions had the same time-frequency power change and coherence in the theta and delta bands, which are argued to also be domain-general indexes of attentional and target detection processes (Gilmore, Malone, Bernat, & Iacono, 2010). Lastly, recent work employed multivariate pattern analysis (King & Dehaene, 2014). MVPA is a new analysis able to classify EEG and other neuroimaging (MEG, fMRI) data based on a template of previous data. The temporal and spatial information of a given ERP component such as P3 can be learned, and other ERP components such as the P600 can be compared to P3 in order to determine the temporal and spatial similarities between the two. MVPA is comparatively bias-free, providing an objective measure of similarity between two cortical responses. If the MVPA algorithm recognises P600 from P3-training, then it demonstrates bias-free similarities of time course (temporal data) and distribution (spatial data) between the two responses. This would strongly suggest that P600 and P3 are similarly generated in the brain. A recent experiment
investigated the proposed similarities of P600 and P3 using MVPA by comparing a language morphosyntactic manipulation and the elicited P600 component to a visual and auditory oddball task that elicited a P3 (Sassenhagen & Fiebach, 2018). The researchers trained MVPA to both the oddball P3 and the morphosyntactic P600, and afterward attempted to classify P600 trials with both pattern trainings. In support of the similarities of P600 and P3, the algorithm successfully classified P600 trials with P3-trained just as well as P600-trained MVPA (Sassenhagen & Fiebach, 2018).

Furthermore, the direct comparison of P3b alongside P600 shows not only a similarity in timing, distribution, and size of response to unpredicted or improbable stimuli, P600 also shows the characteristic frontal shift of its parietal distribution with advanced age (Leckey & Federmeier, 2019). This frontal shift is similar to that seen in P3b-related age changes, where older adults show a more frontal P3b distribution than younger groups. Such findings provide support for a similarity of P3b and P600 at a deeper level of analysis beyond superficial similarity. The implications of these collective findings extend to testing P3b-like behaviour in P600, in order to further extend the comparisons that can be made between P600 and P3b.

As reviewed here, new analyses and models of the P600 raise new questions of the behaviour and electrophysiology underlying syntax-related responses. The recent revisitations of the P600-as-P3 hypothesis have suggested a neuroanatomically plausible system in the LC-NE to drive P3 as well as P600. Not only is this hypothesis theoretically valuable in anchoring electrophysiology with neuroanatomy (Nieuwenhuis et al., 2005), the P600 also benefits from the extensive P3 literature (Sassenhagen et al., 2014). The P600-as-P3 hypothesis has already begun to add new findings to the P600 literature. For example, through the use of single-trial and subset analyses (Sassenhagen et al., 2014), galvanic skin response (Sassenhagen & Bornkessel-Schlesewsky, 2015), time frequency analyses (Brilmayer et al., 2017), and MVPA (Sassenhagen & Fiebach, 2018), the P600 component has been examined in novel ways and
new points of comparison made. With the advent of new analyses of EEG data, the P600 and the language-music syntax interaction provides us with several directions to pursue, providing new points of comparison to further understand syntax in language and music, and the P600.

1.4. Comparing Language and Music in Electrophysiology: Can we look at this relationship from new angles?

With the divergence of perspectives regarding the syntax and language/music interaction in particular, there are several ways to further our understanding in this area. Following initial findings of interactive effects of syntax across language and music (Koelsch et al., 2005), EEG research has recently started to converge on simultaneous presentation of both domains. This is done in an attempt to investigate the interactions of ERP components following dual errors, single errors in either domain, or not at all (Carrus et al., 2011, 2013; Maidhof & Koelsch, 2011; Steinbeis & Koelsch, 2007). EEG (Bidelman et al., 2013; Hutka et al., 2013; Maidhof & Koelsch, 2011) and behavioural data (Kunert et al., 2016) have highlighted the importance of examining bidirectionality as well, after highlighting the potential differences of the language-on-music effect versus the well documented music-on-language effect (Carrus et al., 2011, 2013; Fedorenko et al., 2009; Hoch et al., 2011; Koelsch et al., 2005; Slevc et al., 2009; Zioga et al., 2016). As a first study examining the bidirectional effects of music-on-language and vice versa, Maidhof and Koelsch’s (2011) study highlighted the non-trivial differences of brain response as attention is paid to one and not the other domain. They demonstrated that music ERAN was attenuated in the presence of a concurrent language sentence, but did not necessarily need a syntax error to achieve that effect. Further attenuations of the ERAN were noticed only when music was ignored and language irregularities present. More work must be done to further our knowledge of both directions of the electrophysiological response, preferably in a within-subjects design.
Additionally, the literature currently lacks a strong consensus on the tasks employed in the investigation of syntax interaction; tasks range from timbre detection tasks (Maidhof & Koelsch, 2011; Steinbeis & Koelsch, 2007), to error detection tasks (Fitzroy & Sanders, 2013; Sassenhagen et al., 2014), word probe tasks (Schacht et al., 2014), and discrimination/acceptability tasks (Carrus et al., 2013; Zioga et al., 2016). Converging techniques in fMRI have demonstrated the importance of task demand on the subsequent observed interaction (or lack thereof) regarding syntax across domains (LaCroix et al., 2015), and provides impetus to standardise tasks that maximise interactivity. As reviewed earlier, these are argued to be attended syntax tasks that provide the most overlap across domains (LaCroix et al., 2015; Slevc & Okada, 2015). Consequently, timbre detection and word probe tasks may not be the best candidates for investigating overlap as they distract from active syntax processing necessary for conscious processes. These are indexed by the P600 (Schacht et al., 2014). However, error detection or discrimination are good candidates for attentive tasks, as they necessitate the use of decision making in discerning syntax errors in language or in music (Koelsch et al., 2005). More work using attended syntax tasks will help delineate the areas of distinction or overlap between language and music processing.

Another avenue for further investigation is around the possibility of a new method of event marking in language syntax processing. The P600 can sometimes be observed to be somewhat diffuse in the ERP (Carrus et al., 2013; Spotorno, Cheylus, Van Der Henst, & Noveck, 2013), which can be argued to the product of aligning the data with the wrong event. One suggestion is that the P600 aligns to the response (Sassenhagen et al., 2014), and therefore is spread across RT as it varies relative to stimulus onset. Another potential contributor to a diffuse P600 is the possibility is that the stimulus onset is a less precise ERP marker than the exact point at which the syntax error is perceivable. Some have suggested a perceptual centre paradigm instead of stimulus onset, that has produced shorter latencies of the P3b (Otterbein
et al., 2012). Taking this idea further, we suggest the so-called point of deviance (PoD) onset, such as the point where a number agreement becomes plural where a single is expected, or vice versa. Previous research (Sassenhagen et al., 2014) has typically focused on the start of a specific word, such as an incorrectly gendered noun in German (“die Wasser”, correct form “das Wasser”). If the actual time point of the syntactic error was not at the very onset of the word, then the error-related effect would be diffused over a time window that varied according to word length. Consequently, a stimulus onset-aligned ERP would produce a diffused waveform with brain responses spread out over the range of points the actual processing occurs.

An ideal ERP marker would measure the point at which the specific manipulated deviance occurred, such as number agreement violations (Shen et al., 2013), otherwise termed henceforth as the point-of-deviance (PoD). The PoD has the potential to vary substantially from word onset to word deviance (e.g., “cars” versus “passengers”), and will result in the diffusion of P600 if P600 is related to the processing of the deviance of the expected structure. Changing to the PoD for ERP analyses would drastically reduce latency variability for processing syntax-related deviances, thereby averaging deviance-related ERPs relative to a precise and accurate event marker. Changing from stimulus onset to the PoD would shorten the overall latency of RTs, as well as ERP components, and may help clarify the relationships of different components between varied tasks, such as the P3b (Sassenhagen & Bornkessel-Schlesewsky, 2015) of an oddball task versus the P600 (500-1000ms post-onset; Sassenhagen et al., 2014) to a language syntax error. These two components are often observed hundreds of milliseconds apart relative to one another, and thus direct comparisons of P600 and P3 are hindered by the differences in time course. By improving the event marking of the ERP, we may find latencies of P600 similar to P3. This would allow for new comparisons in existing models, such as the P600-as-P3 hypothesis.
Performing ERP analyses to the PoD, rather than stimulus onset, allows a more temporally precise measure of deviance-related processing independent of the variability across words, and may result in increased focalisation of the ERP peaks to error-related processing similar to related research (Otterbein et al., 2012). In contrast, musical errors are immediately perceivable due to the onset of the chord being the onset of deviance; PoD therefore coincides with the stimulus onset in music. New research in this area can validate the use of the PoD in the language syntax electrophysiological response, especially to aid in direct comparison to the musical syntax response.

One drawback of using the PoD in language is the possibility that word onset-aligned, potentially sensory-focused auditory ERP components such as the P1-N1 and (E)LAN components may be largely attenuated or absent in language ERPs. Such a concession would result in the early language syntax components being incomparable to the music auditory ERP waveforms. The focus of the current study would therefore have to centre on the P600 component at the cost of non-central components in the ERP, a practice that has recently been validated in best-practice suggestions in the literature (Luck & Gaspelin, 2017).

Another potential new direction of analysing EEG data involves observing how the EEG response varies with other variables, such as RT, on a trial-to-trial basis. Single-trial analyses include several different techniques, which include the subset analyses mentioned above, ITC low-frequency coherence, and Woody Filter estimated latency of ERP component correlations (Sassenhagen & Bornkessel-Schlesewsky, 2015; Sassenhagen et al., 2014). Such techniques focus on the other aspects of EEG data that can elucidate the relationships between behavioural measures (such as RT) and observed ERP components. Specifically, examining the relationship between P600 and RT, Sassenhagen and colleagues (2014) found a property of response-alignment that was not reported in previous language syntax literature; individual quartile ERPs were calculated for the slowest to fastest RT quartiles and then averaged by the
sample. These were then compared via analyses of variance, and found to have later P600 components as the RT increased; such behaviour is in line with a response-aligned P600, as it would follow the RT. The article argued that this has implications for the P600 component as possibly an expression of a component that also shows response-alignment, the earlier P3b (Nieuwenhuis et al., 2005). However, the averaging process would have eliminated such a relationship in the ERP, and goes against the traditional wisdom that all trial-level variation in brain response can be attributed to unrelated, or noise-related processing (Lopez-Calderon & Luck, 2014). This new point of comparison of response-alignment can be employed to compare cross-domain similarity of the P600, and support or challenge the idea of shared resources if alike or different.

Lastly, the broad variety of analyses employed in language and music experiments necessitate a discussion on what is considered best practice in EEG research. Some researchers have focused on the analyses of single electrodes that are theoretically driven, a priori electrode sites for all critical analyses (Sassenhagen et al., 2014; Sassenhagen & Fiebach, 2019), whereas others emphasise comprehensiveness of covering all possible experimental effects on the EEG signal (Carrus, Pearce, Bhattacharya, 2013; Fitzroy & Sanders, 2013). This difference in approach has generally stemmed from a lack of consensus on the ‘gold standard’ of EEG analysis, with its myriad options in cleaning the data (otherwise known as increasing signal-to-noise ratio). Two papers published recently have shed light on the matter, using simulated and real data to better understand how to reduce spurious effects in the EEG data.

The first paper is written by Joseph Dien (2017), who describes the convention of using analyses of variance (ANOVAs) to analyse ERP data, and how false positives (Type I error) and false negatives (Type II error) can be avoided. Among the key suggestions are a) the use of an average reference for high-density EEG data (128-channels), as well as the minimal benefit of regional analyses using regions of interest (ROIs) compared to single peak electrode
analyses. The common drawback of using ROI analyses was that the desired signal of interest was diluted with non-maximal electrode site activity, and its main benefit of providing less noisy waveforms is confounded by the specific region selected. To date, there is no consensus on what that region should look like, with significant variation in zoning depending on the individual researcher’s preferences and the styling of the EEG cap used.

Another article written by Steve Luck and Nicholas Gaspelin (2017) focused more on current ERP analyses causing widespread Type I errors of false positives, with a Type I error likelihood at 50% for many experiments. A central suggestion for improving experimentwise error rate is to eliminate unnecessary analyses, and specifically focusing on main effects and interactions that test the underlying theory (2017). Non-central effects seen in the data should be treated as suggestive rather than conclusive, especially if the theory or the experimental design precludes the testing of incidental effects unrelated to the central hypotheses. The general reduction of data dimensionality in EEG is crucial, as the repeated analyses of data over many different steps increases the chance of Type I error.

With the suggestions in these two articles serving as a guide for the current project, the aim of examining the P600 and its relation to integration cost in language and music should be analysed with strongly *a priori* single electrode sites, with as little unnecessary analyses implemented as possible. This will drastically reduce the likelihood of Type I error (Luck & Gaspelin, 2017), where false effects would obfuscate the findings of real effects. Furthermore, such a strategy would increase the confidence regarding interpretability of observed effects due to the hypothesis- and theory-driven pre-registered nature of the analyses used.

In summary, the advent of new analysis and methodological techniques allows us to examine EEG data in new ways. This permits the use of classical analyses such as the ERP alongside behavioural data and adds new points of comparison of the brain response between domains. Several of these techniques allow for us to re-examine the relationship between
language and music syntax, and lead to a better understanding of proposed shared resources between the two domains (Patel, 2012).

1.5. Aims

The overarching aim of the current program of research, therefore, is to investigate the recruitment of shared resources in language and music. Additionally, one specific goal of this thesis is to better understand the P600 as a suitable index of integration cost to syntactic violations in language and music. The P600 elicited by language stimuli (language P600) has been shown to be response-aligned but the status of response-alignment of the P600 elicited by musical stimuli (musical P600) is unknown. However, if shared resources exist as outlined in the SSIRH (Patel, 2012) and P600-as-P3 hypothesis (Coulson et al., 1998; Sassenhagen et al., 2014), then we can reasonably predict that musical P600 would also show response-alignment. Additionally, the P600 has not been examined in conditions of simultaneous demand for syntactic resources from language and music. Doing so would help clarify how the P600 component increases in amplitude to co-occurring syntactic errors in both domains, reflecting an increase in the processing cost of syntax that is over and above what is seen in single errors. However, attentional factors may modulate the combinatory effect of P600 amplitude increase to dual syntax errors; there is reason to believe that P600 is attention- (Batterink & Neville, 2013) and task-dependent (Schacht et al., 2014), despite the observed interactions of attended and unattended syntax in behavioural tasks of a similar simultaneous-presentation design (Slevc et al., 2009). It is therefore important to make sure the P600 is being elicited in both language and music tasks, so as to ensure comparability of the syntax violations across domains. If the P600 component is modulated by task and attentional factors, then the anticipated combinatory P600 responses in language and music would only occur when dually attended rather than in a selective-attention task. Comparing P600 amplitude change alongside behavioural measures of RT and task accuracy will help reveal the relationships of
electrophysiological response with task performance. With previous evidence of language and music syntax interacting despite music being unattended, and P600 attention-dependence, there seems to be an ambiguous relationship of P600 with behavioural measures. However, tasks have often varied across experiments, producing varied neural recruitment (LaCroix et al., 2015) as a result. A program of research that examines concurrently presented language and music syntax, under varying conditions of task demand, could investigate the possibility of a functional co-occurrence of P600 amplitude with RT or task accuracy. For example, finding that increased P600 amplitude is reliably coincided with increased RT to syntax errors would provide evidence that P600 is a reliable electrophysiological index of the incurred syntactic integration cost, with RT and accuracy as behavioural indices.

The first experiment will investigate the proposed similarity of response-alignment in language and music P600 to syntax errors. Previous research has found language P600 response-alignment (Sassenhagen et al., 2014), and the SSIRH (Patel, 2012) and P600-as-P3 hypothesis (Coulson et al., 1998; Sassenhagen et al., 2014) suggest that music P600 is similar to that found in language. If so, we predict that P600 in music will also show response-alignment, providing support for shared resources underlying P600 in both domains.

The second experiment involves simultaneous, selective-attention presentation paradigm of syntax errors in language and music. If P600 is a reliable electrophysiological index of incurred syntactic processing cost, then P600 amplitude increase should accompany behavioural effects of syntax errors such as RT increases or task accuracy decreases. Such P600 behaviour should also occur similarly, whether occurring under task conditions where language is attended to and music is not, or vice versa. Since P600 appears to be attention-dependent (Schacht et al., 2014), we expect that P600 amplitude increase should only accompany an attended syntax error in either domain, and unattended syntax errors would not affect P600 amplitude. However, behavioural research has shown the possible effects of unattended
musical syntax on attended language processing (Slevc et al., 2009). If unattended syntax errors affect task performance despite the lack of P600 to unattended errors, we would provide evidence that P600 is not a reliable index of syntax processing under these conditions. In contrast, if P600 amplitude increases coincide with RT increases, then we would provide evidence that P600 is able to index the associated processing cost to syntax reflected at the behavioural level.

The third and final experiment utilises the design of Experiment 2 in a dual-attend syntax task. If P600 is attention-dependent as it appears to be in isolation (Batterink & Neville, 2013), the combinatory P600 effects of simultaneously presented syntax errors in language and music will only co-occur in a dual-attention condition. In contrast to the previous experiment, therefore, dual errors are predicted to have a joint effect that generates higher P600 amplitudes and RTs than single errors in either domain. If we see such a combinatory effect in P600 and RT, it would lead to the conclusion that P600 indexes the additional processing cost incurred in integrating the large syntactic error into its preceding context, and conceptually represents the additional demands that a simultaneous language and music error will place over the shared syntactic resource as posited in the SSIRH (Patel, 2012).

The findings of all three experiments will produce a greater understanding of the P600 as it relates to syntax processing in language and music. Both the SSIRH (Patel, 2012) and P600-as-P3 hypothesis (Coulson et al., 1998; Sassenhagen et al., 2014) claim that P600 is representative of shared resource processing across domains. However, the direct comparison of P600 syntax effects across domains is one aspect that is relatively under-researched, and the present program of research attempts to fill that gap. The first experiment will test P600 similarities beyond the grand average ERP in language and music, and use response-alignment to establish a pattern of increasing P600 latency to increasing RT. The following two experiments will test P600 amplitude change in a simultaneous presentation for language and
music stimuli, differing only in the instructed task to be selective- or dual-attention. Increases of P600 amplitude in any given condition should correspond with increases of RT or decreases in task accuracy, thereby supporting a functional co-occurrence of P600 with behavioural performance effects. By examining the patterns of P600 amplitude change alongside behavioural measurements such as RT and task accuracy, the present program of research will help test the concept of P600 being representative of the processing cost associated with syntax violations processing shared in language and music.
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2. EXPERIMENT 1

2.1. Similarities of syntax error response in language and music: P600s demonstrate contrasting response-alignment patterns

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SIMILARITIES OF SYNTAX ERROR RESPONSE

Abstract

Syntax is a key aspect of both language and music, thus the Shared Syntax Integration Resource Hypothesis (SSIRH; Patel, 2012) posits common brain resources for both domains. The brain responses to detecting language syntax violations (P600) align with the timing of the physical (behavioural) response, so SSIRH would predict that the same pattern should occur for syntax violations in music. We tested this prediction using a repeated measures design with independent variables of Domain (Language, Music) and Stimulus Category (Control, Critical Syntax Error, Distractor Syntax Error). Participants (N=16) listened to 400 sequences comprising seven words or chords. Sequences were completely correct (control) or contained a syntax violation (adjective noun plurality error or dissonant chord) at the end of the sequence (critical syntax error) or in the middle of the sequence (distractor syntax error). Participants indicated whether each sequence was correct or incorrect via keypress. With language syntax violations, we found that P600 aligned with the physical response. Music syntax violation P600s, however, were not response-aligned. These are novel findings against the predictions of the SSIRH. Our result opens the way to other studies to determine whether the similarity between language and music arises from overlapping, but distinct processing of syntax in the same area.

Keywords: EEG, P600, syntax, SSIRH, music, language
Introduction

There is a strong impetus to understand the ways in which the brain processes complex stimuli such as language and music, as they are prime examples of the complexity of human cognition. But how are language and music processed in the brain? Are they both subserved by shared resources, and does that resource serve a specific aspect such as syntax (Patel, 2012), or overlap broader aspects (Tillmann, 2012) of language and music? Two separate lines of research have provided substantial findings on the shared nature of language and music, namely the shared syntax integration resource hypothesis (Patel, 2003, 2012), and the P600-as-P3 hypothesis (Coulson et al., 1998; Sassenhagen et al., 2014). Both converge on a method of novel electroencephalography (EEG) data analysis that clarifies the similarity between brain responses to language and music, otherwise known as single-trial or subset analyses.

Syntax refers to the structural rules that govern language and music. Examples of linguistic syntax violations include morphosyntactic violations (Sassenhagen et al., 2014), subject-extracted or object-extracted clauses (Fedorenko et al., 2009), garden path sentences (Kunert et al., 2016; Slevc et al., 2009), or number agreement violations (Shen et al., 2013); in music, syntax can be violated within a chord progression (Slevc et al., 2009) or a melody (Carrus et al., 2013; Fedorenko et al., 2009). Such violations generate behavioural costs, which are measurable using experiments that collect reading times (Slevc et al., 2009), reaction times (RT; Sassenhagen et al., 2014), comprehension accuracy (Fedorenko et al., 2009), and subjective ratings of music closure (Kunert et al., 2016) among others. Techniques such as EEG enable measurement of brain activity in response to syntax violations, unencumbered by the potential confounds of relying solely on motor responses, and with high temporal precision. This provides the opportunity to observe how brain responses change over a short time interval and inspect the relationship between behavioural and brain responses. In EEG research, the
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most consistently evoked brain-electric responses are grand averaged into the event-related potential (ERP) waveform (Luck, 2014).

Commonly observed ERP components for language syntax errors include the left anterior negativity (LAN), which is a negative electrical response that occurs around 300-400ms post stimulus onset (Carrus et al., 2013; Steinbeis & Koelsch, 2007, 2008), as well as the early LAN (also known as the ELAN), which occurs in specific subsets of grammatical errors (Gouvea et al., 2010). A later component known as the P600 (Brilmayer et al., 2017; Osterhout & Holcomb, 1992, 1993; Schacht et al., 2014) is a positive electrical response centred in the parietal midline, occurring 600ms after the onset of a violating stimulus. Similarly, there are many early and late components of brain responses to music violations. Commonly elicited ERP responses to syntax violations include the early right anterior negativity (Bonfiglio et al., 2015) which occurs 150-350ms after error onset, the N500 (Koelsch et al., 2005; Steinbeis & Koelsch, 2007) as well as the late positive component (LPC, synonymous with the musical P600; Besson & Macar, 1987), which occurs on the scalp ERP parietally-centred 600ms after onset.

These findings may help support existing perspectives regarding language-music overlap. One such perspective is the SSIRH (Patel, 2003, 2012), which focuses on the structural rules that govern language and music (i.e., syntax). The SSIRH claims that language and music refer to different lexical representations in the brain, which then share a cognitive resource for processing syntax. In the EEG literature, the SSIRH hypothesises a late positive brain-electric response to syntax errors known as the P600 (de Leeuw et al., 2018). This appears to be shared between music and language syntax violation responses, with no statistically significant differences in the ERP waveforms in a separately performed, within-participant task (Patel et al., 1998). Additionally, the SSIRH is able to explain experimentally-induced differences in early brain responses of language and music processing, with language and music displaying
early components that have different topography at the scalp level (Koelsch et al., 2005; Maidhof & Koelsch, 2011), and as measured by functional magnetic resonance imaging studies (fMRI; LaCroix et al., 2015). Language and music components should demonstrate some aspect of commonality or interaction to confirm that they are functionally related to one another. One such study was run by Koelsch and colleagues (Koelsch et al., 2005) to investigate the automatic interactions seen in language and music when they co-occurred. Participants attended to a language task and had unattended music errors occasionally appear, and their brain responses were recorded. The authors hypothesised an interaction of the early syntax-related LAN and ERAN in language and music, respectively. Results confirmed their predictions – there was an automatic elicitation of the music syntax-related ERAN even in the absence of attention, and this component coincided with an attenuation of the size of the LAN when a language syntax (structural) error co-occurred. Koelsch (2005) argued therefore for the interaction of syntax even at this early stage, with the attention-independent attenuation of LAN in the presence of a musical syntax error and the ERAN. Conversely, neither linguistic semantic (meaning-related) errors nor physically deviant sounds produced brain responses in the N400 and MMN that interacted with musical syntax errors as measured by the ERAN. This provided support for the idea that music and language share specific resources underpinning the processing of syntax even at an early stage. Maidhof and Koelsch (2011) demonstrated an attenuated music ERAN response when speech was also presented, but were not able to elicit attention-based effects due to the nature of their task. However, they found that ELAN language responses were seemingly unaffected by attention or language-music simultaneous presentation (versus language-only presentation). Steinbeis and Koelsch (2007) demonstrated a reduction of musical ERAN when language syntax errors were concurrently presented, but the music N500 was reduced only when language semantic errors occurred at the same time. Further, language syntax LAN was reduced in size when musical syntax errors occurred,
whereas language semantic N400 was unaffected (Carrus et al., 2013). The results of the above studies lend initial support to the suggestion of an interaction of syntax between domains; therefore, there is a case to further investigate this interaction in detail.

Support for the SSIRH comes from non-electrophysiological literature as well. A recent study by Musso and colleagues (2015) used within-subject functional magnetic resonance imaging (fMRI) and diffusion tensor imaging-based tractography to examine how syntax is processed when violated in language and music. They found that both music and language activated the left inferior frontal gyrus (IFG) and proceeded to dorsal and ventral streams to the temporo-parietal regions. However, music also recruited further resources in the right hemisphere that language did not, and language recruited additional regions adjacent to the left IFG that music did not. They suggested that this differentiated, and yet shared, brain response supports the SSIRH – unique areas are used to represent language and music rules in the brain, and yet a large shared network underlies the processing of syntax in both (Musso et al., 2015). Furthermore, a fMRI meta-analysis has provided further support for a shared left IFG region between language and music, with isolated listening to music or to language recruiting differentiated temporo-parietal cortical networks (LaCroix et al., 2015). Such networks are predicted by the SSIRH, and maps neatly into differentiated representations of language and music that share cognitive analysis resources. It must be said that neural activation overlap may not always signify the cognitive processes between domains are shared; language and music can also be seen as representationally stored in the brain in distinct and separate regions (Patel, 2003), but have overlapping domain-general demands on cognitive resources (Besson et al., 2011) in the frontal lobe and particularly the Broca’s area (Patel, 2012; Slevec & Okada, 2015).

However, the SSIRH is not the only theoretical perspective present in the literature regarding syntax processing in language and music. What if the observed brain syntax responses are similar to responses to less complex stimuli? Such a similarity might suggest that
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denese shared cognitive responses proposed in the SSIRH may not in fact be specific to syntax at all. One way in which this might be the case is in the P600 and P3. For example, a recent study has discovered that the P600, a later positive brain-electric response to syntax violations is remarkably similar to the P3b, a brain response to much simpler stimulus manipulations (Sassenhagen et al., 2014). Given the rich literature on the P3b’s functional significance, and possible neurophysiological underpinnings (Aston-Jones & Cohen, 2005; Nieuwenhuis et al., 2005; Polich, 2007), linking P600 to P3b would help ground the P600 in a neurobiologically sound framework of cortical response generation. In fact, the P600-as-P3 hypothesis claims that P600 is actually a later instance of the P3 family (Coulson et al., 1998; Sassenhagen et al., 2014), and is not a brain response reserved only to syntax processing. There are two main P3 components, P3a and P3b (Polich, 2007). P3b (referred to henceforth as the P3) is temporoparietal in spatial distribution, 200-500ms in latency, and is said to be generated by parietal/norepinephrine pathways (Polich, 2007). Theoretically, P3 is related to working memory, where the attended processing of a task-related target stimulus reliably generates increased P3 amplitude. The P3 component appears to be better aligned to the response to a given task, rather than the presented stimulus (Marathe et al., 2013; O’Connell, Dockree, & Kelly, 2012), and is therefore thought to reflect stimulus-induced, but response-oriented processing (Verleger, Jaskowski, & Wascher, 2005). Indeed, recent research concludes that the P3 and P600 behave similarly in the aspects of response-alignment (Sassenhagen et al., 2014) and correlated galvanic skin response with brain responses (Sassenhagen & Bornkessel-Schlesewsky, 2015), which underlie the relationship of P600 with the locus coeruleus (Corbetta et al., 2008). The latter paper (Sassenhagen & Bornkessel-Schlesewsky, 2015) compared the EEG, behavioural, and psychophysiological responses to visually presented language and face detection tasks, to determine the extent to which P600 resembled P3 through response-alignment. The authors were able to replicate response-alignment in P600 and P3. Furthermore,
the data demonstrated galvanic skin response changes in time with P600 and RT, which is a predicted by-product of norepinephrine and the resultant sympathetic nervous response. Such convergence across multiple data points further supports their theoretical grounding of the P600 within the P3-norepinephrine ventral attention resource network (Sassenhagen & Bornkessel-Schlesewsky, 2015). This grounding of the P3 in a neurologically feasible location is a key strength of the hypothesis over the SSIRH, which does not suggest a plausible cortical source for the shared syntax resource.

In comparison to the SSIRH, the P600-as-P3 hypothesis predicts galvanic responses associated with P600 due to the locus coeruleus being a crucial cortical generator of that brain response, which also causes the release of norepinephrine and the galvanic response (Sassenhagen & Bornkessel-Schlesewsky, 2015). The P600-as-P3 also predicts response-alignment of the P600, akin to the P3 (Coulson et al., 1998) and suggests a domain-general mechanism driving P600 activity. These points draw distinctions between the two perspectives regarding language and music syntax interactions but may not mean a falsification of the one over the other. For example, the SSIRH may not specifically predict response-alignment of the P600, but if this behaviour were seen in both language and music P600, it would be evidence of overlapping neural resources. This is because we would expect the proposed shared neural resource to behave similarly in both language and music syntax. The two theoretical perspectives therefore overlap with regard to P600 response-alignment, the central point of comparison between language and music in the current study. However, the P600-as-P3 hypothesis makes unique predictions related to physiological responses due to the norepinephrine responses associated to neural resources driving P600. As such, one prediction of the hypothesis is that galvanic skin measurements would show an increase in amplitude as a result of P600-related brain activity. This does not impact the SSIRH, as the SSIRH is concerned with the underlying cortical resources underlying language and music and has no
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differentiated predictions regarding physiological response (see Table 2.1). Finally, the P600-as-P3 hypothesis predicts a domain-general, syntax-indifferent process underlying P600 as part of the P3 family. This is directly in contrast to the SSIRH, which says the shared resource is syntax-specific. For example, being able to find interactivity of language-music P600 in a non-syntactic fashion would provide evidence against SSIRH but would support the P600-as-P3.

Table 2.1
SSIRH versus P600-as-P3 hypothesis predictions

<table>
<thead>
<tr>
<th>Prediction</th>
<th>Theoretical framework</th>
</tr>
</thead>
<tbody>
<tr>
<td>Galvanic skin response with P600</td>
<td>SSIRH: No prediction, but would not conflict with central claims of the SSIRH. P600-as-P3 hypothesis: Predicted, with norepinephrine-driven effects on P600 and galvanic skin response.</td>
</tr>
<tr>
<td>Response-alignment of P600</td>
<td>SSIRH: No prediction, but would not conflict with central claims of the SSIRH. P600-as-P3 hypothesis: Predicted, with P3b-like response-alignment expected in P600 component activity.</td>
</tr>
<tr>
<td>Domain-general P600</td>
<td>SSIRH: Against, with the SSIRH stating that the shared resource is specific to syntax between language and music. P600-as-P3 hypothesis: Predicted, stating that the P600 is an iteration of the domain-general P3b component seen in simple tones, face, and pictures.</td>
</tr>
</tbody>
</table>

Existing perspectives on how language and music overlap in their recruited neural resources are limited by the equipment and methodology we employ. Questions of cross-domain relationships have been primarily investigated using lesion studies (for a review, see Friederici & Kotz, 2003), behavioural tasks (Fedorenko et al., 2009), neurophysiological methodologies such as EEG (Sassenhagen et al., 2014) and magnetoencephalography (MEG; Maess, Koelsch, Gunter, & Friederici, 2001) or fMRI (Tune et al., 2016). Of these, the high temporal resolution of electro- and magneto-physiological techniques are best for tracking the precise timing of brain responses. Using EEG/MEG, the dynamics of language and music processing are easier to compare on a moment-to-moment basis. However, most prior research
has focused on the grand averaged waveform, or the ERP. This comprises the amplitude, timing, and topography (or spread) of the average brain response. Such analysis is useful for isolating the most consistent response to a given stimulus, and averages out noise that may distort signal that may be obscured within a single trial (Luck, 2014). However, this averaging process ignores trial-by-trial variations in the brain response, which may prove particularly problematic if trial-by-trial trends reveal more about the data than we can glean from ERP averages alone. Teasing apart the relationships that exist at the trial level can help us clarify areas of similarity or difference between language and music.

An important way that trial-level analyses can provide insight into syntactic processing is that they allow determination of response-alignment. For example, it is possible to see how brain responses vary in latency as reaction time (RT) increases by sorting each trial by increasing RT, thereby generating a plot that illustrates the RT-sorted brain response. By using this method, one can clarify if a given brain response is aligned in time to the onset of a given stimulus, such as the N1 (as seen in Carrus et al., 2013), or as response-aligned such as the P3 (Marathe et al., 2013). By comparing the same brain responses aligned to the onset of the stimulus versus to the response, the more focalised (or sharp) peak would be the better marker with which to measure the specific brain response. As mentioned earlier, a pair of studies by Sassenhagen and colleagues (Sassenhagen & Bornkessel-Schlesewsky, 2015; Sassenhagen et al., 2014) have illustrated the value of single trial analyses (and, particularly in these studies, subset/quartile analyses) in the context of the language literature, by showing the language syntax violation (P600) to be response-aligned. Dividing all trials into RT quartiles, they compared the ERPs of the fastest through to slowest trials and found significant latency differences in language P600. That is, increased RT was associated with later P600 latencies.

As reviewed above, the use of response-alignment was a novel analysis of EEG data compared to the conventional averaging of the ERP. Analysing the data in this way utilised a
characteristic behaviour of one brain response (the P3), which could be investigated in another (the P600). Demonstrating this same behaviour in the P600 would support the hypothesis that both components were of similar neural origin. The novel comparison of these ERP components allowed for a new set of findings to test predictions of the P600-as-P3 hypothesis. However, the application of response-alignment analyses is not limited only to the P600-as-P3 hypothesis – other theoretical perspectives can benefit from the comparison of brain responses in this manner.

The SSIRH, for example, generates the hypothesis that language response-alignment should also be seen in the music domain, if indeed a shared resource underpins both language and music. This purported resource should therefore behave the same way, whether applied to the processing of language or music. Referring to the P600-as-P3 hypothesis, if there were no specific syntax processor and only a late P3 underlying the syntax-related language response, the hypothesis would also predict the same response-alignment in music P600/P3, as seen in the language P600/P3. In either case, music serves as an alternative complex auditory stimulus to examine response-alignment in, which leads to a better understanding of language syntax processing in the brain. Despite the differences of the syntax-specificity of the shared resource as proposed by the P600-as-P3 or SSIRH, both theoretical perspectives predict the same outcome: response-alignment of the language P600 should replicate in music. By extension, we can use subset analyses to test the SSIRH’s predicted similarities in language and music, where we would expect to see similar response-alignment of the P600 in music syntax violations. This converging prediction of response-alignment in music syntax brain responses is therefore of doubled theoretical significance. In summary, if the music P600 shows the same pattern of response-alignment as the language P600, this would provide additional support for the claims of commonality of neural resources between language and music syntax processing. However, if the music P600 doesn’t show response-alignment, but the language P600 does,
then that would indicate that the neural generators underlying P600 in language and music are not alike in this aspect. Such a finding would fail to support claims in the SSIRH of commonality of neural resources between language and music syntax processing (Patel, 2012).

The objective of the current study was to examine the extent to which language and music syntax violations are processed similarly in the brain, as claimed by the SSIRH (Patel, 2012). We aimed to investigate whether response-alignment would occur in music as in language, as predicted by the P600-as-P3 hypothesis (Sassenhagen et al., 2014). Using a combined behavioural-EEG experiment, participants heard language or music sequences, and their task was to detect syntactic violations. We recorded the RT, accuracy, and EEG data for these responses, and tested the extent of response-alignment in the EEG data using subset analyses. We hypothesised that the P600 to syntax violations in language or music would both be response-aligned, thereby supporting the claims of the SSIRH.

**Methods**

**Participants**

The participants were a convenience sample of 21 right-handed (handedness score > .5 as per Bryden’s Handedness Questionnaire; Bryden, 2012); positive scores correspond to being right handed) native English speakers from Murdoch University’s South Street campus in Perth, Western Australia. Right-handedness was chosen on the basis of minimising variability in the ERP signal; right handers produce the most reliable P600 responses, where left handers can produce N400-dominant ERPs to syntactic errors (Grey, Tanner, & van Hell, 2017). Participants were also aged between 18 and 60 years to minimise age effects, as P600 effects can become more anterior after the age of 60 specifically (Faustmann, Murdoch, Finnigan, & Copland, 2007). While P600 did not change in amplitude or latency past that age, the 60 year age bracket was chosen as a precaution nonetheless. Participants also spoke English as their native language, reported to have listened to music primarily from Western tonal music
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throughout their life (pop, blues, jazz, classical), and had no prior musical training (no private one-on-one music classes) in the last ten years. Accepted participants had an average of 1.2 years of prior musical training ($SD = 2.08$ years). Furthermore, participants were required to self-report normal or corrected hearing and vision, and were self-reported to be neurologically healthy, as well as not being on medication affecting the nervous system. Lastly, participants were advised not to consume substances that may affect the nervous system for 24 hours prior to participating, with the exception of caffeine; this was limited to one hour before participating. Three participants were excluded from participating in the study. One individual was ambidextrous instead of right-handed, and two participants were excluded on the basis of currently consuming medication that affected the nervous system, namely lexapro and dexamphetamines, and paroxetine respectively. All information was obtained using a screening questionnaire. Participants received either course credit for participation or an entry into a raffle for a pair of movie tickets.

Participants recruited from the Murdoch University Research Participant Portal received course credit for participation, whereas personal contacts in the general public or students opting out of the course credit received an entry into a raffle for a pair of movie tickets.

**Design**

The experiment was a $2 \times 3$ repeated-measures design, with the within-subjects independent variables of Domain (Language, Music) and Category (Control, Syntax Error, Distractor Error). The dependent measures were behavioural accuracy, RT, and EEG data. Please note that the Distractor Error condition is used for experimental control and is not analysed further.

**Stimuli**
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Table 2.2

*Trial counts by experimental condition*

<table>
<thead>
<tr>
<th></th>
<th>Language</th>
<th>Music</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Syntax Error</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>Distractor Error</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Total</td>
<td>200</td>
<td>200</td>
</tr>
</tbody>
</table>

Stimuli consisted of seven-element sequences; that is, sentences consisting of seven words for language stimuli, or seven chord progressions for music stimuli. The use of seven-element sequences was decided on based on the sentence structure, which was the minimum number of words required to produce a sentence with a subject-verb-object ordering. This would make a sentence stem that can be manipulated to violate language syntax within a single trial. The musical chord sequences were created in order to match the seven-word sentences, using chords played within the same tonality to establish a syntactic context in a single trial. Music chord progressions in previous research has shown that two- (Sammler, Novembre, Koelsch, & Keller, 2013) and five-chord (Sammler et al., 2013; Steinbeis & Koelsch, 2007) sequences have been successfully employed to generate behavioural and ERP effects.

For both domains, stimuli were either: a) control sequences, with no syntactic violations, b) syntactic error sequences, where the final element violated number agreement or harmonic rules, or c) distractor error sequences, where the sentence contained a syntactic error in the middle of the progression. There were equal numbers of trials with and without a syntax error (see Table 2.1 for trial numbers per condition), with a total of 200 language trials and 200 music trials per participant.

**Language.** All language sequences contained a subject performing an action (see Table 2.3). Syntactic sequences had a noun plurality (or number agreement) error on the last word, and distractor sequences had a verb conjugation error on the fourth word. Such grammatical
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errors have produced a P600 response in previous research (Shen et al., 2013). Violations had no prior cue earlier in the sequence, which means that participants could not anticipate the onset of a deviant. Furthermore, sentence stems were just as likely to be correct following a singular (‘that’, ‘this’) or a plural (‘these’, ‘those’) penultimate word – this ensured each trial’s critical word was not predictable in its correctness prior to the presentation of the word itself. 200 language stems were created, which produced all syntax violation stimuli. Control stems were kept unique from the violation stems in two different iterations of the stimulus set, where 100 error-free stems in one version were converted into syntax violations for the other version, and vice versa.

All language stimuli were recorded in an acoustically isolated studio, with a trained sound engineer recording the material. A condenser microphone with a pop filter was applied to ensure no fricatives were overly disruptive to sound quality. Sentences were read out as full error-free control materials – words were pronounced to a metronome that was played to the English speaker through headphones, with words spaced to have an inter-onset-interval of 600 milliseconds (or at 100 beats per minute). After this process, multiple versions of deviant penultimate words were separately recorded. Material were recorded in full raw format, then compressed to 16-bit WAV files for further processing.

Deviant trial stimuli were then created by replacing the penultimate word of a control trial with an erroneous word. These were matched by overall pronunciation of the sentence so as to not sound anomalous to the listener. Words were then tempo-locked to the 600 milliseconds interval stipulated earlier, as pronunciations of the words were not precisely timed enough. This ensured that word onsets were 600 milliseconds apart. Words were then normalised at the software level across sound files and tracks, and were presented at a comfortable volume through the experimental computer’s headphones. As sound file presentation varies significantly with prosody, a measured decibel level for actual experimental
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tracks would not be particularly informative. This is why software normalisation, then consistent stimulus presentation volume levels were implemented instead.

Table 2.3
Sample experimental language stimuli

<table>
<thead>
<tr>
<th>Condition</th>
<th>Control</th>
<th>Syntactic</th>
<th>Distractor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sequence position</td>
<td>The judge is reading out those laws.</td>
<td>The judge is reading out <em>that</em> laws.</td>
<td>The judge is <em>read</em> out those laws.</td>
</tr>
</tbody>
</table>

*Note.* Underlined, bolded, italicised are the critical points of deviance in each condition.

Music. The musical stimuli were sequences of seven chords, with each chord comprising three notes arranged in root position. Table 2.4 depicts an example chord sequence. For the control chord progressions, the chords all fit in the same musical key (thus sounding congruent with the key of the progression); substituting the progression-final chord from a different musical key created a violation that generates a violation of syntactic expectation (Rohrmeier & Koelsch, 2012) to Western music-encultured listeners regardless of musical training. Previous EEG research has successfully elicited P600 effects using a harmonic manipulation (Patel et al., 1998). A sequence-final C Major chord, therefore, would be preceded by a sequence based on B Major. This replacement of the musical progression preceding the final chord ensures that any differences in ERP measurements are due to the syntactic manipulation, not based on acoustic differences. Distractor errors were created in a similar fashion, but introduced in the middle (fourth element) of the sequence in order to encourage attentional allocation to the whole progression, not just the endings. The process of substituting musical contexts to produce progression-final chord syntax violations was repeated with 48 unique progressions in the keys of B, C, E, and F major. The use of these four tonalities
produced a total of 192 unique progressions of 48 each tonality. To produce the 200 musical progressions required to match with the language stimuli, two progressions from each tonality were randomly selected to be repeated. The 200 stems were split into two batches of 100 each, and control stems were reversed into syntax violation stems (and vice versa) for alternating participants.

In order to match the language stimuli, chords were created using a MIDI chord creator and saved as WAV files. These were then edited to have 600ms intervals, matching the language stimuli. The chords were then matched for loudness by software normalisation alongside the language stimuli, reduced in volume if the consistent nature of musical chords led to an overall subjectively louder perception of music, then exported to the experimental computer and played at the same level as the language stimuli were. This ensured that the most consistent conditions were created between language and music stimuli.

<table>
<thead>
<tr>
<th>Condition</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>C</td>
<td>G</td>
<td>A minor</td>
<td>C</td>
<td>F</td>
<td>G</td>
<td>C</td>
</tr>
<tr>
<td>Syntactic</td>
<td>B</td>
<td>F#</td>
<td>C# minor</td>
<td>B</td>
<td>E</td>
<td>F#</td>
<td>C</td>
</tr>
<tr>
<td>Distractor</td>
<td>B</td>
<td>F#</td>
<td>C# minor</td>
<td>C</td>
<td>E</td>
<td>F#</td>
<td>B</td>
</tr>
</tbody>
</table>

*Note.* Underlined, bolded, italicised are the critical points of deviance in each category.

**Syncing points of deviance.** It is important to note that the music and language stimuli differ subtly in terms of when the syntax violation occurs. Specifically, in language trials, an expected plural word ("The judge is reading out those ...") would deviate only at the end of the singular pronunciation ("law"), after which an additional plural modifier ("s" in "laws")
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results in it being processed as correct. In contrast, the musical syntax violation was obvious at
the beginning of the chord (not the end). For both language and music, the EEG responses to
syntax violations are aligned to the onset of the point of deviance, measured as the point at
which the word/chord begins to demonstrate either a correct or erroneous syntax. We therefore
locked brain responses to language stimuli to a) the offset of the singular term, or the b) onset
of the plural term, as they would correspond to the points at which a decision could be made.
For music stimuli, the brain response was locked to the onset of the chord. No temporal jitter
was introduced to trial presentation.

Procedure

Participants provided informed consent, then completed the inclusion criteria
questionnaire and Bryden’s (1977) Handedness questionnaire. An appropriately-sized EEG cap
was placed on their heads, with impedance reduced to below 50kΩs (Ferree, Luu, Russell, &
Tucker, 2001). Closed-back headphones were placed over the ears and cap. Participants were
then positioned 57cm from a computer monitor (1024x768 resolution, refresh rate at 85Hz)
within the Cognitive Neuroscience EEG Research Laboratory at Murdoch University, with the
head resting on a chin rest. Once seated, they listened to language or music sequences presented
at a comfortable volume and rested both hands’ index fingers on the corresponding two
response buttons “1” and “4” buttons for the left and right hand respectively; this was counter-
balanced across participants.
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*Figure 2.1.* A typical trial format, with an example music and language trial. A musical deviant is created by changing the preceding progression, and a syntactic error in language is created by changing the penultimate word in the sentence.

Participants were presented with an instruction slide that outlined the experimental task (see Figure 2.1): Press one button (“1” or “4”) on the serial response box to respond to the presented trials as error-free, and another button (“4” or “1”) to indicate a syntax error was present in language or music. Each trial began with a fixation image (neutral cartoon face) for 100ms, followed by the linguistic or musical sequence. This sequence lasted 4200ms, consisting of seven 600ms words or chords. Participants had 1500ms from the onset of the last element to respond (i.e., 900ms after the end of the final 600ms element); responses outside of this window (either before or after) were considered incorrect. Participants then received immediate feedback with correct or incorrect indicated by the fixation image changing from a neutral face to a smiling or frowning face for correct or incorrect responses, respectively. This was presented for 1000ms plus the remainder of the duration of the response window. The total time for every trial was therefore a maximum of 6200ms, with latencies shifted up to 7ms to account for screen refresh rate (85Hz) frequency.
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To familiarise the participants with the paradigm, each participant completed a practice block comprising ten trials (five language and five music), selected at random from a list separate from experimental trials.

Following the practice trials, the monitor displayed a summary slide with mean block RT and accuracy. The experimental trials were divided into 10 blocks of 40 trials each (50% controls, 40% syntax errors, 10% distractor errors) alternating between language and musical stimuli. Participants were given an untimed rest-break between each block, during which the screen displayed mean RT and accuracy for each completed block. Participants completed the experiment in one 90-minute session. The order of blocks and response mapping was counterbalanced across participants in a 2x2 Latin square design.

**EEG recording and analysis.** EEG was recorded with a 128-channel high density electrode sensor cap, inserted into a NeuroAmp 300 amplifier. Data from the amplifier were coupled with time and event codes from a Windows XP/7 presentation computer with E-Studio Professional 2.0, and were then transferred to a Macintosh computer using Netstation 5.3.0 as the software interface. EEG was recorded at 500Hz using a NeuroAmps 300 amplifier and impedances were reduced below 50kΩ for each electrode (Ferree et al., 2001). An online low-pass filter of 45Hz was used to remove the effects of electrical noise (50Hz in Australia) for monitoring purposes, but full-range data were recorded. Data were then exported from Netstation to Matlab for further processing.

In accordance with recent suggestions for best practice in ERP research (Dien, 2017; Luck & Gaspelin, 2017), data were analysed with a focus on theory- and hypothesis-driven components, single electrodes, and comparisons of interest. This preference is chosen over a more broad analysis strategy in other research (see Fitzroy & Sanders, 2013 for an example), which potentially captures more experimental effects. However, any such findings are argued to be suggestive rather than conclusive findings (Luck & Gaspelin, 2017). In addition, the use
of region of interest (ROI) analyses was eschewed in preference for single electrodes, as single electrodes allow for the measurement of the direct peak of brain-electric activity as opposed to a more diffuse waveform (Dien, 2017). Furthermore, the lack of general consensus on which ROIs to use is evidenced by large variations of the size, distribution, and location of the ROIs (see Carrus et al., 2013; Fitzroy & Sanders, 2013 for examples). With individual researchers and EEG companies varying widely in their ROI layout, which result in inconsistent benefits to the overall signal-to-noise ratio over single electrodes (Dien, 2017), the use of single electrodes was preferred in the current study.

In addition, while the SSIRH may discuss the early components and their interaction (Patel, 2012), these are not a central focus of the study. The P600, in line with best practice (Luck & Gaspelin, 2017), is preferentially examined over the earlier (E)LAN/ERAN components in language and music to syntax manipulations. Experimental design reflects this preference – the use of the PoD, and not word onset, means that the (E)LAN would be drastically attenuated or absent in language ERPs in the current study, which hampers the comparison of (E)LAN and ERAN. Similar sentiments hold true for the word-onset aligned N400 (Sassenhagen et al., 2014). Therefore, the P600 is the only component analysed in the current study, though a diagram of the waveforms of ROI clusters will be included for visual inspection purposes.

Data sets were analysed using Matlab’s EEGLAB plugin (Delorme & Makeig, 2004) alongside ERPLAB, a plugin to EEGLAB (Lopez-Calderon & Luck, 2014). Data were downsampled to 250Hz to facilitate efficient data management. This decision was made based on the distribution of the expected late P600 component, which will not be affected by the reduced temporal resolution of the EEG data. Downsampling is a common practice in EEG literature, where the reduced temporal resolution does not affect the overall expected experimental effects (Tanaka, Watanabe, Maki, Sakriani, & Nakamura, 2019; Ding, Melloni,
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Zhang, Tian, & Poeppel, 2016; Alday, Schlesewsky, & Bornkessel-Schlesewsky, 2017; Kimppa, Kujala, & Shtyrov, 2016; Sassenhagen & Fiebach, 2019). Each set was then Kaiser windowed band-pass filtered at 0.4-40Hz. Excessively noisy sections of the data were removed using the EEGLAB automatic rejection criteria. Data were then pruned with ICA, removing eyeblink, saccade, and noisy channel components. This resulted in a retention of 39.94 components (SD = 11.63), with an average of noise-related 89.07 components removed per participant. This is more than adequate for further analysis, where specific conditions even allow for 1.65 components to represent the brain responses of interest (Wessel & Ullsperger, 2011). Each set was then average re-referenced and epochs were created around correct responses. Incorrectly responded or artefact trials were removed from analysis. A simple voltage threshold epoch rejection protocol was run in EEGLAB to reject trials exceeding ±150µV across all electrodes.

Following the methodology set out by Bishop and Hardiman (2010), each participant’s single-trial difference waves were calculated for the central parietal electrode (Pz) by subtracting the averaged control sentence ERP from each correctly responded syntactic violation. Distractor violations were not examined any further.

A grand averaging process, followed by planned comparisons of conditions, was applied to the data to compare ERP peak amplitude differences between conditions. Separately, RT tertile bins (dividing each participant’s trials into three groups with the fastest, middle, and slowest trials in the respective ranked bins) provided tertiles ERPs averaged within each group; these are described below.

**ERP and ERPimage analysis.** ERPs were plotted and analysed using ERPLAB, an extension of EEGLAB (Lopez-Calderon & Luck, 2014). Each category’s peak amplitudes were analysed in the window in which they appeared, which was earlier in latency than the canonical P600 – this is attributable to the PoD as the start point of the ERP waveform, and a latency of
300-500ms was used across domain and condition. Mean amplitudes across the latency window were extracted for each participant for statistical testing.

Further analyses were conducted on difference trials at the parietal electrode, Pz. RT-sorted ERP images were analysed using EEGLAB; it serves as a useful tool for investigating RT temporal alignment (Jung et al., 2001). Multiple EEG trials were compared horizontally as colour-coded lines that illustrated time and trial number on the x and y axes respectively – hot colours represented positive amplitudes and cold colours indicated negative amplitudes relative to baseline. By averaging the data in the ERP image, we produced the ERP waveforms to both the stimulus-aligned and response-aligned formats. If the brain response was response-aligned, we would have expected the response-aligned component more focal than the stimulus-aligned equivalent with a larger overall amplitude peak. The ERP image function has the capability to sort these collated trials by several variables, which allowed an initial visual examination of response-alignment of EEG components to trials.

The use of RT quartile (or in our study, tertile) bins as demonstrated by Sassenhagen et al. (2014) has shown itself as a reliable way of measuring ERP latency variations in accordance with RT. RT binning has been implemented on P3 measurements in past research (Marathe et al., 2013; Poli, Cinel, Citi, & Sepulveda, 2010), and bins subject trials into multiple, smaller bins. Each subject’s data were then trimmed for the top and bottom 2.5% of trials, then binned by the subject’s RT information. As the positivity was our principal component to be analysed, we set all negative values to zero to avoid N400 affecting amplitudes. Next, we estimated the 33% fractional latency of the area under the positive curve for each bin, and analysed these averaged bin latencies with a repeated-measures two-way analysis of variance (ANOVA). In the current study, RT tertiles were favoured over quartiles as tertiles a) increase the number of trials per bin, thereby increasing the reliability of ERP and RT measurements, and b) tertiles still retained the ability to track a relative change in P600 response-alignment. The choice to
use tertiles therefore leads to a better signal-to-noise ratio in each bin, while achieving its original goal of tracking P600 response-alignment.

Results

Individual datasets were screened for having a low task accuracy (<60%) for any one category, which may indicate an inability to successfully perform the syntax task as instructed. Consequently, a further two datasets (with 41% and 58% performance levels respectively for categorising language errors, and above-threshold performance for the other conditions) were removed from the group of 18. Thus, the final group comprised 16 participants (ten males and six females), with an average age of 25.6 years (SD = 5.37, range 19-42). Of the accepted datasets, all reported native-level English proficiency. See below for a table of the minimum remaining trials pooled from all accepted dataset (Table 2.5); on average, 0.70% of all trials were removed (SD = 1.16%) due to trial-level noise as outlined in the epoch rejection subsection. This minimises the impact of low trial counts on producing noisy final ERP waveforms. Note that all results mentioning syntax errors, unless specifically mentioned otherwise, refer to the sequence-ending syntax violations and not the mid-sequence distractor errors.

Table 2.5
Minimum remaining trials by domain and condition.

<table>
<thead>
<tr>
<th>Domain</th>
<th>Language</th>
<th>Music</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>67</td>
<td>87</td>
</tr>
<tr>
<td>Syntax Error</td>
<td>50</td>
<td>66</td>
</tr>
</tbody>
</table>

Behavioural results

RT and accuracy. RT and accuracy data (see Figure 2.2) were separately analysed with two-way repeated-measures ANOVAs. RT statistics testing showed a significant main
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effect of domain, \( F(1,15) = 57.10, \ p < .001, \ \eta^2 = .33 \), where RT for music was 176.56 ms greater on average than for language trials. There was also a main effect of condition, \( F(1,15) = 12.01, \ p = .003, \ \eta^2 = .02 \), where sequence-ending syntax errors were responded to on average 32.88 ms slower than controls. However, there was a significant interaction between domain and condition, \( F(1,15) = 44.27, \ p < .001, \ \eta^2 = .06 \), which is illustrated on Figure 2.2.

![Figure 2.2](image)

Figure 2.2. Bar graphs of RT and task accuracy for each domain. Black bars represent controls, and red bars syntax errors. Error bars represent +/- 1 standard error of the mean.

This interaction effect was investigated with repeated-measures t-tests, which showed that RTs for language syntax error were on average 96.59 ms higher than language controls, \( t(15) = 6.02, \ p < .001, \ d = 1.50 \), while music syntax error RTs were on average 30.83 ms lower than music controls, \( t(15) = 3.00, \ p = .009, \ d = .75 \). This indicates a pattern of RT increasing from language controls to syntax error conditions, but RT decreasing from music controls to syntax errors. Accuracy showed no significant main effect for domain, \( F(1,15) = 3.60, \ p = .077, \ \eta^2 = .10 \), although there was a significant main effect of condition, \( F(1,15) = 13.79, \ p = .002, \ \eta^2 = .05 \), where syntax errors were 3.61% less accurately responded to than controls. There was also a significant interaction between the two, \( F(1,15) = 7.55, \ p = .015, \ \eta^2 = .04 \), as
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illustrated on Figure 2.2. Repeated-measure t-tests showed that language syntax error task accuracy was 7% lower on average than language controls, \( t(15) = 3.97, p = .001, d = .99 \), while music syntax error accuracy scores were not significantly different (0.39%) from controls, \( t(15) = 0.16, p = .873, d = .04 \). Language syntax errors experienced a significant drop in task accuracy compared to controls, but music syntax errors and controls remained relatively similar in accuracy.
Figure 2.3. Grand average ERPs at nine regions of interest (ROIs) for language stimuli. ROIs are zoned according to the scalp map.
Figure 2.4. Grand average ERPs at nine ROIs for music stimuli. ROIs are zoned according to the scalp map.
**Figure 2.5.** Grand average ERPs at Pz for control (black line) and syntax error (red line) conditions for language (left) and music (right) respectively.

**EEG results**

**ERPs.** Electrophysiological results were analysed on the grand averaged ERP waveform. After inspection of the overall brain responses over the scalp, which can be categorised into regions of interest (ROIs; see Figure 2.3 and 2.4), the middle parietal region and specifically the Pz midline electrode was identified as the best candidate for further analysis. A two-way repeated-measures ANOVA on averaged P600 amplitudes from 300 to 500ms revealed a main effect of condition, $F(1,15) = 24.70$, $p = .0001$, $\eta^2 = .11$ (see Figure 2.5), where the syntax error condition produced on average $0.663\mu V$ higher of a P600 component compared to controls. The effect of domain was not significant, $F(1, 15) = 0.48$, $p = .500$, $\eta^2 = .005$, and the interaction of domain with condition did not reach significance, $F(1,15) = 1.39$, $p = .257$, $\eta^2 = .002$.

**ERPimage and RT tertiles.** The ERPimage plot demonstrates how response is a better marker for brain responses such as the P600. Visual inspection of the language ERPimage difference waves for each trial (see Figure 2.6) demonstrate a more focal, higher amplitude P600 in the response-aligned condition relative to the stimulus-aligned waveform. This pattern appears to repeat in the music difference wave as well. However, this trend must...
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be quantified through statistical testing. Using the RT binning method, we conducted separate extractions of language and music tertile P600 peak latencies and RT, resulting in a condition (control, syntax error) by domain (language, music) comparison of P600 peak latency and RT. Tertile ERPs for language and music are shown below.

As shown in Figure 2.7, the latency of brain responses to language errors followed RT, but showed an inverse relationship for music errors. Language RT tertiles showed a similarity of latency effects between P600 latency and RT tertile millisecond averages (mean 33% fractional area latencies and mean tertile RT from fastest to slowest: 320/344, 465/460, 720/605). Music data showed a surprisingly reversed pattern of increasing RT with a decreasing P600 latency (latency/RT: 401/476, 394/564, 342/702). Tertile data of P600 latency were subjected to a two-way repeated-measures ANOVA with tertile (fastest, middle, slowest) and domain (language, music). Greenhouse-Geisser corrected ANOVA statistics showed a significant main effect of tertile, $F(2,30) = 135.18, p < .001, \eta^2 = .72$, indicating that P600 latency increased significantly as RT tertile increased from fast to slow. The main effect of domain was significant, $F(1,15) = 229.95, p < .001, \eta^2 = .66$, indicating that overall P600 latency was higher in language than music. Lastly, the corrected interaction of tertile and domain was significant, $F(2,30) = 195.93, p < .001, \eta^2 = .82$, and required Holm-Bonferroni corrected post hoc comparisons to clarify their relationship. Language showed a significant P600 latency shift slower from fast to middle tertiles, $t(15) = 6.09, p < .001, d = 1.52$, and from middle to slow tertile, $t(15) = 13.38, p < .001, d = 3.35$. In contrast, music showed a P600 latency decrease for the middle to slow tertile, $t(15) = 3.53, p = .006, d = .88$, but did not show a significant difference from fast to middle tertile, $t(15) = .50, p = .627, d = .12$. 
Figure 2.6. ERP images of language (left) and music (right) single-trial data, with hot and cold colouring to indicate positive and negative EEG amplitude. The top half of the image is response-aligned with the straight black line indicating responses, and the curved line being the PoD or deviance onset. The bottom half of the image is stimulus-aligned with the straight black line showing the PoD, and the curved line indicating the RTs. The two ERPs below that show the averaged waveforms when stimulus-aligned (black line) or response-aligned (red line).
Figure 2.7. RT tertile RT averages with P600 difference waveform (syntax error minus control) latencies for language and music (error bars show +/- 1 standard error of the mean), with the three RT tertiles of fastest (red), middle (blue), and slowest (black) ERP waveforms.
Discussion

Overview

This study used a novel method of analysis, specifically subset analyses from single-trial EEG data, to examine claims of similarity in the brain responses to language and music syntax errors. We predicted that both language and music violations would display a response-aligned P600 as per the SSIRH’s predictions of a similar syntax resource underpinning language and music.

Our study produced three types of data, with behavioural measures of RT and task accuracy, and the electrophysiological P600 component. P600 was successfully elicited in greater amplitudes to syntax errors versus controls in both language and music, with no differences in overall amplitude across domains. This verifies our paradigm regarding eliciting the P600. In language, the syntax error-related P600 was accompanied by an increase in RT as the error occurred relative to controls, as well as a decrease in accuracy relative to controls. However, in music the syntax error and subsequent P600 was accompanied by a decrease in RT and no significant decrease in accuracy relative to controls. The crucial subset analysis used RT-based tertile ERPs from fastest to slowest RTs. If P600 latency in each tertile increased as RT tertile increased, we would demonstrate response-alignment in language or music. We successfully replicated previous work showing a language response-alignment of the P600 (Sassenhagen et al., 2014); P600 peak latency was later when RT was slower. However, music tertiles followed an inverse trend – fast to middle tertiles had no difference in P600 latency, but middle to slow RT tertiles showed a significantly faster P600 latency in the slow tertile. As RT increased, P600 latency decreased.

Together, these results show response-alignment for language but not music P600 components to syntax errors. This difference is present despite similarities in P600 amplitude increases observed at the grand average ERP to language and music syntax errors over error-
free controls. Consequently, the SSIRH’s claims of similar P600s elicited across domains (Patel, 2012) is not supported.

Interpretation

Our grand average ERP results broadly corroborate the early work of Patel and colleagues (1998), which compared ERP results between domains to show similarity in P600 increases to syntax violations relative to controls. P600 amplitude increases seen in the current study are consistent with the view that there is a neural resource that is similarly recruited in the presence of a syntax error measured at the ERP level, with similar increases in P600 amplitude when a syntax violation is presented in language or music; the amplitude, or size of the response, of the P600 component is therefore sensitive to increase coincident with the onset of an attended syntax violation relative to controls. This similarity between domains supports the findings of previous behavioural (Kunert et al., 2016; Slevc et al., 2009) and electrophysiological (Batterink & Neville, 2013b; Carrus et al., 2013; Steinbeis & Koelsch, 2008a) studies. However, a central prediction of the current study extended past the ERP and amplitude change at the grand average. Instead, the phenomena of interest in the current study concerned the variation of P600 latency relative to RT, whereby the P600 component was hypothesised to be response-aligned (Sassenhagen et al., 2014) as a language or music error. Such a finding would have reflected a shared syntax resource recruited in both domains (Patel, 2012), as the P600 resource should behave similarly in language or music.

However, the findings of the current study have established a qualitative difference in P600 response-alignment between language and music. Specifically, while the onset of a syntax violation elicited P600 similar amplitude increases in language and music at the ERP, the music P600 component was not response-aligned whereas the language P600 was response-aligned. Instead, the latency of the P600 component to music syntax errors had a contradictory pattern of occurring earlier in latency to syntactic deviance in the slowest RT tertile, compared
to that of P600 latencies in middle or fast RT tertiles. This lack of response-alignment in P600 to musical syntax violations is unexpected given that language P600 has shown response-alignment in previous research (Sassenhagen et al., 2014) and is replicated in the current study as well. The pattern of language, but not music P600 response-alignment contradicts the predictions based on the SSIRH (Patel, 2012), which would implicate shared resources and therefore similar behaviours of the P600 component. Although the ERP data show similar P600 amplitude increases elicited to language and music syntax violations relative to controls, the manner in which a proposed shared resource is recruited or expressed may be qualitatively different from language to music.

Existing literature around P600 have postulated greater amplitude representing increased neural cost of integrating an error into its context (Molinaro et al., 2011), and a common syntax resource underlying both domains (Patel, 2012). The findings of the current study validate the similarity of P600 responses to syntax violations in both language and music – amplitudes of the P600 component to syntax violations were higher than error-free controls. The ERP data presented in the current study provide evidence of overlapping (and even largely identical) recruitment of the same neural populations in processing syntax between domains at the grand averaged ERP level. However, comparisons of P600 data alongside trial-level RT to compare how both change in sync with each other through response-alignment (Sassenhagen et al., 2014). By utilising this new application of response-alignment based on the P600-as-P3 hypothesis and recent research (Sassenhagen et al., 2014), the current study has demonstrated differences in language and music P600 once it is examined beyond the grand averaged ERP, while challenging predictions from existing literature regarding shared resources in the SSIRH (Patel, 2012).

The SSIRH did not explicitly predict similarities of P600 response-alignment. Despite that, a shared underlying syntax resource between domains (Patel, 2012) would suggest similar
behaviour of brain response with RT. As our understanding of this component’s related neural architecture increases, the changes of P600 latency alongside RT as seen in our study demonstrate that response-alignment can be used to compare between domains of language and music alongside more conventional ERP amplitude change (Schacht et al., 2014) and topographical distribution (Patel et al., 1998).

The discrepancy in domains for the P600-RT relationship appears to indicate a qualitative difference between the characteristics of P600 between language and music syntax processing. This difference has some support from a recent fMRI meta-analysis (LaCroix et al., 2015), which found key areas of overlap between language and music in the inferior frontal cortex (and specifically Broca’s area) but also distinct areas of music- and language-preferential activation, even within the same Brodmann’s area. Although the temporal resolution of fMRI is unable to resolve whether the domain-specific activations in language and music are related to P600-specific activity, domain-specificity of overall hemodynamic response suggests that there may be domain-specific processes that summate into the same P600 component. However, response-alignment may be an area of differentiation that reveals the differences in the processes that summate to that similar P600 in language and music. Such a finding is theoretically valuable as it shows crucial differences between domains despite a similar grand averaged P600 effect, and may suggest that the P600 is not identically generated in language and music. The degree of overlap may even be task-dependent (LaCroix et al., 2015), with attended tasks such as in the current study creating conditions for more overlap compared to passive listening. Given that our experiment was an attended error discrimination task, we would therefore anticipate that we created conditions for optimal overlap between domains. Despite this, our P600 components do not behave similarly past the ERP. The relationship between language and music syntax might therefore best be conceptualised as one of overlapping, but differentially recruited neural resources.
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The SSIRH states that domain-specific neural representations may be distinct, which if damaged, may produce domain-specific impairment (Patel, 2003). However, identical cognitive resources are brought to bear on these domain-specific representations (Patel, 2012). These are postulated to be the shared aspects of language and music syntax processing. These attention-dependent, active aspects of overlap are said to coincide with the P600. However, the observed similarities of P600 effects at the ERP level, but not with regard to response-alignment suggests that while similar neural resources are recruited for syntax violations in language and music, they may not in fact be the same resource brought to bear between domains. Alternatively, it might be the case that the same neural resources interact differently with language and music – this is not a strong deviation from the SSIRH, which already posits areas of overlap but also differentiation between domains (Patel, 2012). The findings in the present study provide new information regarding the complex interaction between language and music, and utilise the fine temporal information contained within EEG data to find deeper relationships between brain response and behaviour.

Other explanations are also important in the consideration of this study’s findings. The observed similarities of P600 effects across both language and music syntax violations may be due to syntactic resource overlap, but may also be modulated by task-related effects. In fact, a review of over 170 language and music fMRI studies suggests that the critical functional overlap between domains is the active processing of word-by-word and note-by-note language and music (LaCroix et al., 2015). That is, task demand on cognitive control resources may ultimately be the driving force of the functional overlap between these two domains, whether in the memorising of a sequence, or by discriminating errors. With that in mind, the SSIRH may not be the conclusive explanation for our findings, as it claims a syntax-specific area of overlap between domains. Instead, it is possible that a more domain-general attention-cognitive error detection processes result in the P600 effect, which may be creditable for the observed
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similarity between linguistic and musical P600. Following are some alternative perspectives to
the SSIRH.

**Alternative perspectives**

Two narrative reviews of the language (Van Petten & Luka, 2012) and music
(Rohrmeier & Koelsch, 2012) literature pertaining to the processing costs related to syntactic
violations concluded that predictions of upcoming stimuli were essential to effective processing
of language and music. A later review postulated that the said overlap of language and music
processing is built on the generation, maintenance, and updating of a mental predictive model
relying on cognitive control (Slevc & Okada, 2015). The cognitive resources employed would
then generate expectations of the upcoming stimuli, which would reinforce or revise the model
for greater predictive power. A hypothesis based on cognitive control is reliant on a much more
evolutionarily simple mechanism that could represent a more complex iteration of cortical
networks seen in primates (Bornkessel-Schlesewsky, Schlesewsky, Small, & Rauschecker,
2015), and therefore is a more parsimonious perspective of the ways in which language and
music are processed as opposed to a syntax-specific, unique resource (Patel, 2012). The task in
the current study was to create expectations of plurality (this/these). Violations of this
expectation would produce task-related, deviant processing; this can be considered in a more
domain-general, non-syntactic framework such as the P600-as-P3 hypothesis (Coulson et al.,
1998) – errors of syntax simply constitute an error in general that requires integration or repair
processes (Molinaro et al., 2011) as related to language, but actually represent more specific
applications of a more generic P3-like resource (Sassenhagen et al., 2014).

Given that the average P3b latency does increase in response to stimulus complexity, it
is possible that the complexity of linguistic stimuli could therefore delay P3b to a P600-like
latency. The P600-as-P3 hypothesis (Sassenhagen et al., 2014) postulates P600 as a late-
occurring iteration of the P3, and therefore neural networks engaged in P3-related processing
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would be employed in the generation of the P600 as well. As such, while there are latency
differences dividing P3 and P600, similarities of response-alignment (Sassenhagen et al.,
2014), of power change in the time-frequency spectrum (Brilmayer et al., 2017), and of EEG
patterns as recognised by machine learning (Sassenhagen & Fiebach, 2018) help support the
idea of similarities between P600 and P3-related cortical activation. Brilmayer and colleagues
(2017) demonstrated a P600 (or P3-like) ERP and spectral power response to musical
instruments that varied in timbre and tone pitch, which meant to represent the complex acoustic
changes present in auditory language and not simply a musical harmonic, rhythmic, or syntax-
related manipulation. The researchers argue that it is the ongoing assessment of a complex
stimulus that delays a P3-like response to the P600 latency range, and that the similarities of
spectral activation between P3 and P600 are more than coincidence; they argue that these are
the same response. The research question in the current study extends the claims of the P600-
as-P3 hypothesis from just language P600 response-alignment to include musical P600 as well.
However, P3-like response-alignment was not seen in our music data. The lack of musical P600
response-alignment violates the claims of the P600-as-P3 hypothesis, and would present a
deviation of P600 from P3-like behaviour.

An interesting question for further research is based on the observed interactions of
simultaneously-presented language and music syntax errors that result in delayed or less
accurate behavioural responses (Fedorenko et al., 2009; Kunert et al., 2016; Slevc et al., 2009),
and attenuated electrophysiological responses (Koelsch et al., 2005; Maidhof and Koelsch,
2011). A shared language and music resource for syntax such as claimed in the SSIRH (Patel,
2012) would predict an interaction of behavioural and brain responses as the simultaneous
errors occur. A pattern of interactions in the processing of simultaneously-presented language
and music syntax errors would provide support for the idea that similar resources are being
recruited between domains. However, P600 has not been examined in relation to simultaneous
syntax errors in such a way before. This is an interesting direction for future research to pursue, especially to investigate a possible interaction between P600 amplitude and behavioural response speed and accuracy. Doing so would further cement P600 as being functionally related to the shared processing in language and music, and support the idea of neural overlap between domains if simultaneous errors produced greater impairment than single errors. An experiment with a simultaneously-presented, yet selective-attention language and music design may help clarify the attention-dependence of the P600, and bring our understanding of this component in line with other ERP components that have demonstrated automatic interactions in the LAN and ERAN (Koelsch et al., 2005), and that of the ERAN/LAN and N400/N500 (Steinbeis and Koelsch, 2008a).

Alongside the use of the RT tertile analysis, our study included two methodological aspects that can be adopted by future research in this area. Specifically, we used the PoD instead of stimulus onset as the event marker for language ERPs. This led to more comparable P600s across domains without confounding N400-like activity, and more importantly it is more precise of an event marker to link to deviance-related activity. Furthermore, the use of the PoD effectively brings P600 latency to that of a P3b in a face detection task (Sassenhagen and Bornkessel-Schlesewsky, 2015), which may allow for P600 effects to be more directly compared to P3 in the ERP. It may be that P600 is an inaccurately-epoched language P3. Further testing using the PoD may allow us to clarify the relationship between P600 and P3. This might take the form of a language-music simultaneous presentation with coincident syntax errors at the PoD for language stimuli. By offsetting the music stimuli, we would then be able to examine the effects of simultaneous syntax errors across domains. Such a task would sidestep the staggered nature of the immediately discernible music error alongside the later language error in onset-matched language-music tasks. Additionally, our study directly compared behavioural alongside P600 effects to compare functional co-occurrences between
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P600 and RT/accuracy. This link between electrophysiology and behavioural performance is crucial to help understand the functional correlates of P600 as reflecting a syntax-related processing stage. P600 amplitude increases may reflect the cost of processing syntax errors, and could coincide with RT increases as seen in our language data. However, the RT reduction in music errors relative to controls suggests this relationship is not as definitive as originally hypothesised; P600 increases may not automatically correlate to behavioural impairment.

Additional observations

Interestingly, we found that the anticipated behavioural cost in RT increases and task accuracy decreases occurred only in language, not in music. Music syntax errors saw counterintuitive decreases in RT, with no differences in accuracy compared to controls. We interpret this difference between domains as part of the task paradigm, with music stimuli consistently lasting 600ms. Language stimuli varied substantially in duration from word to word, with monosyllabic to tri-syllabic words in the same 600ms inter-onset-interval. As such, the regularity of music stimuli duration might have predisposed participants to respond with a regular rhythm around 600ms, with syntax errors representing salient stimuli that were treated differently (and responded as fast as possible as opposed to a regular rhythm). RTs have also shown decreases to strong musical syntax deviants (Ladinig et al., 2009), which may suggest that syntactic errors suspend a possible adherence of RTs to the meter of musical stimuli. However, this is not a well-documented phenomenon, and the conditions under which this RT-metric effect is elicited are unclear. Future work may help clarify the role of stimulus presentation or task demand parameters in inducing this effect.

Summary

In conclusion, the present results found the hypothesised response-alignment in the P600 to syntax errors in language, in line with previous research (Sassenhagen et al., 2014), as evidenced by the use of subset analyses. However, music P600 did not show response-
alignment, contrary to what we expected. This represents a qualitative difference in brain response patterns in language and music, and is not supportive of completely shared neural resources as claimed by the SSIRH (Patel, 2012) and of the P600-as-P3 hypothesis (Coulson et al., 1998). Instead, cortical responses as measured at the ERP may suggest an overlap of overall shared resource recruitment to language and music syntax violations, with some functional differences of latency relative to the physical response. The extent of P600-related neural overlap between domains and functional co-occurrence to behavioural performance can be investigated in future work, using variations of a simultaneous language-music presentation paradigm.

Acknowledgements

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SIMILARITIES OF SYNTAX ERROR RESPONSE

References


Cost-effectiveness


Maidhof, C., & Koelsch, S. (2011). Effects of selective attention on syntax processing in music
SIMILARITIES OF SYNTAX ERROR RESPONSE


SIMILARITIES OF SYNTAX ERROR RESPONSE


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3. EXPERIMENT 2

3.1. Preliminary introduction: Linking Experiment 1 and 2

Language and music P600 components increased in amplitude similarly to syntax violations relative to controls, but showed response-alignment differences – P600 components to language syntax violations increased in latency increased in trials where RT was slow, whereas P600 components to musical syntax violations did not. In fact, the slowest RT tertiles for music syntax violations showed a faster P600 latency than P600 latencies in fast and middle RT tertiles. This showed a qualitative difference of P600 behaviour at the trial level relative to RT, while displaying similar amplitude increases at the ERP. The observed differences in response-alignment across P600 components to language and music syntax violations challenges the SSIRH, which claims a shared resource that underlies language and music syntax processing (Patel, 2012).

Despite the differences seen in language and music P600 response-alignment, we still see interactions of cross-domain syntax processing at the behavioural (Fedorenko et al., 2009; Slevc et al., 2009) and electrophysiological (Carrus et al., 2013; Koelsch et al., 2005; Maidhof & Koelsch, 2011; Steinbeis & Koelsch, 2007) levels. Only one behavioural study examines the effect of language on music processing (Kunert et al., 2016); the majority of behavioural studies focus on the effects of musical syntax on language. Furthermore, only one study has examined the effects of simultaneously presented language on music and vice versa (Maidhof & Koelsch, 2011), with a syntax being unattended and therefore no P600s elicited. Only two studies have examined P600 bidirectionally, but presented in isolation (Fitzroy & Sanders, 2013; Patel et al., 1998).

However, a gap in the literature exists in the examination of language-on-music and music-on-language at both the behavioural and electrophysiological levels. Due to the prevalence of syntax interactions for language and music in the literature, such interactions
should also take place despite the differences of P600 seen in Experiment 1. A selective-attention, simultaneous language-music presentation design would test P600 attention-dependence under novel conditions under which syntax is attended to one stream and not the other. Such an active syntax processing task has not been done in previous work, which has utilised a timbre task instead (Maidhof & Koelsch, 2011). To directly compare patterns of cross-domain P600 and behaviour under these conditions is the basis for Experiment 2.

As increased task complexity and an enriched sensory environment is increased from Experiment 1 to 2, the extent of shared resources being engaged in a simultaneous-presentation design is the focus of the subsequent analyses in the Experiment 2. Therefore, P600 amplitude rather than response-alignment will be the focus, where P600 amplitude change is predicted to reflect attention-dependent processing syntax violations.

We expect that Experiment 2 would clarify the role of attention in modulating the syntax interactions seen in previous research, as well as enabling the direct comparison of behavioural alongside EEG data in that design – P600 responses to syntax violations should coincide with RT effects, and this relationship of EEG with behaviour should be present across both directions in language and music. However, with previous research showing the effects of ignored or unattended music syntax on language processing (Fedorenko et al., 2009; Koelsch et al., 2005; Slevc et al., 2009), we may find interactive language and music syntax processing at both the behavioural measures of RT or task accuracy. Given the well-documented attention-dependence of P600 (Batterink & Neville, 2013; Schacht et al., 2014), however, such attention-independent effects are unlikely.

The possible disconnect of RT and P600 findings may suggest that P600 is not functionally related to response speed at the behavioural level. If we find RT effects together with P600 amplitude changes, however, then we can begin to suggest a functional co-occurrence of P600 with RT, thereby linking electrophysiological response with behavioural
performance. In addition, we may discover the RT-metric effects seen in Experiment 1 to attend-language conditions or the music-attended conditions in Experiment 2. Observing a RT-metric effect in a separate Experiment 2 would corroborate our findings in Experiment 1 in representing a RT effect with a music-attended task, and if only present for the music-attended conditions, would suggest that this effect is replicable and attention-dependent.
References


3.2. P600 to language and music syntax: Selective attention and bidirectional effects

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Abstract

Claims in the Shared Syntax Integration Resource Hypothesis (SSIRH; Patel, 2012) state that the P600 component of the event-related potential (ERP) is an index of shared syntax resources between language and music. Prior research has focused on either behavioural (Kunert, Willems, & Hagoort, 2016) or ERP (Fitzroy & Sanders, 2013) data, but typically do not collect both together. This has led to diverging predictions of what effects are seen when syntax errors co-occur in language and music, especially when selectively attended. The current study collected both data in a simultaneous presentation, selective-attention, repeated measures design. Participants (N=20) listened to 800 auditory sequences of seven simultaneously-played words and chords over two sessions, attending to only one domain at a time. Sequences were error-free (control), had an attended-domain error, a dual error (attended and unattended error), an unattended error, or a distractor error (error in the middle of sequence). Participants pressed one of two buttons to indicate a sequence as correct or incorrect. Across both domains, attended and dual syntax errors elicited increased P600 amplitudes compared to controls, whereas unattended errors did not. RTs increased to attended language errors but were statistically similar across all music-attended conditions; task accuracy was similar through all conditions. The similarity of P600 amplitude increases to language and music errors in a challenging sensory environment provides support for the P600 as an index of shared syntax processing as claimed in the SSIRH.

Keywords: EEG, P600, syntax, SSIRH, music, language
SELECTIVE ATTENTION AND BIDIRECTIONAL EFFECTS

Introduction

Language and music are postulated to share a common processing resource (Patel, 2012). This resource is claimed to be similarly recruited in the processing of domain-specific structural rules, or syntax, for both domains of language and music. Manipulations of linguistic grammar and musical harmony elicit similar late positive responses in the P600 component (Patel et al., 1998). Additional electrophysiological responses such as the early right anterior negative responses in music (ERAN) and the left anterior negativity (LAN) language response (Koelsch et al., 2005) in the electroencephalogram also respond to syntax violations, and all electrophysiological responses are measured as components in the grand averaged event-related potential (EEG; ERP). Subsequent research has provided evidence for the proposed shared syntactic integration resource hypothesis (Patel, 2012), with behavioural (Fedorenko et al., 2009; Jung, Sontag, Park, & Loui, 2015; Kunert et al., 2016; Slevc et al., 2009), electrophysiological (Carrus et al., 2011, 2013; Steinbeis & Koelsch, 2007), and functional magnetic resonance imaging (see LaCroix et al., 2015 for a review; Musso et al., 2015) evidence lending support for the SSIRH’s claim of a syntax-specific shared resource.

One way to examine the ways language and music share this syntax processing resource is to simultaneously present syntax violations in both domains to generate competing demands when an expected syntactic form is violated with an incorrect syntactic form. The generation of expectations in language and music both rely on expectations of incoming stimuli – perceived deviations of structural forms in language rules of grammar (Van Petten & Luka, 2012) and in music rules of harmony (Rohrmeier & Koelsch, 2012) result in the need to integrate the error back into its syntactic context of the sentence or the musical progression (Slevc & Okada, 2015). Simultaneously-presented violations should therefore jointly load onto a shared resource, producing an even greater demand of that load than a single error would. The incurred syntactic processing cost can then be observed through delayed or less accurate behavioural task performance and increased cortical responses to violations of syntax in both domains, measured through EEG.
Research using this simultaneous-presentation experimental design has generally tended to analyse either behavioural or electrophysiological data, not both. One possible reason is because electrophysiological measurements require high trial counts for averaging analyses, whereas behavioural tasks require differences of response speed (Perruchet & Poulin-Charronnat, 2013; Slevc et al., 2009) or accuracy rates (Fedorenko et al., 2009; Kunert et al., 2016; Roncaglia-Denissen et al., 2018); in the latter case this would lead to reduced trial counts and potentially reduce the quality of the averaged EEG waveform, the ERP. This issue of behavioural tasks reducing eligible EEG trials is particularly pertinent when EEG testing is generally conducted in a single session, as it limits the total testing time and therefore the amount of total trials presented. One previous EEG study using a simultaneous-presentation design utilised an easy error detection task to produce high task accuracy averages (Koelsch et al., 2005), therefore retaining a relatively high number of trials from their total presented sequences of 234 sentences and music progressions in total. Other tasks that have been employed in previous research include an occasional sentence comprehension prompt on an infrequent basis (10%; Carrus et al., 2013; 7%; Steinbeis & Koelsch, 2007), a computationally simpler voice or instrument quality (timbre) error detection task (Maidhof & Koelsch, 2011; Steinbeis & Koelsch, 2007), or simply no overt task at all (Carrus et al., 2011). Any study attempting to use a more difficult task along with ERP data would therefore require an increased trial count to account for decreases in total accepted trials.

The lack of direct attention to syntax in the majority of prior simultaneous-presentation research imposes limitations on the observed syntax-related effects on electrophysiological response, because active syntax processing tends to produce the most overlap of associated syntax processes between language- and music-activated networks (LaCroix et al., 2015). A recent review suggests that active processing is a prerequisite for recruiting similar neural resources in language and music (Slevc & Okada, 2015). Tasks employed in electrophysiological studies are generally different from the behavioural literature, which trends toward an actively attended syntax task in either language (Fedorenko et al., 2009; Jung et al., 2015; Perruchet & Poulin-Charronnat, 2013; Slevc et al., 2009).
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or music (Kunert et al., 2016) with the other domain ignored or queried on an occasional basis (33%; Kunert et al., 2016).

Active syntax processing is crucial to generating the ERP component known as the P600 (Batterink & Neville, 2013; Brattico et al., 2006; Schacht et al., 2014). It is a late occurring parietally-centred component that is typically maximal in amplitude 600ms after stimulus onset (Osterhout & Holcomb, 1992, 1993), and has been elicited in language and music syntactic errors in a similar fashion (de Leeuw et al., 2018; Patel et al., 1998). This component is said to represent the similarity of shared resources seen in language and music syntax processing (Patel, 2012), and is elicited in the presence of an attended syntactic error in either domain (Besson & Schön, 2001). By simultaneously presenting language and music errors, it is possible to observe how the shared processes as indexed by the P600 appear to interact – SSIRH would suggest that they jointly load onto the same shared resource (Patel, 2012), and perhaps result in the enhancement of P600 effects. However, despite the importance of shared resources and the P600 in the SSIRH, there appears to have been no direct examination of the P600 in this simultaneous-presentation design to date. Consequently, there is no current understanding of how P600-related effects are modulated by simultaneous syntactic violations.

One criticism of the SSIRH and its postulation that P600 is indicative of shared syntax resources is that P600 effects appear to be attention-dependent, whereas behavioural findings in the literature demonstrate that music syntax violations affect language processing despite being unattended (Fedorenko et al., 2009; Slevc et al., 2009), and of language syntax errors affecting music processing despite being unattended as well (Kunert et al., 2016). If the P600 component fails to capture unattended syntax effects that seem to be behaviourally measurable, it would lead to the conclusion that P600 is inadequate to index syntax interactions at the cortical level that significantly impact task performance at the behavioural level. A recent review of the language and music fMRI literature pointed to the importance of experimental task in eliciting cross-domain shared resources, where an attended syntax task appeared to produce the BOLD activations of highest overlap (LaCroix
et al., 2015). However, while behavioural task experiments have employed a single-attended syntax task in a simultaneous presentation design (Fedorenko et al., 2009; Kunert et al., 2016; Sleve et al., 2009), electrophysiologically-focused experiments have not followed the same trend.

The only simultaneous presentation, single-attended EEG experiment with an active syntax task found that syntax errors generated P600 effects whether attended or otherwise (Koelsch et al., 2005); unattended music syntax errors produced P600 amplitude increases akin to those found in the attended language syntax error. This finding of P600 attention-independence is not supported by subsequent research suggesting P600 attention-dependence (Batterink & Neville, 2013; Schacht et al., 2014). If unattended syntax errors do not elicit P600 effects, yet produce increased sentence reading time (Slevc et al., 2009), reduced sentence comprehension accuracy (Fedorenko et al., 2009), and reduced musical closure ratings (Kunert et al., 2016), then the P600 component would not be adequate as an index of the syntax-related processing cost at the cortical level. That is, it would not reflect the behavioural costs incurred when syntax is unattended, suggesting that syntax processing involves pre-attentive resources that the P600 is unable to index due to its attention-dependence. However, such a direct comparison of behaviour and P600 effects has not yet been conducted. The use of the same attended syntax task in eliciting both behavioural and electrophysiological responses would provide new information about the role of the P600 component in indexing syntax processing cost as reflected in the behavioural data.

Furthermore, there is also the question of bidirectionality of syntax interactions in language and music. Findings in one direction of unattended music effects on attended language, for example, may not necessarily be true for unattended language effects on attended music (Maidhof & Koelsch, 2011). This study involved an attended timbre task that manipulated sound quality changes of voice or musical instrument through a filtered sound effect, but sentences and musical progressions contained syntax violations that would be processed automatically. The authors initially hypothesised that the early language and music ERP responses, the early left anterior negativity (ELAN) and the early right anterior negativity (ERAN), would both show automatic responses independent of
attention, and interact by potentially attenuating the music-related ERAN syntax response when a linguistically deviant syntax violation is presented (Maidhof & Koelsch, 2011). They found that the ERAN to music syntax violations was reduced from music-only presentation to the concurrent presentation of language and music, and that an unattended music syntax violation had reduced ERAN when presented with a language syntax violation versus no language violation. The language-related ELAN was unaffected in conditions of attention (attended or not) or presentation format (single or simultaneous). The pattern of results suggests that language and music cortical responses can differ in terms of automaticity, and these differences only appear by examining both directions of the music-on-language and language-on-music ERP responses.

The authors also mention the importance of understanding shared resources in language and music under conditions of high attentional load (Maidhof & Koelsch, 2011) such as the simultaneous-presentation design as employed in a handful of other studies (Koelsch et al., 2005; Maidhof & Koelsch, 2011; Steinbeis & Koelsch, 2007). The differences across domains of ELAN and ERAN attention-dependence were somewhat unexpected in this study, as they appeared to be similar in time course and scalp distribution in the ERP (despite a left preponderance in ELAN and right preponderance in ERAN). Given the similar time course and scalp distribution in the P600 across language and music (Patel et al., 1998) in simpler acoustic environments of language-only or music-only presentation, there remains the possibility that attention-dependence of the P600 may show differences between domains if examined under a simultaneous-presentation design. This is especially so due to the elicitation of a seemingly attention-independent P600 to music syntax violation in a previous study (Koelsch et al., 2005). If shared resources are being recruited to operate on language and music syntactic manipulations in a similar fashion (Patel, 2012), then similar patterns of attention-dependence should be present across P600 in either domain.

The aim of the current experiment is therefore to determine the usefulness of P600 as reflecting syntax violation processing cost in language and music, as claimed by the SSIRH (Patel, 2012). Using an active syntax task in a simultaneous language-music presentation, selective-attention
design, the current experiment will compare behavioural alongside electrophysiological responses to syntax errors in both directions of the language-attended and music-attended conditions respectively. Based on previous behavioural research (Fedorenko et al., 2009; Kunert et al., 2016; Slevc et al., 2009), behavioural measures of RT are predicted to increase in the case of syntactic errors of an attended or unattended nature. Cortical response to syntax as evidenced by the P600 component of the ERP are predicted to increase only to attended, not unattended syntax errors (Batterink & Neville, 2013; Brattico et al., 2006; Schacht et al., 2014). Expectations based on previous research therefore predict a divergence of syntax violation-related behavioural and electrophysiological effects, with RT and accuracy capturing attention-independent interactions of syntax and P600 showing attention-dependent syntax effects. Such a pattern of results will suggest that P600 is not sensitive enough to reflect a shared syntactic resource (Patel, 2012), and that other components of the ERP would be required to fully capture the processing costs evident at the behavioural level.

However, if behavioural effects follow the attention-dependent P600 effects, then that pattern of results would suggest that P600 is an adequately sensitive index of shared syntax resources as initially suggested in the SSIRH (Patel, 2012). Moreover, claims of a shared syntax resource (Patel, 2012) predict that syntax violations in either domain will elicit similar patterns of P600 amplitude change across domains, with attend-language and attend-music syntax conditions producing P600 amplitude change to attended errors only. Failure to observe similar P600 patterns in language and music would provide evidence that music and language P600 components do not represent similar cortical activations, and by extension shared resources across domains.

**Methods**

**Participants**

The participants were a convenience sample of 23 self-reported right-handed English-speaking university students from Perth, Western Australia. Right-handedness was chosen on the basis of minimising variability in the ERP signal; right handers produce the most reliable P600 responses, where left handers can produce N400-dominant ERPs to syntactic errors (Grey et al.,
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Participants were also aged between 18 and 60 years to minimise age effects, as P600 effects have been shown to become more anterior with advanced age; Faustmann, Murdoch, Finnigan, & Copland, 2007). While P600 did not change in amplitude or latency past that age, the 60 year age bracket was chosen as a precaution nonetheless. Participants also spoke English as their native language, listened to music primarily from Western tonal music throughout their life (pop, blues, jazz, classical), and had no prior musical training (no private one-on-one music classes) in the last ten years; the average prior training for accepted participants was 0.5 years (SD = 1.01 years). One exception was a participant who reported seven years apart from one year of percussion/drums training, but reported they had no training in musical theory. Furthermore, participants were required to self-report normal or corrected hearing and vision, and were self-reported to be neurologically healthy and not being on medication affecting the nervous system. Lastly, participants were advised not to consume substances that may affect the nervous system for 24 hours prior to participating, with the exception of caffeine; this was limited to one hour before participating. One participant was excluded from the study on the basis of currently consuming Tramadol, an opioid analgesic. All information was obtained through the use of a screening questionnaire. Participants received either course credit for participation or an entry into a raffle for a pair of movie tickets.

Design

The experiment was 2x5 repeated-measures design comprising independent variables of attend-condition, or domain attended (Language, Music) and condition (Control, Attended Error, Unattended Error, Dual Error, Distractor Error). The dependent variables were behavioural accuracy, RT, and the P600 component of the ERP.
Stimuli were presented in simultaneous language-music, seven-element sequences, and an online repository of sample stimuli can be accessed via the link: [https://tinyurl.com/y3k2cvd8](https://tinyurl.com/y3k2cvd8). The use of seven-element sequences was decided on based on the sentence structure, which was the minimum number of words required to produce a sentence with a subject-verb-object ordering. This would make a sentence stem that can be manipulated to violate language syntax within a single trial.

The musical chord sequences were created in order to match the seven-word sentences, using chords played within the same tonality to establish a syntactic context in a single trial. Music chord progressions in previous research has shown that two- (Sammler, Novembre, Koelsch, & Keller, 2013) and five-chord (Sammler et al., 2013; Steinbeis & Koelsch, 2007) sequences have been successfully employed to generate behavioural and ERP effects.

Categories are as follows for each domain attended: a) control sequences, with no syntactic violations, b) attended syntactic error sequences, where the final attended element violates number or harmonic agreement, c) unattended syntactic error sequences, where the domain not attended produces a violation of number or harmonic agreement, d) dual syntactic error sequences (attended
and unattended error), where both a number and harmonic violation are present, and e) distractor error sequences, where the sequence contains a number or harmonic violation in the middle of the progression. The number of trials per condition are shown in Table 3.1. A total of 400 trials were created with 200 error-free language and music progressions that would then produce 200 progressions with a syntactic violation in either language, music, or both. These would comprise the 400 trials for one session of testing, with each trial representing unique combinations of attend-language and attend-music sequences.

The second session would reverse the attend-conditions of each trial so that the unattended sequence in any given trial was attended and vice versa. To minimise practice or habituation effects, participants were not allowed to take part in the second session until a week after the first. The use of a high number of presented trials and of multi-session testing was with the intention of increasing total trials. Doing so minimised the degrading effects of an increased difficulty of the behavioural task reducing total accepted trials, thereby minimising low trial count effects on ERP waveform quality.

Table 3.2

*Sample experimental language stimuli*

<table>
<thead>
<tr>
<th>Condition</th>
<th>Sequence position</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td></td>
<td></td>
<td>judge</td>
<td>is</td>
<td>reading</td>
<td>out</td>
<td>those</td>
<td>laws.</td>
</tr>
<tr>
<td>Syntactic</td>
<td></td>
<td></td>
<td>judge</td>
<td>is</td>
<td>reading</td>
<td>out</td>
<td><strong>that</strong></td>
<td>laws.</td>
</tr>
<tr>
<td>Distractor</td>
<td></td>
<td></td>
<td>judge</td>
<td>is</td>
<td><strong>read</strong></td>
<td>out</td>
<td>those</td>
<td>laws.</td>
</tr>
</tbody>
</table>

*Note.* Underlined, bolded, italicised are the critical points of deviance in each condition.

**Language.** All language sequences were auditorily presented with a fixed inter-onset-interval (IOI) between words, each containing contained a subject-verb-object progression. Syntactic sequences had a noun plurality (or number agreement) error on the last word, and distractor sequences had a verb conjugation error on the fourth word. Distractors were infrequently presented to minimise the possibility of participants fixating on the final elements of the progression without processing the
sentential context. Number agreement grammatical errors have produced a P600 response in previous research (Shen et al., 2013). Violations had no prior cue earlier in the sequence, which means that participants could not anticipate the onset of a deviant; note that the deviant conditions varied in the penultimate element, and thus the critical element remained physically and acoustically identical to control conditions. Furthermore, sentence stems were just as likely to be correct following a singular (‘that’, ‘this’) or a plural (‘these’, ‘those’) penultimate word – this ensured each trial’s critical word was not predictable in its correctness prior to the presentation of the word itself.

Critical sentence-ending words were required to have no homophones, be between one and three syllables long, and chosen so that critical word syntactic deviance was only perceptible at the end of the word (“those laws”, critical word underlined; see Table 3.2), where a measurable point of deviance (PoD) could be marked at the point where the plurality (“s”) would dictate the word’s numeric agreement with the context. The PoD was first defined by the authors of the current study, then independently defined by two additional individuals unrelated to the current study. Any differences in the PoD between the three definitions were checked and revised where necessary. 200 language stems were created, which produced all syntax violation stimuli. Control stems were kept unique from the violation stems in two different iterations of the stimulus set, where 100 error-free stems in one version were converted into syntax violations for the other version, and vice versa.

All language stimuli were recorded in an acoustically isolated studio, with a trained sound engineer recording the material. A condenser microphone with a pop filter was applied to ensure no fricatives were overly disruptive to sound quality. Sentences were read out as full error-free control materials – words were pronounced to a metronome that was played to the English speaker through headphones, with words spaced to have an inter-onset-interval of 600 milliseconds (or at 100 beats per minute). After this process, multiple versions of deviant penultimate words were separately recorded. Material were recorded in full raw format, then compressed to 16-bit WAV files for further processing.
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Deviant trial stimuli were then created by replacing the penultimate word of a control trial with an erroneous word. These were matched by overall pronunciation of the sentence so as to not sound anomalous to the listener. Words were then tempo-locked to the 600 milliseconds interval stipulated earlier, as pronunciations of the words were not precisely timed enough. This ensured that word onsets were 600 milliseconds apart. Words were then normalised at the software level across sound files and tracks, and were presented at a comfortable volume through the experimental computer’s headphones. As sound file presentation varies significantly with prosody, a measured decibel level for actual experimental tracks would not be particularly informative. This is why software normalisation, then consistent stimulus presentation volume levels were implemented instead.

Music. The musical stimuli were sequences of seven chords, with each chord comprising three notes arranged in root position (see Table 3.3). Figure 3.1 depicts an example chord sequence occurring in an experimental trial. For the control chord progressions, the chords all fit in the same musical tonality (thus sounding congruent with the key of the progression). Syntactic violations were created by replacing the musical context with a sequence from a musically distant tonality, based on the manipulations used in previous research that successfully elicited P600 effects (Patel et al., 1998). A sequence-final C Major chord, therefore, would be preceded by a sequence based on B Major. This replacement of the musical progression preceding the final chord ensures that any differences in ERP measurements are due to the syntactic manipulation, not based on acoustic differences. The distractor errors were similar in the nature of harmonic violations seen in the progression-ending chords but were introduced in the fourth chord (middle) of the sequence in order to encourage attentional allocation to the entire sequence, not simply the endings. B Major-ending progressions were replaced with C Major chords respectively, and vice versa. A similar manipulation of chord progressions was made for E Major and F Major progressions. The use of these four tonalities produced a total of 192 unique progressions of 48 each tonality. To produce the 200 musical progressions required to match with the language stimuli, two progressions from each tonality were randomly selected to be repeated.
The 200 stems were then split into batches of 100 each, where control stems were reversed into syntax violation stems (and vice versa) for alternating participants.

In order to match the language stimuli, chords were created using a MIDI chord creator and saved as WAV files. These were then edited to have 600ms intervals, matching the language stimuli. The chords were then matched for loudness by software normalisation alongside the language stimuli, reduced in volume if the consistent nature of musical chords led to an overall subjectively louder perception of music, then exported to the experimental computer and played at the same level as the language stimuli. This ensured that the most consistent conditions were created between language and music stimuli.

Table 3.3

<table>
<thead>
<tr>
<th>Condition</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>C</td>
<td>G</td>
<td>A minor</td>
<td>C</td>
<td>F</td>
<td>G</td>
<td>C</td>
</tr>
<tr>
<td>Syntactic</td>
<td>B</td>
<td>F#</td>
<td>C# minor</td>
<td>B</td>
<td>E</td>
<td>F#</td>
<td>C</td>
</tr>
<tr>
<td>Distractor</td>
<td>B</td>
<td>F#</td>
<td>C# minor</td>
<td>C</td>
<td>E</td>
<td>F#</td>
<td>B</td>
</tr>
</tbody>
</table>

*Note. Underlined, bolded, italicised are the critical points of deviance in each category.*

**Syncing points of deviance.** Music and language stimuli were somewhat different in terms of when the syntax violation occurs. Specifically, in the language trial in Table 3.2, the expected plural word ("The judge is reading out those ...") would deviate only at the end of the singular pronunciation ("law"), after which an additional plural modifier ("s" in "laws") results in it being processed as correct. In contrast, the musical syntax violation was obvious at the beginning of the chord (not the end). For both language and music, the EEG responses to syntax violations were aligned to the onset of the PoD, measured as the point at which the word/chord began to demonstrate either a correct or erroneous syntax. Brain responses were locked to language stimuli to a) the offset of the singular term, or the b) onset of the plural term, as they would correspond to the points at which a decision could be made. For music stimuli, brain response was locked to the onset of the chord. The
language and music errors have differing points of deviance (PoD), that need to co-occur to ensure a simultaneous demand on shared syntax resources. In order to ensure both critical stimuli were presented at the same time, the music stimuli were offset so that the onset of the critical chord was in time with the point at which language deviance could be assessed. This was done on a per-trial basis to ensure adherence to the principle. No temporal jitter was introduced to trial presentation.

Procedure

Participants provided informed consent, then completed the screening questionnaire containing all our exclusion criteria. An appropriately-sized EEG cap was then fastened on the participant’s head, impedances reduced to below 50kΩs (Ferree et al., 2001), and closed-back headphones placed on the ears and above the EEG cap. Participants were then seated 57cm from a computer monitor (1024x768 resolution, refresh rate at 85Hz), with chins rested on a stand in front of the monitor. Once seated, they listened to language/music sequences presented via the headphones at a comfortable volume while resting both hands’ index fingers on the corresponding “1” and “4” buttons on a serial response box.

![Diagram of trial format](image)

**Figure 3.1.** A typical trial format, with an example music and language trial. A musical deviant is created by changing the preceding progression, and a syntactic error in language is created by changing the penultimate word in the sentence.
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Participants were presented with an instruction slide that outlined the experimental task (see Figure 3.1): Press one button (“1”) on the serial response box to respond to the presented trials as error-free, and another button (“4”) to indicate a syntax error was present in the attended domain only. Participants were told that language and music were to be presented simultaneously, but to attend to only one and ignore the other. Each trial began with a fixation image (neutral cartoon face) for 100ms, followed by the simultaneous linguistic and musical sequence. This sequence comprised seven 600ms elements in each domain, with music offset a certain latency on a per-trial basis as described below. Participants had 1500ms from the onset of the last chord or word to respond (i.e., 900ms after the end of the final 600ms element); responses before or after this window were considered incorrect. Participants responded as fast as possible, then received immediate feedback via the changing of the fixation image. This varied from a neutral face to a smiling or frowning face to indicate correct or incorrect response respectively. The face was presented for 100ms plus the remainder of the duration of the response window. The total trial time was therefore 5300ms, with latencies shifted up to 12ms to account for screen refresh rate (85Hz) frequency. To familiarise the participants with the paradigm, each participant completed ten practice trials in each attend condition (one attending language and one music), selected at random from a list separate from experimental trials. The assignment of button responses (“1” and “4”) was counterbalanced across participants and sessions. Immediately after the button press, the neutral fixation face cartoon was replaced with a feedback face cartoon indicating a correct or a missed or incorrect response. Following the presentation of feedback, the next trial began. Participants were advised to remain quiet and still and respond accurately and quickly.

Following the 20 total practice trials, the monitor displayed a summary slide with mean block RT and accuracy. The subsequent experimental protocol was structured into ten blocks of 40 trials per experimental session (25% controls, 20% attended errors, 25% unattended errors, 20% dual errors, 10% distractor errors), with two experimental sessions in total. Responses were thus equiprobable as error-free (comprising equal numbers of controls and unattended errors) and syntax violating (comprising equal numbers of attended errors and dual errors, and infrequent distractor
errors). The conclusion of each block was followed by a summary slide presenting mean block RT and accuracy. Trial blocks alternated between attend-language and -music conditions, with short rest breaks between blocks that generally lasted 15-20 seconds. The starting order of blocks was counterbalanced between participants and sessions. Each of the two testing sessions took approximately 90 minutes, with an experimental duration of 55 minutes.

**EEG recording and analysis**

EEG was recorded with a 128-channel high density electrode sensor cap, inserted into a NeuroAmp 300 amplifier. Data from the amplifier were coupled with time and event codes from a Windows XP/7 presentation computer with E-Studio Professional 2.0, and is then transferred to a Macintosh computer using Netstation 5.3.0 as the software interface. EEG was recorded at 500Hz using a NeuroAmps 300 amplifier and impedances were reduced below 50kΩ for each electrode (Ferree et al., 2001); an online low-pass filter of 45Hz was used to remove the effects of electrical noise (50Hz in Australia) for monitoring purposes, but full-range data were recorded. Data were then exported from Netstation to Matlab for further processing.

In accordance with recent suggestions for best practice in ERP research (Dien, 2017; Luck & Gaspelin, 2017), data were analysed with a focus on theory- and hypothesis-driven components, single electrodes, and comparisons of interest. This preference is chosen over a more broad analysis strategy in other research (see Fitzroy & Sanders, 2013 for an example), which potentially captures more experimental effects. However, any such findings are argued to be suggestive rather than conclusive findings (Luck & Gaspelin, 2017). In addition, the use of region of interest (ROI) analyses was eschewed in preference for single electrodes, as single electrodes allow for the measurement of the direct peak of brain-electric activity as opposed to a more diffuse waveform (Dien, 2017). Furthermore, the lack of general consensus on which ROIs to use is evidenced by large variations of the size, distribution, and location of the ROIs (see Carrus et al., 2013; Fitzroy & Sanders, 2013 for examples). With individual researchers and EEG companies varying widely in their ROI layout,
which result in inconsistent benefits to the overall signal-to-noise ratio over single electrodes (Dien, 2017), the use of single electrodes was preferred in the current study.

In addition, while the SSIRH may discuss the early components and their interaction (Patel, 2012), these are not a central focus of the study. The P600, in line with best practice (Luck & Gaspelin, 2017), is preferentially examined over the earlier (E)LAN/ERAN components in language and music to syntax manipulations. Experimental design reflects this preference – the use of the PoD, and not word onset, means that the (E)LAN would be drastically attenuated or absent in language ERPs in the current study, which hampers the comparison of (E)LAN and ERAN. Similar sentiments hold true for the word-onset aligned N400 (Sassenhagen et al., 2014). Therefore, the P600 is the only component analysed in the current study, though a diagram of the waveforms of ROI clusters will be included for visual inspection purposes.

Data sets were analysed using Matlab’s EEGLAB plugin (Delorme & Makeig, 2004) alongside ERPLAB, a plugin to EEGLAB (Lopez-Calderon & Luck, 2014). Data was downsampled to 250Hz to facilitate efficient data management. This decision was made based on the distribution of the expected late P600 component, which will not be affected by the reduced temporal resolution of the EEG data. Downsampling is a common practice in EEG literature, where the reduced temporal resolution does not affect the overall expected experimental effects (Tanaka, Watanabe, Maki, Sakriani, & Nakamura, 2019; Ding, Mellon, Zhang, Tian, & Poeppel, 2016; Alday, Schlesewsky, & Bornkessel-Schlesewsky, 2017; Kimppa, Kujala, & Shtyrov, 2016; Sassenhagen & Fiebach, 2019). Each set was then average re-referenced and Kaiser windowed band-pass filtered at 0.4-40Hz. Data were then pruned with ICA using the SASICA plugin (Chaumon, Bishop, & Busch, 2015), removing eyeblink, saccade, and artifactual components. This resulted in a retention of 43.82 components (SD = 9.52), with an average of 85.18 noise-based components removed per participant. This number of components is suitable in analysing brain activity, with certain conditions even allowing for 1.65 components to represent the brain responses of interest (Wessel & Ullsperger, 2011). Each set was then epoched around correct responses (-500 to 1500ms post-PoD). No baseline correction was
employed in the EEG data, as per recent methodological recommendations (Maess, Schröger, & Widmann, 2016) and already implemented in recent research (Brilmayer et al., 2017). In order to further improve signal-to-noise ratio by removing residual artifactual trials, a simple voltage threshold epoch rejection protocol removed trials exceeding ±150µV at any time point over all electrodes.

**ERP analysis**

ERPs were averaged, plotted and analysed using ERPLAB, which is an extension of EEGLAB (Lopez-Calderon & Luck, 2014). Due to changes in latency of the P600 by implementing the PoD, peak amplitudes were analysed in an earlier window compared to previous research (500-800ms post-onset; Sassenhagen et al., 2014). The electrode Pz was analysed to represent responses in the parietal region between 300-500ms post-PoD in both language and music for comparable statistics testing.

**Results**

Distractor errors were removed from the following analyses, as they did not occur at the same point in the progression as the other trials. Additionally, both sessions’ data were collapsed into one data file. This brought the design of data analysed to that of a 2x4 (Domain Attended x Condition). Furthermore, the two sessions of data per participant was collapsed to form a single data file, with independent components analysed across sessions. Overwhelmingly, the components isolated as neural activity were identified as similar across sessions, with the most common session-dependent activity being eyeblink and saccade components. This suggests that the underlying brain activity was similar between sessions, but the way in which people blinked or moved their eyes between trials may have differed between sessions. This would not constitute a theoretically confounding effect on the final dataset, as such blink or saccade components were eventually removed as artifactual (or noisy) activity.

Two participants’ data were rejected on the basis of below-chance performance (<60% for any one category) on the behavioural task for language errors. The final group of 20 comprised ten males, with an average age of 24.5 years (SD = 5.91, range 18-43). Of the accepted datasets, all reported native-level English proficiency. See Table 3.4 of the minimum remaining trials pooled from
all accepted datasets; on average, 1.40% of all trials were removed ($SD = 1.31\%$) due to trial-level noise as outlined in the epoch rejection subsection. This minimises the impact of low trial counts on producing noisy final ERP waveforms.

Table 3.4

Minimum remaining trials by domain attended and condition.

<table>
<thead>
<tr>
<th></th>
<th>Language</th>
<th>Music</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>83</td>
<td>63</td>
</tr>
<tr>
<td>Attended Error</td>
<td>62</td>
<td>58</td>
</tr>
<tr>
<td>Dual Error</td>
<td>60</td>
<td>58</td>
</tr>
<tr>
<td>Unattended Error</td>
<td>78</td>
<td>69</td>
</tr>
</tbody>
</table>

**Behavioural results**

**Reaction time.** RT data were subjected to a 2x4 (Domain Attended, Condition) repeated-measures analysis of variance (ANOVA), with results illustrated in Figure 3.2. The main effect of domain attended was significant, $F(1,19) = 39.84, p < .001, \eta^2 = .11$, indicating that the attend-language conditions ($M=449.56\text{ms}$) were responded to faster than that of attend-music conditions ($M=512.23\text{ms}$). Mauchly’s sphericity was violated for Condition and the interaction of condition and attended domain, so Greenhouse-Geisser corrected values are reported instead. The main effect of condition was significant, $F(3,57) = 5.00, p = .024, \eta^2 = .008$, which indicates that at least one significant differences exists between the domain-collapsed conditions of error-free controls ($M=473.92\text{ms}$), attended errors ($M=487.53\text{ms}$), dual attended and unattended errors ($M=489.60\text{ms}$), and an unattended error ($M=472.54\text{ms}$). There was also a significant interaction of domain attended and condition, $F(3,57) = 23.53, p < .001, \eta^2 = .027$, which suggests that the error-related RT effects (i.e., effect of condition type) were different between the two domains attended. The significant interaction effect compelled further, domain-specific testing.
Figure 3.2. Bar graph of RT averages for each experimental condition, separated by domain attended. Error bars represent +/- 1 standard error of the mean.

Paired sample t-tests clarified the relationships within language attended conditions as necessitated by the interaction effect observed above. Holm-Bonferroni corrected, post hoc paired samples t-tests were used to correct for multiple comparisons, and only the corrected p-values are reported henceforth. Controls were responded to 38.91ms faster than attended errors, \( t(20) = 4.60, p = .001, d = 1.03 \), and 41.82ms faster than dual errors, \( t(19) = 4.38, p = .001, d = 0.98 \). Unattended errors were responded to 47.08ms faster than attended errors, \( t(19) = 4.48, p = .001, d = 1.00 \), and 49.99ms faster than dual errors, \( t(19) = 4.61, p = .001, d = 1.03 \). However, control and unattended RTs were not significantly different from one another, where controls were 8.17ms slower than unattended errors, \( t(19) = 1.86, p = .156, d = .42 \), and neither were attended and dual error RTs, where dual errors were 2.91ms slower on average than attended errors, \( t(19) = 0.55, p = .586, d = .12 \).

Music data showed a different pattern, with no significant effects observed. A difference of 11.7ms slower control compared to attended error trials was not significant, \( t(19) = 1.49, p = .610, d = .33 \), and the controls compared to dual errors generated a non-significant difference of 10.47ms, \( t(19) = 1.40, p = .610, d = .31 \). Unattended errors were not significantly slower than attended errors.
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at 17.09ms slower, \( t(19) = 2.48, p = .130, d = .55 \), and were not significantly slower than dual errors with an average 15.86ms slower RT, \( t(19) = 2.49, p = .130, d = .56 \). Attended and dual errors were not different in RT, where dual errors were 1.23ms slower on average, \( t(19) = .33, p = .740, d = .07 \), and neither were comparisons of controls versus unattended errors, where unattended errors were 5.39ms slower than controls, \( t(19) = 1.19, p = .610, d = .27 \).

Table 3.5

<table>
<thead>
<tr>
<th></th>
<th>Language</th>
<th>Music</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>91.95(3.39)</td>
<td>91.17(6.10)</td>
</tr>
<tr>
<td>Attended Error</td>
<td>89.94(4.05)</td>
<td>90.28(4.19)</td>
</tr>
<tr>
<td>Dual Error</td>
<td>88.06(5.28)</td>
<td>90.29(4.37)</td>
</tr>
<tr>
<td>Unattended Error</td>
<td>91.35(5.22)</td>
<td>91.68(6.56)</td>
</tr>
</tbody>
</table>

Accuray. Accuracy descriptive statistics are outlined in Table 3.5. A two-way repeated measures ANOVA revealed that the main effect of attend-domain was not significant, \( F(1,19) = .15, p = .698, \eta^2 = .001 \). This suggests that there were relatively similar accuracies between the language- \((M=90.33\%)\) and music-attended \((M=90.85\%)\) accuracy. Sphericity was violated for mean and interaction effects, and so Greenhouse-Geisser corrections were applied to \( p \)-values. There was no significant main effect of condition, \( F(3,57) = 2.49, p = .102, \eta^2 = .021 \), which indicated that control \((M=91.56\%)\), attended error \((M=90.11\%)\), dual errors \((M=89.18\%)\), and unattended errors \((M=91.51\%)\) did not differ on task accuracy. Lastly, the interaction between domain attended and condition was not significant, \( F(3,57) = 1.23, p = .303 \), \eta^2 = .006 \), which indicates that there were no significant differences between the pattern of results seen in language and music.
Figure 3.3. Grand average ERPs at nine regions of interest (ROIs) for attend-language conditions. ROIs are zoned according to the scalp map.
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Figure 3.4. Grand average ERPs at nine regions of interest (ROIs) for attend-music conditions. ROIs are zoned according to the scalp map.
After inspection of the overall brain responses over the scalp, which can be categorised into regions of interest (ROIs; see Figure 3.3 and 3.4), the middle parietal region and specifically the Pz midline electrode was identified as the best candidate for further analysis. The parietal scalp electrode, or Pz, was selected for ERP analysis (see Figure 3.5) as the P600 typically occurs in the parietal region (Molinaro et al., 2011; Patel et al., 1998) and also because the P600 effects appeared to centre around the middle parietal region in the data presented here. Additionally, visual representation of the difference waves of control waveforms subtracted from the error conditions show the topographical distribution of the syntax-related effects in the time window of interest (300-500ms post-PoD) in the form of a scalp map (see Figure 3.6) – a posterior positive electrical enhancement in the parietal region occurs in both domains. A two-way repeated-measures ANOVA was conducted
to examine the effects of domain attended (language, music) and condition (control, attended error, dual error, unattended error) on the P600 amplitude.

There was an overall main effect of condition, $F(3, 57) = 11.66, p < .001, \eta^2 = .05$, which suggests that there were significant differences between controls ($M=0.556\mu V$), attended errors ($M=0.994\mu V$), dual errors ($M=0.927\mu V$), and unattended errors ($M=0.420\mu V$). There was no main effect of domain attended, $F(1,19) = 0.77, p = .390, \eta^2 = .003$, which indicates that language and music P600 mean amplitudes collapsed over conditions do not differ overall from language ($M=0.784\mu V$) to music ($M=0.665\mu V$). Lastly, there was no significant interaction between language and music experimental conditions, $F(3,57) = 0.62, p = .607, \eta^2 = .002$. Overall, the pattern of results indicates that there is a significant effect of the experimental conditions that did not interact or differ between conditions, and the conditions were thus collapsed across domains attended and subject to a post hoc comparison using Holm-Bonferroni adjusted paired-sample t-tests.

P600 amplitudes were significantly higher in attended errors than controls with a difference of $0.438\mu V, t(39) = 3.33, p = .006, d = .25$, and P600 amplitudes for dual errors were significantly higher in than controls with a difference of $0.371\mu V, t(39) = 3.58, p = .004, d = .21$, but P600 amplitudes were not significantly higher in attended compared to dual errors with a difference of $0.068\mu V, t(39) = .68, p = .503, d = .037$. Unattended error P600 amplitudes were not significantly lower in amplitude to controls with a difference of $0.136\mu V, t(39) = 1.60, p = .237, d = .08$, but unattended error P600 amplitudes were significantly lower in P600 amplitude compared to attended errors with a difference of $0.574\mu V, t(39) = 5.35, p < .001, d = .34$, and dual errors, $t(39) = 4.78, p < .001, d = .30$. 
Figure 3.6. Electrophysiological responses. ERP waveforms for language- and music-attend conditions at the parietal electrode. Below each ERP are syntax condition minus control (difference) scalp maps for attended, dual, and unattended errors.
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Discussion

The findings of the current experiment supported predictions of the utility of the P600 response in the ERP as reflecting shared syntax violation processing costs in language and music, as claimed in the SSIRH (Patel, 2012). Previous research had suggested behavioural processing costs for both attended and unattended syntax violations in language and music (Fedorenko et al., 2009; Slevc et al., 2009), but also P600 lacking effects for unattended syntax violations (Batterink & Neville, 2013; Brattico et al., 2006; Schacht et al., 2014). This difference in P600 attention-dependence versus task performance led to the prediction that there would be a divergence of P600 and behavioural results – behavioural measures of RT and task accuracy were expected to reflect the increased processing cost of attended and unattended syntax violations in language and music, whereas P600 effects were expected only for attended, but not unattended violations. Finding a P600 effect alongside behavioural effects of RT or accuracy would provide support for the P600 as a suitable ERP correlate of syntax processing cost. Furthermore, the patterns of P600 and behavioural measures were predicted to be similar across attend-language and attend-music conditions (by domain), as a similar syntax processing resource is postulated in the SSIRH (Patel, 2012).

Results showed that only attended syntax errors in either domain produced increases of P600 amplitude, which were less reliably reflected in RT for attended language but not music syntax violations, and did not decrease task accuracy for either domain. As such, the similarity and reliability of P600 amplitude increases across language and music syntax errors provides support for shared resources in language and music, as claimed in the SSIRH (Patel, 2012).

Increases in P600 amplitude were similarly elicited in both domains attended for an attended error or a dual error, which contained an attended alongside an unattended error. However, RT differences were somewhat different with language attended RTs increasing to an attended or dual error, but not an unattended error, whereas music attended RTs showed no significant differences between conditions. P600 amplitude increases and RT effects were no different between attended and dual error conditions within each domain. This lack of a P600 or RT variation following an unattended
error indicates that the presence of an unattended error provided no additional electrophysiologically or behaviourally expressed processing cost. As task accuracy did not vary between conditions or domains, it was not discussed further.

The pattern of results in the current study support the claims in the SSIRH of P600 being reflective of syntax processing by a shared language-music resource (Patel, 2012). While earlier behavioural research (Fedorenko et al., 2009; Slevc et al., 2009) suggested that the attention-dependent P600 (Batterink & Neville, 2013) would be inadequate to capture unattended syntax error effects on an attended syntax task, the findings in the current study suggest that the P600 component is useful in indexing syntactic processing cost at the cortical level – it demonstrates sensitivity to the same errors that behavioural measurements may miss, especially when attending to music. Further work must be done to examine the effects to musical syntax errors using RT to understand why the P600 amplitude-increasing attended music syntax violations failed to produce RT increases as in language attended errors. The dissimilarity in the pattern of results between behavioural and P600 effects across domains indicates that P600 amplitude change is better able to reliably measure processing costs incurred for language and music syntax violations, with RT showing a lack of sensitivity to changing with music syntax errors in particular. The findings in the current study therefore support the claims of P600 being a useful index of syntactic shared resources being recruited similarly in language and music (Patel, 2012), demonstrating the ability of P600 amplitude change to coincide with relevant attended syntax violations in either domain attended.

Unexpectedly, the behavioural and electrophysiological data from both domains suggested that syntax-related processing costs were attention-dependent in the current study. This attention-dependence of RT effects in language attended conditions is in contrast to findings in earlier literature (Slevc et al., 2009), which showed significant interactions of attended language syntax violations with unattended musical syntax violations. The findings in the current study suggest that the syntax interactions of selectively-attended language and music are attention-dependent under certain conditions as specified here, with music attended RTs even showing no measurement of processing
costs incurred to attended or unattended syntax violations. Behavioural attention-independence may be related to the demographic differences in the previous study (Slevc et al., 2009) – musically-trained individuals comprised half their experimental sample, and may have contributed to the overall effects seen in that study’s observed reading time interactions of attended language and unattended music. Another study that showed behavioural interactions of attended and unattended syntax did not report musical expertise in their participant information (Fedorenko et al., 2009).

Earlier research suggested that decision-based rather than pure perceptual factors may be influenced by musical expertise (Besson & Faita, 1995; Zioga et al., 2016), which may therefore affect P600 processes that depend on active decisional processing to elicit as in the current study’s task. Expertise-dependent processing of musical stimuli may be the prerequisite for combinatory effects with language syntax violations when one is attended and the other unattended. Regardless, the current study showed an interesting lack of syntax-related RT change to music-attended or unattended language errors. The lack of RT effects in attend-music conditions in the current study appears to obscure the effects of processing an attended syntax violation as observable at the electrophysiological level, where P600 amplitude increases to attended music syntax violations are evident. In contrast, attend-language syntax violations resulted in an increase of RT relative to error-free controls, which is reflected at the electrophysiological level through P600 amplitude increases to attended language errors.

Aside from an account based on musical expertise, the lack of attention-independent processing of unattended syntax violations despite being behaviourally measured in previous research (Fedorenko et al., 2009) may be attributable to the effects of task demand. Related previous research has shown that an engaging attended task may decrease the effects of distractors on P600 amplitude change and task performance (Causse, Peysakhovich, & Fabre, 2016). This might be a possible explanation why the current study was not able to observe the combinatory effects of syntax errors when they co-occur – the attended task was challenging enough to demand resources that might otherwise be employed to process an unattended syntax error.
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Previous research had employed a dually attended task in language and music to find interactions of ERP components for language and music (Steinbeis & Koelsch, 2007). The music automatic response to syntax errors, the ERAN, was reduced in amplitude when music errors were presented with a language syntax error. The amplitude of a later music component, the N500, was reduced only when music errors were presented with a language semantic error; language syntax errors had no significant effect on the N500. This observation of two ERP amplitude interactions with music and language syntax errors leads to the idea that interactions are possible under certain task conditions. However, an earlier study by Koelsch and colleagues (2005) demonstrated that the LAN was reduced in amplitude when a concurrent music syntax error was presented alongside a language syntax error. This was despite the study instructions being to ignore the music stimuli altogether and decide if the language was syntactically correct or not. In this case, ERP measures of the interactivity of language and music syntax were detectable despite the lack of attention on the music stimuli altogether. Both studies outlined here lead to the conclusion that language and music can interact at the electrophysiological level despite a lack of attention paid on one domain. Such a statement would initially seem to challenge the findings we have found here as anomalous.

However, it is important to note that both studies did not measure or analyse the P600 component, which is featured in the current study. The attention-dependence of the P600 component in previous research (Schacht et al., 2014) supports the current study’s findings. The current study extends our understanding of the P600 component by directly comparing attention-dependence across domains of language and music. This is particularly relevant because previous research analysing earlier components has found attention-independent interactions of the LAN/ERAN. In our analysis, we found that P600 does not behave in such a way across language and music; P600 amplitudes increased when an attended syntax error was encountered, not an unattended error. Furthermore, the data in the current study demonstrated that P600 amplitudes remained similar, whether in cases of a single attended syntax error, or in cases of a single attended error alongside a single unattended error. The interaction of language-music syntax at the P600 component is therefore dependent on attention
to occur, if at all – the current study was unable to find such interactions either at the behavioural or the electrophysiological level.

Design limitations of trial counts in the current study did not allow for a dually-attended simultaneous language and music syntactic violation. Future research could examine the existence of a dual language-music error effect under simultaneously-attended conditions. For example, if using the same design and stimuli as the current study, the proposed shared syntactic resource as in the SSIRH (Patel, 2012) should, in the case of dually attended language and music syntax violations, predict increases of P600 amplitude and of RT delays in dual errors above that found in single attended errors in either language or music. This would provide evidence that P600 reflects the combined demand of co-occurring language and music syntax errors as they are processed simultaneously.

In summary, the current study validated the utility of the P600 component in indexing syntax-related processing cost where attend-music behavioural measures of RT and accuracy failed to capture significant differences between conditions. This was particularly important in the light of behavioural research showing the effects of unattended music syntax violations on attended language processing (Fedorenko et al., 2009; Slevc et al., 2009), which suggested that the attention-dependent P600 (Batterink & Neville, 2013) was not adequately sensitive to the effects of unattended syntax violations. Additionally, no direct comparison of P600 amplitude change had yet been made alongside behavioural measures of RT or task accuracy in the same experiment. The present study found that P600 amplitude increases coincided only with attended syntax violations in both language and music, not unattended violations. Additionally, RT effects showed differentiated language and music results – attend-language RTs to attended syntax errors were significantly increased, whether presented with an unattended music error-free control or with an unattended music syntax violation, whereas attend-music RTs were not significantly different across all conditions.

The comparison of P600 alongside behavioural effects supports a view of P600 as a useful electrophysiological correlate of processing cost incurred to syntactic violations in both language and
music, as well as reflective of shared syntax resources in language and music that are recruited similarly in the presence of an attended syntax violation (Patel, 2012).

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4. EXPERIMENT 3

4.1. Preliminary introduction: Linking Experiment 2 and 3

In line with the predictions as outlined by the SSIRH about shared resources between language and music, Experiment 2 showed that P600 amplitude increased only to attended errors in both domains – attend-language and -music conditions showed strong similarities in terms of the amplitude change associated with an attended syntax error. However, only language attended syntax violations were correlated with increased RTs relative to controls, whereas attend-music conditions lacked any group differences in RT. Unattended syntax violations in both attend-language and attend-music conditions produced no additional P600 amplitude change, RT increase, or task accuracy decrease relative to controls. This pattern of results is in line with electrophysiologic evidence on the P600 (Batterink & Neville, 2013), and helps resolve the differences seen in the electrophysiologic and behavioural literature. Specifically, attention appears to be important in allocating cognitive resources to relevant events in syntax (Causse et al., 2016) and in simpler tasks (Polich, 2007), and reflects a similarity of P600 and P3b in that regard.

These findings of P600 and RT attention-dependence have implications for future research. We may have created unique conditions under which an unattended syntax stimulus is unable to significantly affect RT or P600 in either language or music, conditions which are therefore qualitatively different from that of previous research in the behavioural space that has suggested language and unattended music syntax processing interactions (Fedorenko et al., 2009; Slevc et al., 2009). The attended syntax task in Experiment 2 was one of the methodological differences between previous work and the present program of research, which resulted in increased attentional resources needed to perform well in the primary task. This has documented effects on attenuating the electrophysiologic response to secondary or unattended tasks in the P3b (Polich, 2007) and recently in the P600 literature (Causse et al., 2016), and may suggest that previous research demonstrating syntax interaction of attended and unattended syntax may indeed be the product of a low attentional demand of the primary task, which allows for reallocation of unused attentional resources to process...
unattended syntax violations. Such a reallocation process would, in effect, allow for a secondary or unattended task to be fully processed as if it were the primary, with corresponding electrophysiological responses as a result.

The findings of Experiment 2 therefore point to the need to examine simultaneously presented language and music under dually attended conditions. Task-related effects have had documented effects on the P600 component (Causse et al., 2016), which suggests that increased cognitive load may well affect P600-related brain activity. A future experiment following from Experiment 2 could focus on the effects of that workload on the relationships between language and music syntax. By changing the task demand of Experiment 2, we can create a new task with double the task load (processing language and music for errors simultaneously) and an identical sensory load (with the same stimuli in both Experiment 2 and 3).

In Experiment 2, selectively-attended syntax streams of language and music produced behavioural (RT) and electrophysiological (EEG) effects to syntax violations, whereas unattended syntax violations did not produce significant changes to either behaviour or brain response. With the active processing of syntax in both domains, one prediction from the findings in Experiment 2 is that Experiment 3 would show corresponding increases in P600 amplitude and RT to single errors in either language or music over the error-free control condition. However, in addition to this finding we should also see combinatory increases of P600 amplitude and RT to dual errors over single errors, in contrast to the selectively-attended stimuli in Experiment 2. The emergence of unique dual error effects in Experiment 3 would demonstrate a hypothesised combinatory effect of syntax processing as the proposed shared syntactic integration resource is dually taxed (Patel, 2012).
References


4.2. Interactive syntax: Combined cost of simultaneous errors in language and music

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Abstract

Claims in the Shared Syntax Integration Resource Hypothesis (SSIRH; Patel, 2012) outline a common resource underlying language and music syntax processing, and that the P600 component of the event-related potential (ERP) reflects this shared resource. Simultaneously presented and attended syntax errors in language and music are predicted to produce combinatory effects on P600 amplitude and RT increases, or accuracy decreases, greater in effect than that of a single error. The current study collected behavioural and P600 data in a repeated measures design with Condition (Control, Language Error, Music Error, Dual Error, Distractor Error). Participants (N=22) listened to 400 auditory sequences of seven simultaneously-played words and chords and pressed one of three buttons to indicate an error-free control, a single error (language or music), or a dual error. P600 amplitudes and RTs showed significant increases alongside a decrease in task accuracy for dual errors over single errors. Single errors had similar effects across language and music and produced significantly higher P600 amplitudes and RTs than controls, however task accuracy was not different from controls. P600 topography also shifted to a central instead of the typical parietal maximum. The confirmation of hypothesised combinatory P600 alongside RT effects in dual syntax errors in language and music supports the SSIRH, and supports a view of the P600 as an index of syntax-related processing cost across language and music.

*Keywords: EEG, P600, syntax, SSIRH, music, language*
Introduction

Syntax refers to a set of structural rules that underpin complex content such as language and music (Patel, 2012), with language employing syntactic rules in morphology (Sassenhagen et al., 2014), verb forms (Shen et al., 2013), and number agreement (Balconi & Pozzoli, 2005). Musical rules of harmonic syntax can be violated by introducing a chord that does not belong with the musical key of the surrounding tonal context (Krumhansl & Cuddy, 2010), whether as a chord (Koelsch, Gunter, Wittfoth, & Sammler, 2005; Steinbeis & Koelsch, 2008), or melody (Carrus et al., 2013; Fedorenko et al., 2009). When language and music syntax is violated, the brain responds with cortical activations that can be measured using electroencephalography (EEG), and averaged over many trials to form the components that comprise the event-related potential (ERP). Syntax violations generate early and automatic ERP components in language and music (Koelsch et al., 2005; Maidhof & Koelsch, 2011). Furthermore, a later brain response appears to occur similarly in language and music known as the P600 (Osterhout & Holcomb, 1993; Patel et al., 1998). A comparison of the language and music P600 components reveals that they are similar; early research in the area shows that they are not different from one another in terms of latency, distribution, or amplitude (Patel et al., 1998). This is in contrast to the earlier automatic components for language and music, which happen in opposite hemispheres in the temporal lobes, with the language response being generally left-lateralised and the music response generally right-lateralised (Carrus et al., 2013; Koelsch et al., 2005); though notable exceptions of a left-lateralised early component in music exist (Maess et al., 2001). However, these components do not simply occur in isolation with no interaction; in conditions where both an attended language and an unattended music error are present, there is an attenuation of the early language response (Koelsch et al., 2005). There is therefore an interactive nature of early brain responses to syntax. Syntax violations also result in behavioural costs as the brain integrates the error into its preceding context (Kunert et al., 2008).
COMBINED COST OF SIMULTANEOUS ERRORS

2016; Sleve et al., 2009). Task-related reaction time is slowed, which indicates an increased difficulty of response and compensatory slowing to maintain accuracy (Sleve et al., 2009), and the accuracy of comprehending a sentence may also be negatively impacted as the individual attempts to integrate the stimulus back into its syntactic context (Fedorenko et al., 2009).

The similar brain responses in language and music (Patel et al., 1998), as well as the interaction of language and music on subsequent responses have given rise to the shared syntactic integration resource hypothesis (SSIRH; Patel, 2012), which states that there are a) distinct representational neural networks underlying syntax in language or music likely situated in either hemisphere, and b) a syntax-specific, cognitive resource shared between language and music. In the SSIRH, the recruitment of the latter-described shared syntax resource is claimed to be correlated with the P600 component, where P600 is elicited as a positive brain-electric response centred around the medial parietal region of the scalp (Patel et al., 1998). P600 is correlated to the engagement of attention-dependent syntax processing, which disappears when attention is taken away from the syntax form of the content (Batterink & Neville, 2013; Schacht et al., 2014). Yet, the processing of syntax is important enough to language comprehension that P600s to syntactic violations are the first observable responses to syntax violations when a language is first learned (Mueller, Hahne, Fujii, & Friederici, 2005), and can be elicited when attending but not responding to language syntax violations (Balconi & Pozzoli, 2005). Moreover, syntax of a variety of forms elicit P600 effects, whether in morphology (Sassenhagen et al., 2014), number agreement (Shen et al., 2013), melody (Carrus et al., 2013) and harmony (Featherstone, Waterman, & Morrison, 2012). Syntax is therefore an important aspect of language and music perception, and P600 effects regularly correlate to manipulations of syntax that deviate from an expected form in language and music.

SSIRH’s claims of shared syntax processing have generated research into the shared nature of this resource, with various studies pursuing experimental designs with separately
presented language and music stimuli (Fitzroy & Sanders, 2013; Patel et al., 1998), as well as simultaneously presented language and music (Carrus et al., 2013; Fedorenko et al., 2009; Kunert et al., 2016; Maidhof & Koelsch, 2011; Perruchet & Poulin-Charronnat, 2013; Slevc et al., 2009; Steinbeis & Koelsch, 2007). Tasks range from attending to the syntax specifically (Koelsch et al., 2005), to deciding on sentence acceptability (Carrus et al., 2013), to attending to the timbre of a syntax-violated language or music stimulus (Maidhof & Koelsch, 2011; Steinbeis & Koelsch, 2007), or an attended variable-pitch tone with an attended but offline-responded sentence (Batterink & Neville, 2013), and comprehending the global meaning of the progression (Fedorenko et al., 2009; Slevc et al., 2009). In a majority of these cases, there was an interaction of syntax processing in language and music that produced either a behavioural cost (Fedorenko et al., 2009; Slevc et al., 2009), or an early brain response interaction and attenuation (Carrus et al., 2013; Koelsch et al., 2005; Maidhof & Koelsch, 2011; Steinbeis & Koelsch, 2008). Even by looking at the behavioural and early electrophysiological brain responses, there seems to therefore be strong evidence of a syntax interaction between language and music, which supports the claims of the SSIRH (Patel, 2012).

One of the crucial, but under-researched elements of the language-music interaction is the effect of simultaneous attended syntax errors on the later brain response, the P600. The majority of earlier work has focused on the automatic, attention-independent components of the brain response, which is also the bulk of electrophysiological evidence for the SSIRH (Patel, 2012). However, later components are often correlated to the processing of meaning in language and music (N400 and N500; Steinbeis & Koelsch, 2007) and to effortful syntax processing (P600; Sassenhagen et al., 2014). There has not yet been a published study that examines the P600 interaction of syntax between language and music. In addition, the electrophysiological processes underlying syntax are crucial to understanding the delays of processing speed (Slevc et al., 2009) and reduced comprehension accuracy (Fedorenko et al.,
2009) seen in behavioural research, where syntax violations in language and music are presented simultaneously. A hypothesised shared syntax resource would therefore encounter competing simultaneous demands under such a situation, and generate increased electrophysiological responses as the result of that increased simultaneous demand. If the recruitment of P600-related cortical resources are meant to reflect shared syntax resources (Patel, 2012), then P600 effects should accompany the observed interactions seen in previous behavioural research (Fedorenko et al., 2009; Slevc et al., 2009). More recent behavioural work has shown interacting, but distinct effects of language and music syntax processing (Roncaglia-Denissen et al., 2018). This latter study collected reaction times (RTs) as well as task accuracy in musicians and non-musicians, with either a selective-attention or dual-attention design on language, music, or both. Dual errors or no error at all generated more accurate responses across groups, and single errors were least accurately responded to. The authors argued that syntactic congruity, or the presence of simultaneously correct or erroneous syntax facilitates accurate responses in a dually-attended condition. This effect was observable whether in a music-attend or dual-attend condition, but not in a language-attend condition (Roncaglia-Denissen et al., 2018), and was proposed as evidence of shared decision making resources rather than a syntax-specific shared resource between language and music. Attention-based differences in the effects seen in behavioural task performance suggest that prior evidence of interference effects of an unattended music on attended language task (Slevc et al., 2009) may not automatically be assumed to occur in unattended language syntax violation effects on attended music, and vice versa (Roncaglia-Denissen et al., 2018). The previously-unseen syntactic congruency effects in this recent study (Roncaglia-Denissen et al., 2018) provide contradictory evidence against the SSIRH, which would claim that simultaneously presented syntax errors in language and music would doubly tax the proposed shared syntax resource (Patel, 2012). Predictions based on the SSIRH would be of worse performance in dual errors compared to single errors,
but this was not the case (Roncaglia-Denissen et al., 2018). The behavioural data from this study (Roncaglia-Denissen et al., 2018) have made even more ambiguous the effect of simultaneously attended syntax violations in language and music on the P600 component, especially as it is claimed in the SSIRH to reflect recruitment of shared syntax integration resources (Patel, 2012). A study incorporating both behavioural and electrophysiological responses would tie in the role of ERP measures of brain activity with behavioural performance. Relating electrophysiology to behavioural effects would help provide evidence for a functional co-occurrence between the P600 and RT, for example, and help clarify the implications of amplitude, latency, and topographical change for the P600 component within the ERP.

In a recent narrative review, it was suggested that active or attended processing may be a crucial prerequisite for any proposed shared processing mechanisms (Slevc & Okada, 2015). However, previous EEG research has not consistently applied an active syntax processing task in examining the interplay of syntax violations between language and music. Instead, previous work has focused on either a passive syntax task, with an active timbre task (Maidhof & Koelsch, 2011; Steinbeis & Koelsch, 2007), attending only language but not music (Carrus et al., 2013; Fedorenko et al., 2009; Koelsch et al., 2005), or a selective-attended timbre task that focused on language or music, but not both (Maidhof & Koelsch, 2011). There may not even be an overt task at all (Carrus et al., 2011). Interestingly, only one EEG study has utilised an active syntax processing task examining unattended music syntax effects on attended language syntax effects (Koelsch et al., 2005), and found that an unattended musical syntax violation elicited a P600 effect. An unattended syntax error generally does not elicit P600 effects in the majority of past research (Batterink & Neville, 2013; Brattico et al., 2006; Schacht et al., 2014). This means that the P600 may not be fully understood with regard to attention-dependence, but especially so in the case where language and music syntax violations have been presented and
attended simultaneously. The importance of active syntax processing in recruiting shared resources in language and music (Jung et al., 2015), the reliance on attention for P600-related effects (Brattico et al., 2006; Schacht et al., 2014), and the claims of P600 effects being reflective of shared syntax processes in the SSIRH (Patel, 2012) all indicate that conducting an experiment utilising active syntax processing and eliciting the P600 effect under conditions of simultaneously-presented language and music syntax violations could demonstrate the behaviour of these proposed shared resources when competing syntax demands are imposed in language and music.

New research could fill in a gap in the literature by examining the attention-dependent processes of online syntax comprehension, specifically the late P600 component in the ERP that has been less well-documented in its response to simultaneously presented syntax errors. The SSIRH proposes shared cognitive resource being employed similarly in a linguistic or musical context – these resources are being recruited in order to integrate a given error (Patel, 2012). The literature so far has found similar effects of neural recruitment, whether it is in language or music (Patel et al., 1998). Simultaneous errors in language and music should therefore lead to the previously documented reductions in comprehension accuracy (Fedorenko et al., 2009) and reading time (Slevc et al., 2009) at the behavioural level, but should additionally be reflected in the P600 component as well. If the claims in the SSIRH are true (Patel, 2012) of shared syntax resource recruitment being reflected through P600 effects, then it will be possible to see simultaneous demand of language and music syntax violations producing combinatory effects of P600 amplitude change. P600 amplitude increases in this dual error condition will be over and above that seen in single errors in either language or music syntax, and accompany behavioural processing costs that result in reduced task accuracy or increased RT.
The aim of this study is therefore to investigate the proposed interactive behaviour of simultaneously attended language and music syntax processing at the electrophysiological level, as put forth by the SSIRH. Specifically, it will examine whether it is possible to observe a combinatory effect of the P600 response to syntax errors in language and music, especially when they occur at the same time. Previous evidence suggests that this dual error interaction produces a behavioural cost over and above a single error (Fedorenko et al., 2009), and the SSIRH’s second principle of shared resources (Patel, 2012) suggests that electrophysiological measures of syntax-related processing to dual errors (as indexed by the P600) will be amplified relative to single errors; additional cognitive cost of integrating an error would be reflected in increased neural activity. Using a combined behavioural-EEG paradigm, participants will be simultaneously presented with language and music sequences. Syntactic violations could occur in either language or music, both at the same time, or have no error at all. By attending to both language and music stimuli, participants will then make a decision on the syntactic correctness of both sequences. The similarities of P600 effects to syntax violations in language and music (Patel et al., 1998) lead to the prediction that P600 will be increased in amplitude similarly in single errors to language and music, relative to error-free control trials. However, increased deviance of a simultaneously-attended dual error would require even more shared syntax resources to process, leading to the prediction that dual errors would produce greater P600 effects than that of single errors in either domain. It is also expected that behavioural measures of syntactic violations processing cost would be reflected in RT and task accuracy, with a pattern of increased RTs and diminished task accuracy of single language or music syntax errors versus controls. In a similar way to the P600 effects, dual errors would require greater shared resource recruitment to process, which will result in greater RT and accuracy effects of dual errors compared to single errors. In doing so, the predictions of a shared syntax resource being recruited to process dual errors would be observable at both the behavioural and
electrophysiological level, as RT or accuracy and P600 reflect greater syntax processing cost to combined syntactic violations. Establishing a correlated pattern of behavioural and electrophysiological cost to single errors over controls, and of dual errors over single errors would validate the claims in the SSIRH of the P600 being an index of shared language and music syntax resources (Patel, 2012).

Methods

Participants

The participants were a convenience sample of 28 self-reported right-handed native English speakers from Murdoch University’s South Street campus in Perth, Western Australia. Right handers were chosen so as to maximise a strong P600 response – left handers are more susceptible to producing N400-dominant responses to syntax violations (Grey et al., 2017). Participants were 18-60 years old to minimise age-related effects on the P600, even though P600 did not change in amplitude or latency past that age. The 60 year age bracket was thus chosen as a precaution nonetheless (Faustmann et al., 2007). In addition, participants spoke English natively, primarily listened to Western tonal music (pop, blues, jazz, classical music) and were not formally musically trained in the last ten years; formal training was defined as private, one-on-one music lessons. For accepted participants, the average prior training was 0.95 years ($SD = 1.68$ years). Participants had self-reported normal hearing and normal or corrected-to-normal vision, self-reported being neurologically healthy, and were not on medication affecting the nervous system. Lastly, participants were advised to not consume substances affecting the nervous system 24 hours prior to participating, with the exception of caffeine (one hour before participating). All information was obtained through a screening questionnaire.
Participants recruited from the Murdoch University Research Participant Portal received course credit for participation, whereas personal contacts in the general public or students opting out of the course credit received an entry into a raffle for a pair of movie tickets.

**Design**

The experiment was a single factor, repeated-measures syntax condition (Control, Language Error, Dual Error, Music Error, and Distractor Error) design. The collected measures were behavioural accuracy, RT, and the P600 component of the ERP.

**Stimuli**

Table 4.1

*Trial counts by experimental condition*

<table>
<thead>
<tr>
<th>Condition</th>
<th>Number of Trials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>100</td>
</tr>
<tr>
<td>Language Error</td>
<td>90</td>
</tr>
<tr>
<td>Music Error</td>
<td>90</td>
</tr>
<tr>
<td>Dual Error</td>
<td>80</td>
</tr>
<tr>
<td>Distractor Error</td>
<td>40</td>
</tr>
</tbody>
</table>

Stimuli (see Table 4.1 for trial counts) were presented in simultaneous language-music, seven-element sequences. An online repository of sample stimuli used can be accessed at the following link: [https://tinyurl.com/y3k2cvd8](https://tinyurl.com/y3k2cvd8). The use of seven-element sequences was decided on based on the sentence structure, which was the minimum number of words required to produce a sentence with a subject-verb-object ordering. This would make a sentence stem that can be manipulated to violate language syntax within a single trial. The musical chord sequences were created in order to match the seven-word sentences, using chords played within the same tonality to establish a syntactic context in a single trial. Music chord progressions in previous research has shown that two- (Sammler, Novembre, Koelsch, & Keller, 2013) and
five-chord (Sammler et al., 2013; Steinbeis & Koelsch, 2007) sequences have been successfully employed to generate behavioural and ERP effects.

Categories are as follows for each condition: a) control sequences, with no syntactic violations, b) language syntactic error sequences, where the sentence-final critical word violates number agreement, c) music syntactic error sequences, where the domain produces a violation of harmonic agreement, d) dual syntactic error sequences, where language and music syntax violations are presented at the same time, and e) distractor error sequences, where the sequence contains a number or harmonic violation in the middle of the progression. A total of 400 trials were created, with 200 language and music progressions that would then produce 200 progressions with a syntactic violation in either language, music, or both.

**Language.** All language sequences were auditorily presented with a fixed inter-onset-interval (IOI) between words, each containing contained a subject-verb-object progression (see Table 4.2). Syntactic sequences had a number agreement (or noun plurality) error on the sentence-final critical word, and distractor sequences had a verb conjugation error on the fourth word. Distractors were infrequently presented to minimise the possibility of participants fixating on the final elements of the progression without processing the sentential context. Number agreement grammatical errors have produced a P600 response in previous research (Shen et al., 2013). Violations had no prior cue earlier in the sequence, which means that participants could not anticipate the onset of a deviant. Furthermore, sentence stems were just as likely to be correct following a singular (‘that’, ‘this’) or a plural (‘these’, ‘those’) penultimate word – this ensured each trial’s critical word was not predictable in its correctness prior to the presentation of the word itself.

Critical sentence-ending words were required to have no homophones, be between one and three syllables long, and chosen to that critical word syntactic deviance was only perceptible at the end of the word ("those laws", critical word underlined), where a measurable
point of deviance (PoD) could be marked at the point where the plurality ("s") would dictate the word’s numeric agreement with the context. The PoD was first defined by the authors of the current study, then independently defined by two additional confederates unrelated to the current study. Any differences in the PoD between the three definitions are checked and revised where necessary. The penultimate word in the example stimuli in Table 4.2 ("those" to "that") was manipulated similarly across each sentence to make the sentence-final critical word physically identical across all conditions, thereby controlling for acoustic differences of the critical word ERPs. 200 language stems were created, which produced all syntax violation stimuli. Control stems were kept unique from the violation stems in two different iterations of the stimulus set, where 100 error-free stems in one version were converted into syntax violations for the other version, and vice versa.

All language stimuli were recorded in an acoustically isolated studio, with a trained sound engineer recording the material. A condenser microphone with a pop filter was applied to ensure no fricatives were overly disruptive to sound quality. Sentences were read out as full error-free control materials – words were pronounced to a metronome that was played to the English speaker through headphones, with words spaced to have an inter-onset-interval of 600 milliseconds (or at 100 beats per minute). After this process, multiple versions of deviant penultimate words were separately recorded. Material were recorded in full raw format, then compressed to 16-bit WAV files for further processing.

Deviant trial stimuli were then created by replacing the penultimate word of a control trial with an erroneous word. These were matched by overall pronunciation of the sentence so as to not sound anomalous to the listener. Words were then tempo-locked to the 600 milliseconds interval stipulated earlier, as pronunciations of the words were not precisely timed enough. This ensured that word onsets were 600 milliseconds apart. Words were then normalised at the software level across sound files and tracks, and were presented at a
comfortable volume through the experimental computer’s headphones. As sound file presentation varies significantly with prosody, a measured decibel level for actual experimental tracks would not be particularly informative. This is why software normalisation, then consistent stimulus presentation volume levels were implemented instead.

Table 4.2

<table>
<thead>
<tr>
<th>Condition</th>
<th>Sequence position</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>The judge is reading out those laws.</td>
</tr>
<tr>
<td>Syntactic</td>
<td>The judge is reading out <em>that</em> laws.</td>
</tr>
<tr>
<td>Distractor</td>
<td>The judge is <em>read</em> out those laws.</td>
</tr>
</tbody>
</table>

*Note. Underlined, bolded, italicised are the critical points of deviance in each condition.*

**Music.** The musical stimuli were sequences of seven triad chords, each chord comprising three notes arranged in root position. Table 4.3 depicts an example chord sequence varied by experimental condition. Syntactic violations were created by replacing the musical context with a sequence from a musically distant tonality, based on the manipulations used in previous research that successfully elicited P600 effects (Patel et al., 1998). A sequence-final C Major chord, therefore, would be preceded by a sequence based on B Major tonality. This replacement of the musical progression preceding the final chord ensures that any differences in ERP measurements are due to the syntactic manipulation, not based on acoustic differences. The distractor errors were similar in the nature of harmonic violations seen in the progression-ending chords but were introduced in the fourth chord (middle) of the sequence in order to encourage attentional allocation to the entire sequence, not simply the endings. B Major-ending progressions were replaced with C Major chords respectively, and vice versa. A similar manipulation of chord progressions was made for E Major and F Major progressions. The use
of these four tonalities produced a total of 192 unique progressions of 48 each tonality. To produce the 200 musical progressions required to match with the language stimuli, two progressions from each tonality (B, C, E, and F Major) were randomly selected to be repeated. These 200 stems were split into two batches of 100 each, where control stems were switched into syntax violation stems (and vice versa) for alternating participants.

In order to match the language stimuli, chords were created using a MIDI chord creator and saved as WAV files. These were then edited to have 600ms intervals, matching the language stimuli. The chords were then matched for loudness by software normalisation alongside the language stimuli, reduced in volume if the consistent nature of musical chords led to an overall subjectively louder perception of music, then exported to the experimental computer and played at the same level as the language stimuli were. This ensured that the most consistent conditions were created between language and music stimuli.

Table 4.3
Sample experimental music stimuli

<table>
<thead>
<tr>
<th>Condition</th>
<th>Sequence position</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Control</td>
<td>C</td>
</tr>
<tr>
<td>Syntactic</td>
<td>B</td>
</tr>
<tr>
<td>Distractor</td>
<td>B</td>
</tr>
</tbody>
</table>

Note. Underlined, bolded, italicised are the critical points of deviance in each category.

Syncing points of deviance. Music and language progressions varied in the points at which deviance occurred – the PoD (see Language subsection) would vary on a trial-by-trial basis in language, whereas the musical chords would have immediately presented deviance on chord onset. The musical progressions were therefore offset so that the point of deviance of the critical chord was aligned to the onset of the PoD of the critical word at either a) the offset of
the singular term, or b) the onset of the plural term, depending on the critical word of each trial; the point of syntactic violation was therefore as temporally close across domains as possible.

**Button mappings.** Physical responses were mapped using a three-choice format: error-free, single error in either domain, and dual error. Due to the presence of three choices of responses in this task, there was a need to determine the best format for these responses. Pilot testing \((N = 3)\) of two possible formats compared a left-to-right mapping for either hand with a medial to lateral mapping. The left-to-right mapping meant that a left-hand response would be mapped with an error-free trial using the ring finger, and dual errors with the index finger – right-hand responses would be mapped with the right index finger for error-free controls, and dual errors with the ring finger. In contrast, the medial to lateral mapping meant that both index fingers would correspond to error-free controls, and both ring fingers mapped to dual errors. Middle finger responses were standardised in either mapping to single errors. Our results indicated that the medial to lateral mapping was more ergonomic especially when swapping response hands halfway through the experiment. No temporal jitter was introduced to trial presentation.

**Procedure**

Participants provided informed consent, then completed the screening questionnaire containing all information regarding the stated exclusionary criteria. An appropriately-sized EEG cap was then fastened on the participant’s head, impedances reduced to below 50kΩs (Ferree et al., 2001), and closed-back headphones placed on the ears and above the EEG cap. Participants were then positioned 57cm from a computer monitor (1024x768 resolution, refresh rate at 85Hz) with head resting on a chin rest within the Cognitive Neuroscience EEG Research Laboratory at Murdoch University. Once seated, they listened to language or music sequences presented at a comfortable volume, and rested their index, middle, and ring fingers on three
possible response buttons on a serial response box ("2", "3", "4" for left hand, or "6", "7", "8" for right hand).

Figure 4.1. A typical trial format, with an example music and language trial. A musical deviant is created by changing the preceding progression, and a syntactic error in language is created by changing the penultimate word in the sentence.

Participants were presented with an instruction slide that outlined the experimental task (see Figure 4.1): Press one button ("4" or "6") on the serial response box to respond to the presented trials as error-free, another button ("3" or "7") to indicate only one syntax error was present in language or music, or a third alternative button ("2" or "8") to indicate the presence of two syntax errors, one in language and another in music. Assignment of button response hand was counterbalanced across participants, and response hand was changed from left to right hand and vice versa at the halfway point of the experiment. To familiarise the participants with the task, each participant completed 20 practice trials randomly selected from a separate list from experimental trials.

Each trial began with a fixation image (neutral cartoon face) for 100ms, followed by the simultaneous linguistic and musical sequence (see Figure 4.1). Each language-music sequence comprised seven 600ms elements in each domain, with music offset a certain latency on a per-trial basis. Participants had 2000ms from the onset of the last word to respond (i.e.,
1400ms after the end of the final 600ms word); responses outside of this window (either before or after) were considered incorrect. Participants responded as soon as they made a decision on the nature of the stimulus as containing a single, dual error, or syntactically correct form. Immediately after response, the fixation image changed from a neutral face to a smiling or frowning face to indicate a correct or incorrect response respectively. This was presented for 100ms plus the remainder of the duration of the response window. The total trial time was therefore 5800ms, with latencies shifted up to 12ms to account for screen refresh rate (85Hz) frequency. Following the presentation of feedback, the next trial began. The conclusion of the practice block was followed by a summary slide presenting mean block RT and accuracy. Participants were advised to remain quiet and still and respond accurately and quickly.

Following the practice trials, experimental blocks comprising ten blocks of 40 trials each (25% controls, 22.5% language error, 22.5% music error, 20% dual error, 10% distractor error) were presented with short self-timed breaks in between. Responses probabilities were structured to produce approximately equiprobable presentation of each condition, except for the infrequently-presented distractor trials. The conclusion of each block was followed by a summary slide presenting mean block RT and accuracy. The entire testing session took approximately 90 minutes, with an experimental duration of 55 minutes.

**EEG recording and analysis.** EEG was recorded with a 128-channel high density electrode sensor cap, inserted into a NeuroAmp 300 amplifier. Data from the amplifier were coupled with time and event codes from a Windows XP/7 presentation computer with E-Studio Professional 2.0, and is then transferred to a Macintosh computer using Netstation 5.3.0 as the software interface. EEG was recorded at 500Hz using a NeuroAmps 300 amplifier and impedances were reduced below 50kΩ for each electrode (Ferree et al., 2001); an online low-pass filter of 45Hz was used to remove the effects of electrical noise (50Hz in Australia) for
monitoring purposes, but full-range data were recorded. Data were then exported from Netstation to Matlab for further processing.

In accordance with recent suggestions for best practice in ERP research (Dien, 2017; Luck & Gaspelin, 2017), data were analysed with a focus on theory- and hypothesis-driven components, single electrodes, and comparisons of interest. This preference is chosen over a more broad analysis strategy in other research (see Fitzroy & Sanders, 2013 for an example), which potentially captures more experimental effects. However, any such findings are argued to be suggestive rather than conclusive findings (Luck & Gaspelin, 2017). In addition, the use of region of interest (ROI) analyses was eschewed in preference for single electrodes, as single electrodes allow for the measurement of the direct peak of brain-electric activity as opposed to a more diffuse waveform (Dien, 2017). Furthermore, the lack of general consensus on which ROIs to use is evidenced by large variations of the size, distribution, and location of the ROIs (see Carrus et al., 2013; Fitzroy & Sanders, 2013 for examples). With individual researchers and EEG companies varying widely in their ROI layout, which result in inconsistent benefits to the overall signal-to-noise ratio over single electrodes (Dien, 2017), the use of single electrodes was preferred in the current study.

In addition, while the SSIRH may discuss the early components and their interaction (Patel, 2012), these are not a central focus of the study. The P600, in line with best practice (Luck & Gaspelin, 2017), is preferentially examined over the earlier (E)LAN/ERAN components in language and music to syntax manipulations. Experimental design reflects this preference – the use of the PoD, and not word onset, means that the (E)LAN would be drastically attenuated or absent in language ERPs in the current study, which hampers the comparison of (E)LAN and ERAN. Similar sentiments hold true for the word-onset aligned N400 (Sassenhagen et al., 2014). Therefore, the P600 is the only component analysed in the
current study, though a diagram of the waveforms of ROI clusters will be included for visual inspection purposes.

Data sets were analysed using Matlab’s EEGLAB plugin (Delorme & Makeig, 2004) alongside ERPLAB, a plugin to EEGLAB (Lopez-Calderon & Luck, 2014). Data was downsampled to 250Hz to facilitate efficient data management. This decision was made based on the distribution of the expected late P600 component, which will not be affected by the reduced temporal resolution of the EEG data. Downsampling is a common practice in EEG literature, where the reduced temporal resolution does not affect the overall expected experimental effects (Tanaka, Watanabe, Maki, Sakriani, & Nakamura, 2019; Ding, Melloni, Zhang, Tian, & Poeppel, 2016; Alday, Schlesewsky, & Bornkessel-Schlesewsky, 2017; Kimppa, Kujala, & Shtyrov, 2016; Sassenhagen & Fiebach, 2019). Each set was then average re-referenced and Kaiser windowed band-pass filtered at 0.4-40Hz. Data were then pruned with ICA using the SASICA plugin (Chaumon et al., 2015), removing eyeblink, saccade, and artifactual components. This pruning resulted in a retention of 48.89 components ($SD = 14.91$), with an average of 80.11 noisy components removed per participant. The number of remaining components is suitable in analysing brain activity, with certain circumstances even allowing for 1.65 components to represent the brain responses of interest (Wessel & Ullsperger, 2011). Each set was then epoched around correct responses (-500 to 1500ms post-PoD). No baseline correction was employed in the EEG data, as per recent methodological recommendations (Maess et al., 2016) and already implemented in recent research (Brilmayer et al., 2017). In order to further improve signal-to-noise ratio by removing residual artifactual trials, a simple voltage threshold epoch rejection protocol removed trials exceeding ±150µV at any time point over all electrodes.

**ERP analysis.** ERPs were averaged, plotted and analysed using ERPLAB, which is an extension of EEGLAB (Lopez-Calderon & Luck, 2014). Using each individual’s waveform
data, we extracted the period 300 to 500ms post-PoD for statistical testing. This is earlier than previous P600 time windows in other studies (Sassenhagen et al., 2014), but an earlier time window is to be expected following our use of the PoD instead of stimulus onset as the event marker.

**Results**

Distractor errors were removed from the following analyses, as they did not occur at the same point in the progression as the other trials. Additionally, both sessions’ data were collapsed into one data file. This brought the design of the current analysed data to that of a univariate factor of condition (Control, Language Error, Music Error, Dual Error).

Of the 28 datasets collected, six were rejected for unsuitability for the study (overall accuracy fell below threshold of 50% accepted trials per category, with chance performance defined as 33% based on button response probability). The final group comprised 22 participants (eight males), with an average age of 22.95 years ($SD = 5.46$, range 18-43). Of the accepted datasets, all reported native-level English proficiency. Please refer to the table below for the minimum trials for each condition across all accepted datasets; on average, 2.59% of all trials were removed ($SD = 5.76\%$) due to trial-level noise as outlined in the epoch rejection subsection. This minimises the impact of low trial counts on producing noisy final ERP waveforms.

Table 4.4

*Minimum remaining trials by condition.*

<table>
<thead>
<tr>
<th></th>
<th>Minimum remaining trials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>61</td>
</tr>
<tr>
<td>Language Error</td>
<td>65</td>
</tr>
<tr>
<td>Dual Error</td>
<td>41</td>
</tr>
<tr>
<td>Music Error</td>
<td>59</td>
</tr>
</tbody>
</table>
**Behavioural results**

Table 4.5

<table>
<thead>
<tr>
<th>Condition</th>
<th>RT average</th>
<th>Task accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>847.08(45.13)</td>
<td>90.18(7.44)</td>
</tr>
<tr>
<td>Language Error</td>
<td>899.09(65.32)</td>
<td>91.82(7.27)</td>
</tr>
<tr>
<td>Music Error</td>
<td>918.96(51.93)</td>
<td>88.18(6.76)</td>
</tr>
<tr>
<td>Dual Error</td>
<td>967.75(34.77)</td>
<td>76.42(8.53)</td>
</tr>
</tbody>
</table>

**RT.** RT data were analysed between conditions using a one-way repeated-measures analysis of variance (ANOVA; see Table 4.4 for list of means). Mauchly’s sphericity was violated for the variable of condition, $W = .502$, $p = .019$. This produced a significant Greenhouse-Geisser corrected effect of condition, $F(3,63) = 21.49$, $p < .001$, $\eta^2 = .086$. Follow up paired-sample t-tests were Holm-Bonferroni corrected, and showed significantly higher RT for single errors in language versus controls, $t(21) = 3.22$, $p = .008$, $d = .69$, and higher RTs for music errors versus controls, $t(21) = 4.83$, $p < .001$, $d = .103$. Dual error RTs were higher versus controls, $t(21) = 10.08$, $p < .001$, $d = 2.15$, higher than language errors, $t(21) = 4.16$, $p < .001$, $d = .89$, and higher than music errors, $t(21) = 4.95$, $p < .001$, $d = .106$. Lastly, language versus music errors did not produce significant RT differences, $t(21) = 1.00$, $p = .330$, $d = .21$.

**Accuracy.** Task performance accuracy was analysed in the same manner, and the repeated-measures ANOVA produced a significant effect of condition, $F(3,63) = 18.92$, $p < .001$, $\eta^2 = .226$. Follow up pairwise comparisons produced significantly lower accuracy performance of dual errors versus controls, $t(21) = 5.58$, $p < .001$, $d = 1.19$, whereas single errors in language were not significantly different from controls, $t(21) = .79$, $p = .437$, $d = .17$, nor for music errors versus controls, $t(21) = .90$, $p = .378$, $d = .19$. Dual errors were significantly
less well responded to compared to single language errors, $t(21) = 5.98, p < .001, d = 1.28$, and likewise for dual errors versus music errors, $t(21) = 5.28, p < .001, d = 1.13$. Lastly, language and music errors were not significantly different from one another, $t(21) = 1.81, p = .09, d = .38$. 
Figure 4.2. Grand average ERPs at nine regions of interest (ROIs) for experimental conditions. ROIs are zoned according to the scalp map.
Figure 4.3. Grand average waveforms for each experimental condition in the parietal electrode, Pz.

**ERP results**

In order to gain an overall insight into the brain responses over the scalp, ERPs were averaged over nine regions of interest (ROIs) to represent anterior to posterior and left to right regions (see Figure 4.2). A visual inspection revealed that the parietal midline region appeared to have a likely syntax-related increase of P600 amplitude. These ERP results (see Figure 4.3) were subject to a one-way repeated-measures ANOVA on the average amplitudes for individual data collected from the window 300-500ms post-PoD (see Figure 4.4). This corresponds to the P600 time window at the parietal electrode Pz. The Greenhouse-Geisser corrected ANOVA produced a non-significant overall effect of condition, $F(3,63) = 2.05$, $p = .132$, $\eta^2 = .027$. P600 at electrode Pz was not different across conditions.
Figure 4.4. Bar graph of mean window amplitudes for each experimental condition in the parietal electrode, Pz. Error bars represent +/- 1 standard error of the mean.

However, a visual inspection revealed that the differences of brain response are centrally maximal, rather than parietally (see red increases of brain responses reflected in Figure 4.5). Our comparisons at the chosen site may have only analysed electrophysiological responses on the periphery of the actual P600 effect. Previous evidence of more central (or vertex) brain response differences to syntax (Friederici, Hahne, & Saddy, 2002; Molinaro et al., 2011) indicate that in this study there may have been a topographical distribution shifting forward in response to syntactic complexity. By subtracting the error-free control waveforms from the error condition waveforms, the difference in positive response was centred on the central (vertex) region also 300-500ms post-PoD. As such, even though the *a priori* comparisons included only the parietal electrode Pz, a data-driven exploratory analysis of the central (or vertex) electrode Cz was conducted, which appears to be the centre of this syntax error-related activation difference.
Figure 4.5. Difference wave (experimental condition minus control) scalp maps from 0ms to 1000 milliseconds post-PoD, in 100ms intervals.
A repeated-measures ANOVA of the 300-500ms time window of the ERP waveform at the vertex electrode Cz (see Figure 4.6) revealed that there was a significant main effect of condition (see Figure 4.7). Mauchly’s sphericity was violated, $W = .52$, $p = .023$, which adjusted the final result, $F(3,63) = 11.45$, $p < .001$, $\eta^2 = .148$. Holm-Bonferroni corrected paired sample t-tests revealed that the language error condition was significantly higher in amplitude to controls, $t(21) = 3.09$, $p = .022$, $d = .51$, and music errors produced higher positive amplitudes than controls, $t(21) = 2.78$, $p = .033$, $d = .49$. Dual errors elicited a higher positivity than controls, $t(21) = 4.53$, $p = .001$, $d = .84$, than language errors, $t(21) = 2.78$, $p = .033$, $d = \ldots$
.26, and were also higher in amplitude than music errors, \( t(21) = 3.85, p = .005, d = .38 \).

Additionally, P600 amplitudes to language single syntax errors were not significantly different from central P600 amplitudes to equivalent music syntax errors, \( t(21) = 0.77, p = .451, d = .08 \).

![Figure 4.7](image.png)

*Figure 4.7.* Bar graph of mean window amplitudes for each experimental condition at the vertex electrode, Cz. Error bars represent +/- 1 standard error of the mean.

**Discussion**

The aim of the current study was to determine the extent to which the P600 was reflective of shared syntax processing as proposed in the SSIRH (Patel, 2012). The design of the experiment optimised for P600 elicitation through the use of an active syntax processing task (Batterink & Neville, 2013; Brattico et al., 2006; Schacht et al., 2014) that is meant to maximise cognitive overlap between language and music processing (LaCroix et al., 2015; Slevc & Okada, 2015). P600 effects had not yet been examined using an active syntax processing task with simultaneously presented, dually attended language and music syntax
processing, yet the processing of these attended dual errors is theoretically important in understanding the utility of the P600 in reflecting shared syntax resources (Patel, 2012).

One aspect that remains especially unclear was the ability of electrophysiological responses like the P600 in indexing the behavioural reductions of task accuracy to simultaneously presented and attended language and music syntax as seen in prior behavioural research (Roncaglia-Denissen et al., 2018). In line with claims of a shared syntax integration resource, attended dual linguistic and musical syntax violations were predicted to produce a combined processing cost that is measurable at the P600 component (Patel, 2012). Such a combined cost would be predicted to result in deleterious combinatory effects on behavioural performance (RT and task accuracy) and P600 response (Patel, 2012). Under dually attended conditions, P600 amplitude was thus hypothesised to be significantly higher in dual errors versus single errors in either language or music, which were in turn predicted to be higher than that of error-free controls. Furthermore, these P600 amplitude increases were also hypothesised to coincide with RT increases and task accuracy decreases over and above that seen in single errors.

The findings from the current study showed the predicted combinatory effects of dually attended and simultaneously presented syntax violations in the P600, as well as in RT measures of processing speed and task accuracy. Such findings validate P600 amplitude change as reflective of the recruitment of the proposed shared resource (Patel, 2012). P600 amplitudes measured at a central maximum were significantly higher in dual errors versus single error conditions, indicating greater cost of processing the more deviant dual error stimulus. Moreover, the hypothesised links between P600 and RT were supported as well, with similar patterns of processing cost seen in RT as in P600 data. This similarity of findings in behavioural and electrophysiological measures suggests that the P600 is a functional correlate of behaviourally validated syntax processing cost.
Electrophysiological data revealed that the *a priori* analyses conducted at the parietal electrode (Pz) did not produce significant differences between conditions – P600 appeared to be inadequate in indexing the condition-related syntax processing costs even for single errors over control conditions, despite P600 amplitude increases being a documented finding in previous literature (Molinaro et al., 2011; Sassenhagen et al., 2014; Schacht et al., 2014). However, the maximal point of difference between the experimental conditions was not at the parietal region, as evidenced by the topographical distribution of the scalp map data. Instead, an examination of the difference wave scalp maps showed a centrally maximal positive component that occurred in the 300-500ms window, which appears to reflect an anteriorly-shifted P600 effect (see Figure 4.6). This is a main contributor to the lack of significant amplitude change across experimental conditions at Pz; the P600 effect appeared to shift anteriorly from the parietal region, and amplitude comparisons based on the parietal electrode only showed peripheral amplitude changes that did not reflect the centrally maximal P600 elicited in the current study. Exploratory analyses on this central P600 effect showed amplitude increases for single errors over controls, and that of higher P600 amplitudes for dual errors over single errors. Existing perspectives regarding a more central P600 component suggest that both centrally and parietally maximal P600 effects are observable to syntax violations in language, and is said to be related to the process of integrating or repairing a syntax error into its syntactic context (Molinaro et al., 2011).

The amplitude changes measured at the central P600 component validate the functional relationship of RT measures of behavioural processing cost with P600 response. Dually attended syntax violations in language and music produced combinatory effects on P600 amplitude, and were accompanied by RT increases and accuracy decreases above the effects seen in single errors in either language or music. Previous research had not used simultaneous attended language and music syntax violations to elicit P600 effects, instead choosing to
selectively attend one domain or ignore syntax in the main task (Koelsch et al., 2005; Steinbeis & Koelsch, 2007). This limited the observation of the attention-dependent P600 component (Batterink & Neville, 2013) from demonstrating a sensitivity to dually attended violations in language and music. Such research could therefore not support an account of simultaneous language and music syntax violations collectively loading onto a shared resource, which would produce combinatorial P600 amplitude increases as predicted in the SSIRH (Patel, 2012). Consequently, the P600 amplitude increases to dual errors in the present study provide support for a shared resource simultaneously recruited in the presence of dually attended errors, and that the P600 component may function as an index of the recruitment of that shared resource.

This significant P600 amplitude increase to dual errors over single errors is important, as it clarifies the processes that P600 amplitude is sensitive to. Alternative accounts of syntax processing included the role of syntactic congruency, where dual errors in language and music were argued to be processed just as easily as an error-free control, as language and music both either showed errors or not at all (Roncaglia-Denissen et al., 2018). Single errors in simultaneously presented language and music were asymmetrical in their syntactic correctness, and thus generated greater accuracy decrements over dual errors in Roncaglia-Denissen and colleagues’ study (2018). If syntactic congruency is the process underlying language and music shared processing, and if P600 reflected that shared processing (Patel, 2012), then attended dual errors would either produce similar or attenuated P600 amplitudes relative to single errors as a more congruent language-music dual error is encountered. However, the findings in the current study support a view of P600 amplitude reflecting the integration of the syntax error into its sentential or musical context (Patel, 2012), where greater difficulty of syntax integration is correlated with increased P600 amplitude.

The predicted behavioural impairment of dual errors was evidenced through significantly higher RTs and a lower task accuracy average than the single error conditions.
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Similar increases of RT were observed when single language or music syntax errors were presented over error-free controls, whereas dual errors produced significantly higher RTs over single errors. Task accuracy in discriminating errors was also reduced only in the dual error condition relative to other conditions, indicating that dual errors incurred a greater overall cost of processing relative to any other condition.

Finding combinatory behavioural effects to dual errors over single errors also affirms the claims in the SSIRH of a shared syntax resource (Patel, 2012), additionally validating the view of P600, RT, and task accuracy effects in the current study as reflecting the processing cost of increased syntactic deviance from single to dual errors rather than alternative accounts of syntactic congruency (Roncaglia-Denissen et al., 2018). The functional co-occurrence of combinatory P600 amplitude increases with RT increases and reduced task accuracy supports the idea of P600 being an electrophysiological measure of the processing cost incurred in integrating a syntactic error back into its context (Patel, 2012), the effects of which may be driving RT and accuracy effects at the behavioural level.

The findings in the present study also provide a better understanding as to the changes in P600 topography as task complexity increases. The increased task demand of the current task is greater than that of previous simultaneous-presentation tasks that have only used an active language syntax task with an unattended music stream (Koelsch et al., 2005) or a timbre error detection task (Maidhof & Koelsch, 2011). Simultaneously presented and attended syntax violations produce a more centrally maximum P600 effect, which reflects task demand. An anterior shift to task complexity is a pattern also seen in P3b research (Segalowitz, Wintink, & Cudmore, 2001), and our findings of P600 distribution may contribute toward a body of growing support for the revisited idea that P600 may be an iteration of the P3 family of responses (Sassenhagen et al., 2014). Recent work that has shown P600 response-alignment similar to P3 (Sassenhagen & Bornkessel-Schlesewsky, 2015; Sassenhagen et al., 2014),
similarity of power change in the delta and theta bands between P600 and P3 (Brilmayer et al., 2017), and of machine learning classification of P600 trials using algorithms designed to detect only P3-like EEG patterns (Sassenhagen & Fiebach, 2018). The findings of a more anterior topography of the P600 in response to increased task difficulty is not predicted in the SSIRH (Patel, 2012), but is explained when viewing the P600 as similar to P3 such as in the P600-as-P3 hypothesis (Coulson et al., 1998; Sassenhagen et al., 2014), and thereby a more domain-general model of P600 generation.

In addition to the more centrally maximal P600 component, the use of the PoD in the current study has reduced latencies of the P600 to more closely resemble a P3-like time window – typical analysis time windows of the P600 range from 500-800 milliseconds post stimulus-onset (Molinaro et al., 2011), whereas our findings were primarily in the 300-500ms range. The use of the PoD situates EEG data relative to the exact time point at which the syntactic violation occurs and is intended to produce increased precision of the ERP response to violations of syntax. The reduction in P600 latency due to the use of the PoD, however, also helps aid in the comparison of P600 with P3b, which typically occurs around 300ms after the onset of a task-relevant stimulus (Carrión & Bly, 2008; Polich, 2007). P600 effects can possibly be viewed, therefore, as imprecisely measured instances of P3 effects to points of task-relevant syntactic deviance.

Future research can develop these initial findings by further examining the P600 as it relates to processing language and music. Increased P600 amplitudes to simultaneously-presented language and music syntactic manipulations may reflect increased syntax-specific processing costs (Patel, 2012). However, there is behavioural evidence suggesting attended semantic language and unattended syntactic music interact when co-occurring. This is shown by significantly higher sentence chunk-by-chunk reading times (Perruchet & Poulin-Charronnat, 2013) or RT increases to a lexical decision task (Hoch et al., 2011). Specific types
of semantic violations, such as seen in semantic garden path sentences (Perruchet & Poulin-Charronnat, 2013), may potentially generate a semantic P600 (Kuperberg, 2007). Semantic garden path manipulations could therefore be compared alongside musical syntax violations to jointly tax P600-related resources. Such a pattern of findings may challenge the current claims in the SSIRH about syntax-specificity (Patel, 2012). If semantic garden paths produce combinatory effects on P600 amplitude and RT when presented with attended musical syntax violations, such future findings may challenge the syntax-specificity of a shared language-music resource as claimed in the SSIRH (Patel, 2012). Additionally, linguistic semantic and musical syntactic combinatory effects on the P600 would provide further support for the P600 as a valuable index of processing cost, whether syntactic or not. However, as the current study stands, the pattern of results is consistent with claims in the SSIRH about a shared syntax resource between language and music.

A second potential direction is related to the observed anterior shift of P600 topography in response to increased task complexity. If P600 topography responds to task complexity, then a simpler, separately presented language syntax violation should produce a more parietal P600 than a simultaneously presented and dually attended language-music progression with a language syntactic violation, even within the same participant. A study could compare P600 components elicited in a) a language-only design with a syntax error versus b) a simultaneous-presentation, dually attended language-music design with a language error. If P600 varies as a function of task complexity, the simultaneous language-music P600 effect to the language syntax violation will be more anterior to that of the language-only P600 to the language syntax violation.

Summary

In conclusion, the results of the current study found the hypothesised combinatory effects of syntax errors in language and music at the electrophysiological and behavioural
levels. Previous research had not examined the effects of simultaneous syntax violations under a dual-attended task, and thus could not observe the predicted combinatory amplitude increases related to the attention-dependent P600 component to dual errors over single errors. At the electrophysiological level, P600 amplitudes were significantly higher for dual errors over single errors, which were in turn higher in P600 amplitude compared to controls. RT data showed that dual errors were responded to significantly more slowly than single errors, which were in turn more slowly responded to than error-free controls. In addition to this, we found a unique effect of dual errors producing reduced task accuracy compared to either single errors or controls. Lastly, we saw an anterior shift of the P600 component to a central maximum instead of the typical parietally maximal scalp distribution.

Taken together, these findings suggest an overlap in neural resources underlying syntax processing in language and music, where increased syntactic deviance in simultaneous language and music errors produces greater processing cost (Patel, 2012). The increased syntactic integration cost of dually presented and attended syntactic violations elicited higher P600 amplitudes, slower RTs and lower task accuracy than that of single errors. P600 amplitude is thus sensitive to the greater processing cost incurred in dual errors over single errors. This finding is a novel one, owing to a prevalence of previous research either employing selective-attention or non-syntactic active tasks that restricted observation of the attention-dependent P600 component. Additionally, the current study provides evidence of a functional co-occurrence of P600 with RT in measuring the cost of processing required to integrate a syntactic violation into its context. The findings in the current study directly support the claims in the SSIRH of shared language and music syntax resources (Patel, 2012) and more broadly supports the utility of the P600 component as an index of that shared resource between language and music.

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5. GENERAL DISCUSSION

5.1. Summary of findings

The current program of research investigated interactions of language and music syntax processing. Different theoretical perspectives of this interaction exist: the SSIRH (Patel, 2012) predicts syntax-specific shared resources across language and music, whereas recent models of shared resources such as the P600-as-P3 hypothesis (Sassenhagen et al., 2014) claim a more parsimonious P3-based model that is not specific to syntax. In doing so, the latter models have proposed new applications of analyses and predictions for comparing language and music. Using a variation of EEG analysis using response-alignment, and an attended simultaneous task of selective and dual attention, new examinations of the SSIRH were possible in the current program of research. The overall purpose of the present program of research was to examine the claimed shared resource underlying language and music, particularly in the aspects of the late P600 ERP component and how it relates to behavioural performance speed and accuracy; in doing so, these experiments tested the usefulness of P600 as an index of shared syntax-related processing cost (Patel, 2012).

The current program of research compared P600 effects between language and music in order to delineate the aspects where the elicitation of P600 effects are similar or distinct between domains. P600 elicited to language syntax violations had shown an alignment of amplitude change timed to RT; P600 elicited to music syntax violations had not been examined in such a manner, but if driven by a shared language-music syntax resource (Patel, 2012) should also predict the same response-alignment. Additionally, if language and music shared a syntax integration resource as claimed in the SSIRH (Patel, 2012) then the co-occurrence of syntax violations in language and music should jointly tax the shared resource. A dual error condition of co-occurring violations should therefore produce combinatory effects on increased P600 amplitude, reflecting the increased recruitment of shared neural resources to process the increased deviance of the incoming stimulus. However, the conditions under which said P600 combinatory amplitude effects appear may rely on attention-dependent processes (Batterink & Neville, 2013). A program investigating P600 effects should thus conduct a
selective-attention and a dual-attention experiment. Doing so would clarify the conditions under which combinatory syntax-related P600 amplitude change is elicited, especially since behavioural indices of shared syntax processing cost appear to not require attention to elicit (Fedorenko et al., 2009; Slevc et al., 2009). The failure of the attention-dependent P600 to capture behaviourally-observed effects to unattended syntax violations would challenge the eligibility of the P600 component to index the recruitment of a shared syntax resource (Patel, 2012).

The first study in the current program of research was designed to compare directly the P600 in music and language, and its alignment to RT. Extending the use of a novel application of response-alignment analyses in the P600 elicited from language stimuli (Sassenhagen et al., 2014), we sought to investigate the shared resource claims of the SSIRH by testing response-alignment in the P600 to musical syntax violations. Dividing individual trials into RT tertiles from fastest to slowest, it was predicted that language P600 in those tertiles would increase in latency as the RT tertile increased in latency. P600 response alignment in both music and language would demonstrate support for both the claims in the SSIRH and P600-as-P3 hypothesis, which respectively claim a similar shared syntax resource (P600) that behaved similarly regardless of the domain of the syntax violation (Patel, 2012) and of a generic P3-like response-aligned P600 component also regardless of domain (Sassenhagen et al., 2014). If the P600 component elicited in language and music syntax violations reflect similar processes across domains, then both P600 effects should display similar response-aligning behaviour.

In Experiment 1, the P600 amplitude increase in response to a language syntax violation (language P600) displayed response-alignment as found by Sassenhagen and colleagues (2014). Contrary to what was predicted by the SSIRH, the P600 amplitude increase to a musical syntax violation (musical P600) did not show that same pattern of response-alignment. In fact, music P600 latency was lowest in the slowest RT tertile, whereas language P600 latency was highest in the slowest RT tertile. Despite statistically similar grand averaged P600 amplitude increases to language and music syntax errors, response-alignment analyses revealed differences in response-alignment that were obscured by the grand average ERP. These results show that while there were similar P600 amplitude increases in
response to language and music syntax violations in the grand average ERP, thus suggesting an extent of overlap in shared resources, the lack of musical P600 response-alignment suggests differentiated neural processes from both language P600 and P3 (Sassenhagen et al., 2014), suggesting either that a) the purported shared resources are recruited differently in language and music, or b) there are domain-specific, but anatomically proximal resources recruited in language and music that appear similar in the ERP.

Interestingly, Experiment 1 also showed some behavioural findings that were not predicted by broad claims of the literature. Language syntax violations had higher overall response times (RTs) than language error-free controls; however, RTs for musical syntax errors were faster than that of controls. In particular, RTs for the music control condition appeared to be slower than expected, which effectively nullified the possibility of observing RT effects of syntax violation in music. Language syntax errors were also less accurately discriminated relative to controls, but musical syntax errors were no less accurately responded to than controls. The behavioural data therefore demonstrated unexpected differences in the RT and task accuracy observed between domains. However, recent research has shown similarly unpredicted RT patterns as well, with faster RTs to language syntax errors versus error-free controls, and no RT impairment for music syntax errors versus controls (Roncaglia-Denissen et al., 2018). Some suggested explanations are possible for the observed findings in our data, such as a possible influence of a regular rhythm in affecting music RTs. The isochronous timing and duration of chords (600 ms) may have resulted in participants synchronising their RT with the temporally regular musical sequences. As such, we saw average RTs for controls around the 600ms intervals played per chord. However, the onset of a music syntax error may suspend this regularity effect, overwhelming any RT temporal regularity effects, and instead resume the initiation of immediate responses as seen in the language conditions. An as-fast-as-possible strategy in this case would produce faster RTs to syntax violations compared to controls. Furthermore, the musical harmonic error might have been relatively easy to process, which would lead to the lack of accuracy differences for musical errors versus controls. One possible defence of
the robustness of the syntax manipulations in music lies in the measurement of EEG data for comparisons. The P600s elicited in music conditions appears to reflect similar patterns of activation compared to language equivalents, and followed overall predictions for P600 amplitude increases to syntax violations. This supports that idea that the syntax manipulation in music syntax violations was able to produce a comparable effect with language equivalents. Despite this support for the robustness of the actual syntax manipulations in music conditions, the RT results from the data in Experiment 1 need to be interpreted with some caution.

Nevertheless, an unattended musical syntax violation still influences an attended language comprehension task (Fedorenko et al., 2009). Attention therefore may influence the cross-domain interaction at the behavioural and electrophysiological level. In order to understand how behavioural impairment in simultaneous language-music presentation can occur (Fedorenko et al., 2009; Slevc et al., 2009) despite a qualitative difference of P600 as evidenced by response-alignment in Experiment 1, a second experiment examined P600 under simultaneous language and music presentation.

Previous research showed that the effect of an unattended language syntax error on attended music syntax processing is less clear (Maidhof & Koelsch, 2011) than the unattended music syntax violation on attended language syntax processing (Koelsch et al., 2005). The second experiment in the present program of research sought to examine the effects of simultaneously presented, but selectively-attended syntax errors on the P600 in both directions – the effects of unattended music syntax violations on an attended language syntax task, and the effect of an unattended language syntax violation on an attended music syntax task. Experiment 2 collected behavioural comparisons of RT and accuracy as well as P600 data between conditions. Experimental conditions were separated into error-free control trials, trials with an attended or unattended single syntax error, or a dual error condition comprising both an attended and unattended syntax error. Participants underwent a two-session experiment, alternating between attending to language or music. This second experiment found a significant RT increase to an attended language error relative to controls, whereas an attended music syntax error showed no RT difference relative to controls. Unattended errors in either the
attend-language and attend-music domains produced no change in RT relative to controls. All conditions produced similar accuracy statistics.

P600 data showed cross-domain similarities, with attended errors producing increases in amplitude relative to controls. Dual errors in either attend-domain produced increases in P600 amplitude relative to controls that were similar to that of an attended error relative to controls. Unattended errors in either attend-domain did not produce significant increases to P600 amplitude relative to controls. This supports P600 attention-dependence observed in previous research (Batterink & Neville, 2013; Brattico et al., 2006; Schacht et al., 2014), even when presented with an unattended syntax error and regardless of the domain attended. This similarity of electrophysiological responses across language and music indicates similarities of syntax processing in both directions of the language-music comparison, and could provide evidence for similar recruitment of a shared syntax resource as claimed in the SSIRH (Patel, 2012). The P600 component demonstrates utility as an electrophysiological index of syntactic processing cost similarly incurred across domains, even when behavioural effects may not be unambiguous. For example, attention-dependence of language RT increases is a novel one that seemingly contradicts previous literature showing attention-independent syntax interactions (Fedorenko et al., 2009; Slevc et al., 2009).

However, the Experiment 2 RT data show unexpected differences between domains. The lack of music syntax violation RT increases relative to controls was unexpected, as we predicted a similar increase of RT for attended music errors versus controls as was seen in the attended language syntax errors relative to controls. The lack of RT differences between the attended music syntax violation and control conditions in Experiment 2 display a different pattern from findings in Experiment 1, which showed decreases of RT in syntax violations versus controls. This difference in RT effects for music stimuli across Experiments 1 and 2 may be influenced by an increased difficulty of the error detection task in Experiment 2, which would result in an increased RT to accurately process the attended musical syntax violation. It may be that similar to Experiment 1, control trials were responded to around 600ms to follow a regular presentation rhythm, and syntax violations suspended
this regularity to produce as-fast-as-possible RTs. However, unlike Experiment 2, the syntax violations were responded relatively slower given the more challenging sensory environment, which produced relatively higher RTs than syntax violation RTs in Experiment 1. This could be one explanation for the lack of RT effects in attended music errors for Experiment 2.

At any rate, RT was not sensitive enough to index syntax processing costs to an attended syntax violation in music. That said, the results from Experiment 2 appear to support the role of P600 as a more suitable accurate correlate of the processing costs for syntax violations over that of behavioural measures of RT and accuracy. P600 amplitude increased in both attended language and music syntax violations versus controls, but increased RT and reduced task accuracy were not as reliably elicited. Importantly, unattended syntax violations in either attend-domain produced no behavioural or P600 amplitude effects. This validates the attention-dependence of syntax processing under the active syntax processing, simultaneous language-music presentation, selective-attention design employed in Experiment 2. Given the attention-dependence of the effects found in Experiment 2, further work was needed to examine this shared resource under a simultaneous presentation, dual-attention task in order to investigate the effect of a simultaneous attended syntax load on behaviour and the P600.

Consequently, the third experiment replicated Experiment 2 with a dual-attend syntax processing task across language and music. The aim was to understand the role of P600 in being reflective of shared syntax integration resources as claimed in the SSIRH (Patel, 2012). Experiment 2 demonstrated attention-dependent P600 amplitude increases for attended language and music syntax violations compared to controls, alongside attention-dependent RT increases in language conditions. By manipulating attention, it would be possible to examine the extent to which simultaneously attended language and music syntax errors would increase P600 amplitude relative to single errors. Furthermore, increased syntactic processing costs under a dual error condition were predicted to also increase RT and reduce task accuracy relative to single errors. This is said to reflect competing demands for language and music syntax processing (Patel, 2012). Increased syntactic
processing cost specifically to co-occurring language and music syntax has been shown to produce combinatorial increases in behavioural measures, including musical closure ratings (Kunert et al., 2016), language reading times (Slevc et al., 2009), and language comprehension (Fedorenko et al., 2009). These language and music syntax manipulations produced combinatorial behavioural effects in ways that loudness (Fedorenko et al., 2009), semantic (Slevc et al., 2009), and arithmetic (Kunert et al., 2016) errors did not, which suggests that it is not simply attention-related distractor effects of any form that cause the noted language and music syntax combinatorial effects.

Behavioural RT data showed that dual errors in language and music produced the predicted combinatorial effects of increased RT above those of single errors. In turn, single syntax errors in either language or music coincided with RT increases relative to error-free controls. Task accuracy data showed dual errors produced the only significant reduction in accuracy compared to single errors and controls, which all performed comparably to one another.

The P600 component in Experiment 3 was centrally maximal unlike the parietally maximal P600 components seen in Experiments 1 and 2, and a priori comparisons of P600 at the parietal electrode resulted in no significant amplitude increases. However, measuring P600 amplitude increases at the central site resulted in effects similar to RT data. The predicted increased syntactic cost to dual errors was observed, with higher P600 amplitudes in dual errors compared to single errors. Single errors elicited P600 amplitudes greater than that of controls.

Similar patterns of P600 amplitude increases with RT increases to dual errors can be argued to be representative of the processing cost related to a large syntactic deviance. This deviance demands greater shared syntax resources (Patel, 2012) to integrate back into its preceding syntactic context. The measurement of both behavioural and P600 measurements of this dual error effect validates the claims in the SSIRH of shared resources, with P600 amplitude change as being reflective of the recruitment of the shared resource (Patel, 2012). The findings in Experiment 2 and 3 therefore indicate the P600 component is an electrophysiological correlate of the observed RT impairments to
syntax errors, and is an index of the shared processing resources subtending syntax in language and music (Patel, 2012).

In contrast to Experiments 1 and 2, where RT data showed a difference in the increases and decreases or lack thereof between language and music syntax violations compared to controls, Experiment 3 RT data showed similar effects of language and music syntax violations relative to controls. In this experiment, musical syntax errors produced RT increases relative to controls, a pattern that resembled language syntax violation RT increases relative to controls in Experiment 1, 2, and 3. The most direct comparison of task-related RT effects in the behavioural data are seen in the comparison of Experiment 2 and 3. The exact same material was employed in both cases, but the task instructions were amended from a selective attention to a dual attention task. In the former case in Experiment 2, there were increases in RT for conditions with a syntactic error present in language, but not for music syntactic errors; unattended errors elicited no RT increases. However, in the latter case of Experiment 3, RT increases were observable for syntactic errors in both domains attended. This contrasts directly with the pattern of music syntax error RT effects between the two experiments.

One possible explanation to the music data in Experiment 2 may be related to the inter-onset-interval of the musical stimuli, which is 600ms. Coupled with a regular rhythm in music and a seven-chord sequence, this may have prompted participants to wait 600ms to respond (a so-called RT-metric effect). Conversely, a syntax violation in music may have been processed in two different ways: 1) a suspension of this RT-metric effect of 600ms response and the use of an as-fast-as-possible response that eventuates into RTs that end up similar to ~600ms control RTs, or 2) the continuation of this RT-metric effect in music syntax violation conditions to produce ~600ms RTs as well. In either case, control and music syntax error conditions would merely have coincided in RT due to the regularity of the chord presentation, or to RTs that ended in a similar time window. Such a phenomenon would have masked the behavioural cost of a cognitive processing cost such as hypothesised in processing a syntactic violation.
In language stimuli, the inter-onset-interval is also 600ms, but stimuli ranged widely in duration and may have helped obscure the regularity of the word presentation. This may have led to the lack of an RT-metric effect in language, regardless of experiment. The relative salience of chord regularity also seemed to be reduced in cases of Experiment 3, where control conditions (music and language chord/words with no errors present) elicited lower RTs than syntax violation condition RTs in either language or music. Two explanations exist here as well: 1) the confounding RT-metric effects were ignored or minimised following a high task load, which has been shown to reduce non-task effects (Causse et al., 2016), or 2) participants were simply ignoring music data and responding to the language stimuli, which would produce low RTs for controls relative to syntax error conditions. The latter perspective is possible, but unlikely, as participants performed above-threshold for the music and dual error conditions. If they did not, that would suggest a heuristic strategy that ignored music to prioritise language task proficiency. Instead, we found comparable task performance in language and music single errors, which suggests equal attention was paid to both streams of stimuli. The former idea of task load minimising this effect is therefore the more likely suitable explanation.

The anterior shift of the P600 component in Experiment 3 could be indicative of a topographical change following a different P600-eliciting processing stage, as argued in an earlier review (Molinaro et al., 2011). The centrally maximal P600 component in this case may reflect either a change in a processing stage from syntactic repair, which is characterised by a more parietal P600, to that of syntactic integration, which is characterised by a more central P600 (Molinaro et al., 2011). According to the authors, syntactic repair is more computationally intensive, and produces increased processing cost as a coherent syntax structure is pursued through reanalysis of the previous processing stages to fix the encountered anomaly. However, syntactic integration may represent a processing stage that focuses on comprehending the syntactic anomaly within its context, without necessarily repairing the error into a coherent form (Molinaro et al., 2011).

Molinaro and colleagues (2011), however, argue for these processing stage differences to not only influence topography, but also latency of the P600 – the parietally maximal P600 is argued to...
occur around 900 milliseconds post word-onset, whereas the more central P600 is said to occur 600 milliseconds post word-onset. Most ERP studies investigating P600 components have generally adhered to the more central P600 latencies for ERP analysis (Molinaro et al., 2011). It is therefore debatable that the functional descriptions of repair and integration are entirely applicable to the P600 in Experiment 3, as the anterior shift of the P600 in Experiment 3 was not accompanied by a latency change of over 300 milliseconds.

A more plausible approach to understanding the anterior shift in the P600 maximum in Experiment 3 comes from the P3 literature. Task complexity may influence the distribution of P3 components to a more central as opposed to a parietal maximum (Segalowitz et al., 2001), a pattern also observed in P600 as well (Friederici et al., 2002). The frontal P3 may be correlated to an individual’s ability to adapt to the experimental task, where frontal P3 amplitude attenuates more slowly when task difficulty is high compared to an easier task (Wintink, Segalowitz, & Cudmore, 2001). Easier tasks therefore show more parietal maximums because of the quick attenuation of the frontal P3, and more difficult tasks show a more frontal distribution due to the slow attenuation of frontal P3. The P3 literature also argues for a more frontal P3 to represent focal attention (Polich, 2007), where more attention is paid to a difficult or distracting stimulus. Therefore, if the P600 component behaves similarly to that of P3 (Brilmayer et al., 2017; Sassenhagen & Fiebach, 2018; Sassenhagen et al., 2014), then the more complex task in Experiment 3 may have resulted in prolonged frontal P600 adaptation compared to Experiments 1 and 2. This would have resulted in a more centrally maximal P600 effect compared to the more parietal maximums seen in the Experiments 1 and 2.

In summary, dual errors in Experiment 3 resulted in increased P600 amplitude and RT over single errors, and single errors elicited increased P600 amplitude and RT over controls. This shared pattern of P600 amplitude with RT suggests a functional co-occurrence of P600 amplitude and RT latency. Such a pattern stands in contrast to the differences seen in music and language P600 response-alignment with RT latency in Experiment 1 – the comparisons in Experiment 1 related P600 latency
with RT, whereas in Experiment 3 it was P600 amplitude with RT. As increased task complexity and an enriched sensory environment increased from Experiment 1 to 2 and 3, it was the degree of shared resources being engaged in dual error conditions that was the focus of the subsequent analyses in the latter experiments. Therefore, P600 amplitude rather than response-alignment was the focus of Experiments 2 and 3, which in Experiment 2 were predicted to reflect attention-dependence in processing just the attended and not the unattended error in dual errors. In contrast, P600 amplitude was predicted to increase significantly for dual errors over single errors as reflective of the dual errors simultaneously taxing shared language and music syntax resources (Patel, 2012).

5.2. Implications: Updating the Current Understanding

These behavioural and electrophysiological findings validate the utility of the P600 in indexing the cost of processing an attended linguistic or musical syntactic violation. The present program of research provides broadly supportive evidence for the concept of neural overlap in the SSIRH, and of the P600-as-P3 hypothesis. Specifically, language and music P600 showed similar patterns across domains whether in aspects of attention-dependence and electrophysiological response in Experiment 2, or with regard to similar behavioural cost and electrophysiological response when simultaneously processed in Experiment 3. By a systematic examination of the P600 under different task conditions, the present program of research has shown convincing support for shared resources as postulated by both the SSIRH (Patel, 2012) and P600-as-P3 hypothesis (Coulson et al., 1998; Sassenhagen et al., 2014), and again demonstrate the utility of the P600 component in understanding shared aspects of processing cost in integrating syntactic anomalies. While the postulated scope of shared resources for each hypothesis are qualitatively different, they converge on the same conclusion; similar patterns of electrophysiological response and performance were expected across domains for attention-dependence, as well as an expectation of combinatory effects in syntax processing of simultaneously attended errors. These predictions were validated with our results.
However, Experiment 1 challenges the claims of both hypotheses with regard to similar response-alignment in music as in language. SSIRH claims a similar syntax resource across domains that should both align to response, and the P600-as-P3 hypothesis suggests that both iterations of the P600 are variations of P3, which should therefore show response-alignment as well. With the musical P600 latency decreasing in the slowest RT tertile relative to the faster two tertiles, there remains the question as to why we observe this apparent reversal of the language P600-RT latency pattern. Despite strong support for a shared resource between language and music, the lack of music response-alignment as found in Experiment 1 is a theoretically relevant finding that requires modifications of the SSIRH and P600-as-P3 hypothesis; these will be discussed below, and can be summarised a) in the SSIRH as P600 representing a shared neural resource that is recruited in differentiated ways that summate into similar P600 amplitude change in both language and music, and b) in the P600-as-P3 hypothesis extending P600 P3-like similarities from just resembling P3b-like activity (Sassenhagen et al., 2014) to resembling the variety of P3 components including the P3b, as well as the P3a, or novelty P3 (Polich, 2007).

The SSIRH (Patel, 2012) claims that changes in the P600 component is related to the recruitment of shared syntax resources. Despite early evidence showing the potential benefits of using P600 as a tool to index integration cost across both music and language (Patel et al., 1998), the literature has not filled this gap of examining the P600 bidirectionally; the only subsequent study to match this description showed differences in distribution and latency in P600 between domains (Fitzroy & Sanders, 2013). The present program of research sought to better understand the language-music syntax relationship using the P600 using response-alignment analyses, and a simultaneous-presentation, selective- and dual-attention task. A shared syntax resource in language and music would be evidenced by a) similar response-alignment of the P600 component in language and music, b) similar attention-dependent P600 amplitude increases only to attended syntax errors in language and music, and c) combinatory effects of increased P600 amplitude of dually attended syntax errors over single errors in either language or music. The P600 has shown to be a reliable index of incurred
syntactic processing cost in language and music. The attention-dependent RT increases in language in Experiment 2 coincided with attention-dependent P600 amplitude increases in language and music, showing the sensitivity of the P600 component when syntactic violations are encountered. Additionally, the predicted combinatorial P600 amplitude increases to dually attended errors were observed in Experiment 3. Furthermore, the finding of P600 amplitude coinciding with RT increases in Experiment 3 provides further indication that P600 represents the processing cost of syntactic integration across domains.

However, the findings from this program of research did not universally support these predictions, with P600 response-alignment only in language and not in music. Consequently, the P600 appears to show evidence of being driven by distinct neural activation in language and music, or at least a shared resource that is differentially recruited in language and music. Findings of partial differentiation are supportive of earlier interactions (or lack thereof) showing a partial distinction between language and music syntax (Maidhof & Koelsch, 2011), while providing first evidence that even the later processing stages of the SSIRH, purported to be shared across domains, may actually recruit slightly differentiated networks that produce an overlapping overall P600 component.

Shared syntax processing resources, supposedly recruited in a similar way in the current iteration of the SSIRH, have now shown themselves in the current program of research to be equal in magnitude across domains but not in alignment characteristics. As such, SSIRH may in fact accommodate this finding by adopting a similar-but-distinct principle used in earlier components (LAN and ERAN) to the P600 as well (Patel, 2003, 2012). The distribution, latency, and amplitude of the grand averaged P600 component are similar across language and music syntax violations, suggesting that the overall ERP neural recruitment is comparable across language and music. However, the P600 response-alignment seen in language but not music could suggest qualitative differences in which shared syntax resources are recruited. For example, response-alignment of the P600 elicited to language syntax errors indicate that P600-related cortical resources were oriented to the response – the integrative processes involved in processing a language syntax error (Molinaro et
al., 2011) may directly involve deciding whether a syntax form was erroneous or not, and the decision once made would result in a physical response time-locked to the P600 component.

Music syntax errors may also elicit a P600 component by recruiting shared resources as well, but instead orient these resources to the onset of the musical error. Instead of P600-related cortical resources being used in processing a decision, a simpler novelty heuristic may be used that seeks to process relative salience of an incoming musical stimulus, such as in the case of a tonality-violating musical syntax violation. Because these shared syntax resources were recruited for music stimulus-related processing, not decision-related processing as in language, the P600 to music syntax violations would not be response-aligned as a result.

Explanations based on the interpretation of the P600 as a member of the P3 family may offer an alternative perspective regarding the absence of response-alignment of P600 to musical syntax errors. One prediction of the P600-as-P3 hypothesis (Sassenhagen et al., 2014) is that P600 is a later syntactic iteration of the P3b component and should show response-alignment regardless of domain. The data from Experiment 1 demonstrated response-alignment to language P600 in response to language, but not to music. This finding is inconsistent with the P600-as-P3 hypothesis, because response-alignment is a characteristic of the P3b component (Nieuwenhuis et al., 2005; Verleger et al., 2005). While the P600-as-P3 hypothesis argues for a P600 being a member of the P3 family, it can instead be argued that P600 can be expressed as P3b-like, with response-alignment, or P3a-like, where the component is stimulus-aligned (Polich, 2007). This slight modification to the hypothesis may account for the differences seen in response-alignment in Experiment 1. The P600s to musical syntax violations in non-musicians may thus more resemble a stimulus-aligned P3a response (Polich, 2007).

P600 response-alignment may rely on factors such as musical expertise, or the explicit knowledge of musical theory to understand the nature of a syntactic error. The non-musician samples in the current program of research may lack that knowledge. Previous research has shown that the non-musician brain may result in slower, but similarly accurate behavioural responses as a trained
musician sample (Bigand & Poulin-Charronnat, 2006). However, formally trained musicians still show cortical responses to musical anomalies that non-musicians do not (Poulin-Charronnat, Bigand, & Koelsch, 2006), and that ERAN amplitudes to musical syntax violations are significantly higher in musicians compared to non-musicians (Koelsch et al., 2002). The ERP evidence therefore points to musical cortical response being shaped by musical expertise, though P600 musicianship effects have not been compared as yet. It is therefore plausible that non-musicians may recruit different cortical responses to music syntax violations that may seem similar in P600 amplitude and latency to language syntax violations, but may reflect qualitatively different components similar to P3a rather than P3b (see Polich, 2007 for a review of P3a and P3b). The non-musician may therefore recognise a musical syntax violation and respond as such, but due to the lack of expertise may lack the subsequent knowledge for the integrative processing observed in language syntax errors (Molinaro et al., 2011). Errors in language, however, would exhibit the integration of the syntactic error back into its sentential context – this processing stage may be only possible with prior domain-specific expertise, and may result in the P3b-like behaviour of P600 response-alignment.

In summary, P600 amplitude increases in both domains as the task-relevant deviance increases. Attention was found to be crucial in P600 as is found in P3, and P600 also showed a similar topographical distribution to P3-like activations in similar studies (Sassenhagen & Bornkessel-Schlesewsky, 2015; Sassenhagen & Fiebach, 2018). The characteristics of a parietally maximal distribution, attention-dependence, and of deviance-related amplitude increases are common in P3b research (Polich, 2007), and were observed in P600 amplitude changes Experiments 1 and 2. Some conflicting evidence was observed in P600 response-alignment, which was documented in P3 (Sassenhagen & Bornkessel-Schlesewsky, 2015) and language syntax P600 (Sassenhagen et al., 2014). Experiment 1 showed response-alignment in P600 to language syntax violations as well, but not in P600 elicited to music syntax violations. Furthermore, the conditional anterior shift of P3 (Segalowitz et al., 2001) was also seen in the P600 component elicited in the difficult task in Experiment 3. The combined findings of the present program of research indicate support for (or fail
to refute) the sharing of resources in language and music, whether as syntax-specific shared resources (Patel, 2012) or a P3-like P600 component (Sassenhagen et al., 2014). Both theoretical perspectives contribute towards a greater understanding of the combinatorial effects seen in language and music processing; as such, there is a possibility of fusing key concepts from each perspective to form a coherent whole.

While the lack of response-alignment in music P600 does provide some challenges to the SSIRH (Patel, 2012) and P600-as-P3 hypothesis (Sassenhagen et al., 2014), there are areas of overlap in the predictions put forth by both models with regards to the present program of research. Recent work has further suggested links between P3b-like characteristics with the P600 component, particularly with regard to the syntax-related P600 component (Leckey & Federmeier, 2019). Within the context of syntax processing in the present program of research, both hypotheses claim electrophysiological effects that are similar across language and music – both predict similar patterns of response-alignment, attention-dependence, and increased electrophysiological and behaviourally measured processing cost as double errors take place versus single errors. Aspects of each hypothesis may contribute to a better understanding of the same phenomena. For example, with regard to response-alignment, predictions based on the SSIRH may state that music syntax violation P600s would show response-alignment as in P600s to language syntax violations because of both domains sharing a syntax-specific resource. However, predictions based on the P600-as-P3 hypothesis state that P600 is actually P3b-like, and therefore will show response-alignment regardless of the domain in which it is elicited. With regard to syntax stimuli, both predict P600 response-alignment across domains, but provide different explanations for it. However, the absence of the P600-as-P3 hypothesis would exclude the response-alignment comparison entirely, as there would be no formal predictions for P600 response-alignment.

The SSIRH is analogous to a conceptual, abstract model such as Baddeley’s model of working memory (Baddeley, 2003, 2017). SSIRH is based on cognitive functions that first describe the functional processes underlying the suggested phenomena, then approximate its neurological
mechanisms. In fact, it is explicitly stated in the SSIRH that the proposed shared resources indicate functional connections, not focal brain areas – this may refer to a number of different brain regions, or functionally differentiated networks in the same brain region (Patel, 2012). The claims in the SSIRH are predicated on clinical research of a neurologically damaged population showing that P600 is not just a member of the P3 family, with an absence of P600 but a retained P300 following basal ganglia damage (Frisch et al., 2003), and therefore of P600 being a unique component that had distinguishing characteristics in language and music. As such, predictions based on the SSIRH are predominantly linguistic-musically focused, and therefore explains syntax and shared resources using higher-level structural terms; the initial suggestion that language and music may share structural processing resources in the SSIRH (Patel, 2003) has driven much behavioural and electrophysiological research in the last 20 years. Subsequent findings such as the appearance of a semantic P600 (Kuperberg, 2007) and of interactions of linguistic semantic processing with harmonic music manipulations (Perruchet & Poulin-Charronnat, 2013) have provided challenging evidence to the hypothesis, and suggest that the syntax-specificity of the P600 is not as clear in neurobiology as it is set out conceptually. Nevertheless, there remains strong evidence in support of the SSIRH. For example, the SSIRH is supported by observations of a so-called musician advantage in helping new language learning, pitch processing, or general cognitive processing (Asaridou & McQueen, 2013; Smayda, Chandrasekaran, & Maddox, 2015). This effect of musicianship on auditory processing and language is one phenomena that strongly suggests the interactivity of language-music resources that the SSIRH outlines (Patel, 2012).

In contrast, the P600-as-P3 hypothesis is more akin to a neuroanatomical approach to cognition such as Nieuwenhuis’ model of LC and the P3, which nominates a LC-centred network that drives arousal-related responses to external stimuli and producing what is measured as the P3 response (Nieuwenhuis et al., 2005). This approach involves first determining a plausible neuroanatomical network, then observing the electrophysiological responses related to its activity. The P600-as-P3 hypothesis suggests that the P3b of the P3 family of ERP components constitutes the
shared resources in language and music that are recruited in the generation of the P600 component. Due to the claims of P3b being the underlying neural response, not a language- or music-specific P600, it therefore claims that shared resources in language and music are not limited to syntax as in the SSIRH (Patel, 2012), or across those two domains at all. Instead, P3s (and by extension P600s) are elicited by tasks that require the access and updating of information, irrespective of the domain (Polich, 2007). For example, the onset of a target single-frequency tone in a two-choice auditory oddball will produce P3b (Katayama & Polich, 1998). The P600-related processes similar to P3b are the comparison of incoming stimuli with a prior context, such as a control tone at a certain frequency or the formation of a syntactic context in a sentence. This information is stored in working memory (Polich, 2007). When a target deviant stimulus is encountered, the processes recognising the relevant deviance and generating a response to it summate into the P3b response (Polich, 2007). In a similar fashion, P600 may represent the processing of a relevant syntactic deviance based on a prior sentential context, the content of which is stored in working memory. By claiming that the P3b reflects a general process that is used in both simple stimuli such as tones, and complex stimuli like language and music, thereby linking P600 and P3, the P600-as-P3 hypothesis provides the possibility of amalgamating the knowledge of the neurobiological generators of P3 into the P600 literature (Sassenhagen et al., 2014); for example, recent research has compared galvanic skin arousal responses alongside P600 to demonstrate the coincidence of P600 with LC-related physiological changes in arousal (Sassenhagen & Bornkessel-Schlesewsky, 2015).

The crucial point of difference between the SSIRH and P600-as-P3 hypothesis lies primarily in the aspect of syntax-specificity. The SSIRH constrains the shared resource across language and music, and only to syntax, whereas the P600-as-P3 hypothesis seeks to relate these shared resources to a more generalised neural network that processes domain-general stimuli as well. Where both hypotheses intersect is in syntax, and particularly in attended processing of syntax (LaCroix et al., 2015) across domains. Both theoretical perspectives suggest an identical process underlying both language and music syntax processing and would therefore predict identical patterns in both
directions for language-on-music and music-on-language syntax P600 effects of an attention-dependent nature. This resource would also expect to result in additive effects of syntax errors when dually presented and attended. The predicted pattern of findings was observed across Experiments 2 and 3. In addition, both hypotheses predicted shared response-alignment in Experiment 1, which was not observed in music P600. Further research could clarify the nature of this difference between domains. Nevertheless, by these two accounts, the P600 is therefore a centrally important ERP component to understand shared resources across domains, as it seems to correlate with the processing of a syntactic error. Overall, broadly supportive evidence was found for the P600 component as an index of the processing cost associated with syntactic integration, and P600 amplitude increases similarly to syntactic violations across domains regardless of task or attentional demands. While the present program of research does not directly contrast the SSIRH versus P600-as-P3 hypothesis, the findings of this thesis illustrate the complementary value of using the SSIRH as a theoretical framework by which the predictions of the P600-as-P3 hypothesis can be tested in both language and music P600 effects. The P600-as-P3 hypothesis introduces new analyses in understanding the language-music interaction, as well as postulating an alternative theoretical model of P600 generation. Despite the differences observed between both accounts of the language-music interaction, there is sufficient conceptual overlap to consider unifying both perspectives into a cohesive model; one which combines the neuroanatomical basis of the P600-as-P3 hypothesis with the empirically-focused cognitive model of the SSIRH. Such a model would have to be predicated on a generalised network such as the LC network at its core, with some extent of linguistic-musical specialised activation within that network. One such suggestion to unify both hypotheses is suggested below.

There is evidence implicating basal ganglia activity as part of a network that generates the P600 response (Frisch et al., 2003; Song et al., 2017), whereas the same activations are not consistently observed in P3. One such study mentions the basal ganglia as part of a locus coeruleus network that produces arousal-type responses (Song et al., 2017), such as found in galvanic skin
response with P600 (Sassenhagen & Bornkessel-Schlesewsky, 2015). P600 may therefore be representative of a process that begins initially with a P3-like activation for a syntax error, which appears and behaves similarly to the P3b. The subsequent unique activation that P600 elicits is therefore crucially related to healthy function in the basal ganglia, which is recruited when stimulus complexity is of a sufficiently high level to require more processing. This would explain why P600 is not present when basal ganglia damage has occurred (Frisch et al., 2003), but P3 is still intact. The merger of ideas from both hypotheses would then centre on a ventral attention and arousal network (Corbetta et al., 2008; Song et al., 2017) essential to generating the context updating process as indexed by the P3 and P600, graded in response to include basal ganglia in demanding situations. The P600 response would hence correlate with high-demand conditions of complex stimuli that require active processing, and would typically occur in the presence of challenging syntactic manipulations that may require a reallocation of subject and object in a sentence (Slevc et al., 2009), the repair and integration of an erroneous numeric form into its prior context (Shen et al., 2013), or the recognition and integration of an out-of-key chord into its musical tonality (Steinbeis & Koelsch, 2007). SSIRH and P600-as-P3 may thus converge in the sense of initially recruiting a LC/NE network and P3-like responses, with more complex stimuli in language and music recruiting further neural resources in the related arousal network, including the basal ganglia (Song et al., 2017). The syntax-specificity of the SSIRH is predicated on existing research showing unique syntax ERP responses (including the P600), as well as a differentiated role of the basal ganglia in producing P600 as opposed to the P3 (Frisch et al., 2003). The implementation of a graded P3-P600 response based on a LC plus basal ganglia arousal network could therefore resolve the differences in basal ganglia activation seen in P600, but not P3. P600 would therefore not be syntax-specific, while allowing for some neuroanatomical specialisation of the P600 above that seen in P3. However, the LC network driving P600 would predict that the general characteristics of the P600 would still largely resemble P3. This would help explain the similarities of P600 and P3 in response-alignment, attention-dependence, and combinatorial impairments in the present program of research, as well as similar time-frequency
(Brilmayer et al., 2017) and machine-learned EEG dynamics (Sassenhagen & Fiebach, 2018). As such, a combinatory perspective based on the P600-as-P3 hypothesis but integrating elements of the SSIRH would still support the findings in the present program of research. In order to understand the extent to which the SSIRH or P600-as-P3 hypothesis is a more accurate depiction of real-world electrophysiological response, more research is needed in understanding the conditions under which P600 is elicited to non-syntactic manipulations in action observation (Maffongelli et al., 2015), in arithmetic (Núñez-Peña & Escera, 2007; Núñez-Peña & Honrubia-Serrano, 2004), and in semantic conditions (Brouwer, Fitz, & Hoeks, 2012; Kuperberg, 2007), but perhaps most crucially in understanding the syntactic P600 as it relates to P3 across language and music.

In particular, there are potential comparisons to be made with linguistic versus arithmetic P600 components (Núñez-Peña & Escera, 2007; Núñez-Peña & Honrubia-Serrano, 2004) with regard to response-alignment. Similar to the music error-elicited P600 component, it is possible to ascertain if an arithmetic-based error elicits a response-aligned P600 component as well. Finding this pattern in arithmetic would provide further support that the P600 component behaves similarly across tasks, and therefore the idea that P600 is non-specific to language and music alone. The P600 component may simply represent the processing cost of integrating new information that violates a pattern-based prediction, and therefore apply across all situations where this situation is encountered. Such a conclusion would be much more in line with the claims in the P600-as-P3 hypothesis, and less so with the claims in the SSIRH. As this is not directly related to the language-music comparison, it is not part of the future directions of the project. Nevertheless, its theoretical implications are equally valuable and would supplement the language-music comparison.

One potential avenue to consider is that of syntax-specific processing only occurring in language and music because of the similar task conditions required to process syntax. For example, the identification of structural errors in language and language-like music manipulations (Brilmayer et al., 2017) could depend on the task, rather than language or music stimuli. Shared resources may thus be based on shared recruitment of task-specific resources. Such a perspective may appear to be
superficially distinct from the SSIRH and P600-as-P3 hypotheses, and perhaps provide a middle ground for the resolution of the syntax-specificity dividing both hypotheses. However, the redirection of focus from language and music syntax to that of task-specificity leads to a generalisation of the P600 from syntax-specific to domain-general. Simpler stimuli such as pictures, tones, and faces may well be able to engage a similar task and thus elicit P600-like activity. This would therefore propose P600-related brain activity as domain-general, which is quintessentially the P600-as-P3 hypothesis. However, such a perspective helps clarify and challenge both of the main extant hypotheses, and is valuable in that aspect.

The benefits of having alternative hypotheses such as the SSIRH and the P600-as-P3 hypothesis extend further to understanding the P600 in different linguistic and musical contexts. Apart from the new research questions the P3 family lends to the P600, the P600-as-P3 hypothesis has driven compelling research in machine learning of P3 to classify P600 trials (Sassenhagen & Fiebach, 2018), using language-like music manipulations to produce similar spectral power changes to language syntax violations (Brilmayer et al., 2017), and showing P600 response-alignment similar to P3 (Sassenhagen & Bornkessel-Schlesewsky, 2015). The latter study formed the rationale for Experiment 1, by comparing response-alignment of P600 in language and music. However, Experiments 2 and 3 are also equally eligible to compare P600 to syntax errors across domains. The P600-as-P3 hypothesis suggests that all of these syntactic comparisons will produce similar effects across domains, as P3 is the same resource across language and music (see Future Research Directions for added detail). Also, according to the P600-as-P3 hypothesis, a similarly-taxing semantic language task would equally require an update to the contextual processing and thus an enhanced P3/P600; this prediction generates differentiated hypotheses from the SSIRH, which would predict a lack of P600 in a semantic error. In summary, the P600-as-P3 hypothesis is one that is driving new investigations into the language-music interaction. Novel applications of EEG analyses in this field that can elucidate the relationship between language and music, and perhaps beyond.
Future work can further our understanding by examining this relationship in detail, using some of the new methods employed to better test the claims of the SSIRH.

5.3. Methodological Considerations

The sensitivity and viability of P600. Beyond the new findings that demonstrate the usefulness of the under-researched P600 component to provide an index of the processing cost underlying the processing of language and music syntax, the current program of research has also demonstrated the usefulness of some techniques, components, and analyses in examining the language-music syntax relationship. EEG, and in particular the P600 ERP component, is useful for understanding language and music syntax-related processing. The present program of research has sought to understand the characteristics of the P600 through response-alignment, selective-attention, and dual-attention tasks, in both single and simultaneous auditory presentation conditions. The comparison of P600 alongside behavioural performance shows that it is correlated with RT, though not reliably with task accuracy. This similar pattern in P600 and RT is important, as it highlights the importance of controlled processes in determining response, such as is indexed by the P600. Unattended errors did not affect either the P600 or RT, even when the unattended error coincided with an attended error in Experiment 2. However, in the dual-attention task of Experiment 3, we saw significantly higher P600 and RT for the dual error category. Task demand was the only difference between the two experiments, which demonstrates the crucial importance of seeing the effects of the resultant changes on electrophysiology in the P600 and behavioural performance in RT. As a result, while the earlier automatic processing stages of the ERAN and LAN are important in detecting even unattended syntax errors (Koelsch et al., 2005), it is the later P600 component where we observe performance costs to attended and actively processed syntax. Furthermore, the P600 demonstrates variability in response-alignment, which could possibly differentiate expertise or domain-specific differences in language and music past the grand average ERP alone. This suggests that P600 can isolate aspects of difference while establishing overarching similarities that potentially demonstrate the shared nature of language and music processing. Correlating P600 amplitude with RT and
detecting response-alignment differences are two findings in the present program of research that help validate the importance of this component in indexing the processing cost of syntax integration across domains.

**Single-trial analyses in the language-music comparison.** The present program of research has also showed the value of applying single-trial analyses in understanding the language-music interaction. For example, the use of P600 response-alignment analysis revealed crucial differences between domains, which has presented new information that the SSIRH may not have predicted. The current program of research also demonstrates the utility of developing new theoretical models of the language-music syntax interaction. New revisions of perspectives such as the P600-as-P3 hypothesis have brought in questions and analyses from the P3 family of research, including single-trial analyses and response-alignment, and even the idea of a neural underpinning of the locus coeruleus in driving P3b-related activity. While the SSIRH and P600-as-P3 hypothesis are not distinguishable in their current iterations (syntax-specificity versus domain-general processes), the further investigations of the differences between these theoretical models will allow for a stronger understanding of the neural underpinnings of the syntax-related processing in language and music.

**Use of the PoD in language experimental research.** Moreover, this series of experiments has validated the use of the PoD as a viable, and arguably recommended method of marking language syntax deviance. Doing so has produced more precise epochs that capture the violation-related processing in the language ERP. The P600s to language syntax errors relative to the PoD are now directly comparable to the P600s measured to chord onset in music syntax errors, as both precisely measure the point at which a deviance is perceivable. We find that language and music P600s calculated using PoD are also much earlier in latency compared to the canonical P600 (Osterhout & Holcomb, 1992, 1993), and now more closely resemble P3b in latency (Polich, 2007). Some studies have also reported somewhat diffused P600 effects with a less focal plateau-like P600 peak, indicative of a spreading of the P600 temporally over the grand averaged ERP waveform (Carrus et al., 2013; Spotorno et al., 2013). This may be the effect of temporal smearing as the P600 is recorded at the
stimulus onset if the stimulus onset is not the point at which the syntactic deviance is processed. Owing to the potentially large differences between word length (150-550ms) and the PoD of each word in these studies, P600 components may be less precisely epoched relative to the actual moment of deviance. Imprecise creation of epochs produces less focal ERP components by scattering P600 effects all across the time course of the ERP.

Furthermore, previous research has attempted to minimise this PoD discrepancy between word and error onset by choosing monosyllabic words. The onset of the word is said to therefore more closely mark the point of deviance. However, not only is this methodologically problematic for analysing the processing of the error tens, if not hundreds of milliseconds after the word onset, the set of words that can be utilised is also drastically reduced. The lack of diversity in critical words can be seen as lacking a more naturalistic sentence structure, where critical words are mono- and polysyllabic. Using PoD instead of word onset allows for any number of syllables to be used, as long as the PoD is clearly defined. The use of PoD is therefore a useful alternative to stimulus-onset alignment in measuring deviance-related processing, especially when the PoD for that stimulus is clearly discernible (as in our stimuli, with single/plural violations).

In the case of other syntactic violations, such as seen in morphosyntactic manipulations in German (Sassenhagen et al., 2014), however, the PoD may not be as easily determined. Furthermore, the conventional word onset-aligned responses of the (E)LAN and N400 are much less prominent when using the PoD versus traditional word onset-measured brain responses. Consequently, it is possible that ERPs epoched around the PoD can appear unexpectedly missing the abovementioned components. Coupled with an overall much earlier P600 component, this produces an overall different morphology of the ERP relative to word-onset ERPs. Consequently, the comparisons of language versus music (E)LAN and ERAN, or the N400 and N500 are not viable using the PoD, as such components are not well captured, if at all. The differences between ERP components means that use of the PoD in language syntax research has to be judiciously applied to the task and component of interest, with a clear idea of what effects will be examinable. In the current project, the *a priori*
research questions and hypotheses are heavily weighted toward P600 over the other components, as the extant hypotheses in the SSIRH (Patel 2003; 2012) and P600-as-P3 (Sassenhagen et al., 2014) focus on this component of interest. Preliminary analyses of the data show that the (E)LAN/ERAN and N400/N500 are absent in our dataset, possibly because of the focus on the PoD in the current project.

In addition, the timing of P600 between language and music may be affected by our use of the PoD – in Figure 4.4, for example, there appears to be a negativity that precedes the P600 effect, but it occurs a set duration before the negativity itself. This negative-positive waveform appears to occur earlier in language ERPs, which may be attributable to the use of PoD. There may be a case to be made for analysing language and music ERPs at different intervals if the peaks vary in latency. However, this *ad hoc* seeking of dataset-specific peak measurements is cautioned against in recent best practice guidelines (Luck & Gaspelin, 2017), as the numerous contributors to the amplitudes of the grand average ERP may skew *ad hoc* measurements of P600 to capture noise instead of actual neural signal.

Other considerations must be made to capitalise on the use of the PoD in language. Behavioural data can also be measured relative to the PoD, and specifically RTs can more precisely measure the time taken to process and respond to the exact point where the linguistic syntax violation was presented. This has the methodological advantage of measuring a direct comparison point to the musical chord onset, where the exact point at which deviance is discernible is equally measured across domains. This facilitates more direct comparison of behavioural-based syntax effects in RT, and could lead to a more precise assessment of syntax effects across domains.

Moreover, pre-processing steps need to be very clearly outlined for cross-comparison with conventional ERP studies. The pipeline used for the current project is accordant to conventional practices, with: a justifiable downsampling process for data management, a filter process, basic threshold-based data cleaning, ICA data cleaning, epoching or segmentation, epoch rejection for residual noisy individual trials, then ERP averaging. EEG research using ICA analyses are split
Regarding where they put the ICA in the pipeline, with some opting to use ICA analyses after epoching and others before. This project was analysed with the latter arrangement, as it accords greater flexibility in subsequent steps at the cost of potentially including non-trial noise into the analysis. However, the high density of the EEG system used for the project allows for more margin of error in accounting for noisy data as a separate noise-based component.

ICA analyses. With regard to the ICA analyses, there is some discussion on where the analysis should take place in the pre-processing pipeline. In all three experiments, ICA was initiated after filtering, as well as a broad continuous EEG artifact rejection stage. This comes with its strengths and limitations. One key strength of a later as opposed to an earlier ICA is that much of the excessively noisy portions can be removed first, signals which may otherwise drown out the overall EEG signal. For example, if highpass filter settings are too low, an ICA analysis would produce 128 noise components owing to the large amount of low-frequency noise in some testing environments. The large noise component is inseparable from the much smaller neural activity, and the analysis has no practical benefit to cleaning the data. Having the ICA follow a filter would produce much cleaner ICA components, which can then entirely remove smaller noise components while keeping the neural activity intact.

The key criticism of a later ICA stage is that large artifactual activity, such as the largest eyeblinks and eye movement activity, would be removed from the dataset. This would produce suboptimal eyeblink identification, and thus a suboptimal artifact rejection process through ICA. One justification for this choice of a later ICA stage is simply that a lot of muscular, large eyeblink, eye movement and so on components are removed in full before finer-tuned ICA analyses identify the smaller eyeblinks. This will increase signal-to-noise ratio and give more ICA components for the identification of smaller variations in the eyeblinks. A more granular ICA analysis means a better capturing of the electrical noise caused by eyeblinks and such, and therefore a better overall final signal.
Another criticism of later ICA analysis is that the lowpass filter would produce attenuated eye movement activity. As the higher, filtered-out frequencies are filtered out, eye movements may be much harder for ICA to identify effectively. This was not true of our ICA analysis, with eyeblinks and eye movements still constituting the highest three overall activity-contributing ICA components. Removal of such activity was therefore still very robust despite the lowpass filter. In summary, later ICA stage is particularly helpful in increasing signal-to-noise ratio before the ICA, which then produces high-quality independent ICA components that can remove noise and keep neural activity.

It is possible to improve on the ICA analyses used in the current project, with recent advances in the referencing of electrodes and its subsequent results (see Lepage, Kramer, & Chu, 2014) able to mitigate effects of a chosen reference electrode on relative electrical activity. An average reference of all electrodes is argued to the overall most comprehensive and thus recommended best-practice in the measurement of scalp-level brain activity (Dien, 2017). It may be argued that changing the reference electrode(s) before ICA might distort and change the eyeblink and movement activity, rendering them much harder to detect via the ICA analysis. While this is possible, it is unlikely to happen, as ICA will simply train itself to identify the eyeblinks and movement in its re-referenced form. As ICA analyses rely on relative voltage changes between electrodes, the referencing site (whether average of all or one single electrode) does not significantly impact its outputs. In summary, the analyses used in the current project are in line with current best practices for EEG analyses, though future research could implement even more powerful reference strategies.

**Music RT patterns.** Additionally, interesting RT effects were found in Experiments 1 and 2 with regard to music conditions. Error-free music control trials produced higher RTs than that of music syntax error trials in Experiment 1, which is a reversal of that seen in language trials in all experiments. Experiment 2 found no RT-based differences between error and control conditions to music syntax errors, even though P600 amplitudes were increased to the same music syntax violations compared P600s elicited to controls. It was only in Experiment 3 that music syntax violations produced similar RT increases as seen in language syntax violations versus controls. Perhaps this
variation in music RT effects across experiments has led to the adoption of other dependent performance measures, such as offline musical ratings (Kunert et al., 2016) or language-attended reading times (Slevc et al., 2009) instead of overt music RT tasks; RT may simply be a more challenging metric to capture condition-related behavioural effects in music syntax, though previous work has been able to attain clear RT effects to musical syntax manipulations (Sammler et al., 2013).

Nevertheless, under the right conditions (such as in Experiment 3) the control conditions produce a suitable baseline to measure RT impairments to musical syntax errors. The differences seen in language and music RT effects in the present program of research highlight the possible non-equivalence of eliciting and measuring syntax violations in language and music at the behavioural level, despite eliciting consistent P600 amplitude increases to attended syntax violations in all experiments in the present program of research.

**RT sensitivity and response-alignment.** Another possible reason why music RTs appear to behave unusually compared to our language RT effects is a lack of behavioural sensitivity to the syntax manipulations in the current project. This lack of sensitivity may be attributable to the lack of musical expertise as discussed above (see 5.2. Implications), where musically untrained participants would lack the ability to generate practiced judgments of music stimuli in a timely fashion. As discussed, this could predispose untrained participants to be more susceptible to the observed RT-metric effect, generate a more P3a-like neural activity (as opposed to the P600/P3b), and thus demonstrate a lack of response-alignment in Experiment 1. Future research may be able to confirm the credibility of this claim through replication, alternate links of behavioural or physiological response with P600 (as seen in Sassenhagen et al., 2015), and testing musically trained participants in a similar experimental paradigm.

5.4. Limitations

While the current program of research has shed new light on both the P600 component and the shared resources between language and music (as postulated in the SSIRH, Patel, 2012), there are also limitations that deserve consideration.
Active control conditions. Firstly, there was a lack of active control conditions in the experiments presented. Previous research has employed the use of arithmetic (Kunert et al., 2016), semantic (Koelsch et al., 2005), and loudness (Fedorenko et al., 2009) error conditions to compare syntax-related effects to more general deviance or salience-related processing. This allowed them to make conclusions regarding the unique interactions surrounding language and music syntax (Fedorenko et al., 2009; Koelsch et al., 2005; Kunert et al., 2016). The current study did not employ the same strategy, instead comparing syntax violations to error-free controls. The implementation of distractor trials in the current program of research was to minimise fixation on the critical progression-ending word or chord through the introduction of a syntax violation earlier in the progression. As such, syntax remained the only manipulation across both domains in the current program of research. Consequently, this limits the conclusions drawn from this program of research to inform on the characteristics of shared syntax resources in language and music as argued in the SSIRH, for example (Patel, 2012), and how such resources be similarly taxed across language and music syntax processing. The findings in the current program of research cannot, however, inform regarding the syntax-specificity of this shared resource, as no alternative language or music deviance was introduced. However, as the syntax-specificity of the shared language-music resource is now increasingly under debate (Sassenhagen et al., 2014; Slevc & Okada, 2015; Tillmann, 2012), questions regarding shared resources and syntax-specificity would require non-syntactic manipulations to compare with syntax-related processing costs.

The need to collect as many syntax violation trials for ERP analysis meant that session testing times were maximised for collecting hypothesis-specific syntax conditions, and the potential additions of active controls would have introduced prohibitively high trial counts in a single testing session. This led to a single-tracked focus on syntax violations, to the detriment of alternative comparisons with attention-grabbing non-syntactic deviants.

Response mapping. Secondly, the response mapping of experimental conditions was not kept consistent, especially in the third experiment. In Experiments 1 and 2, the probability of a trial
belonging to that of a syntax violation versus that of an error-free control was 50% – syntax violations were either present at the end of the progression or as a distractor trial with a violation in the middle. Participants in these experiments responded with one of only two possible buttons (error-free or syntax violation). Experiments 1 and 2 were therefore created to produce equiprobability of participant button response probability.

Experiment 2, for example, comprised control trials, attended errors, dual errors, and unattended errors. An unattended error and an error-free control would require the same no-error response (a “no error” response) to be correct, whereas an attended error and a dual error would require an “error” response indicating an error was present. This produced an equal likelihood of an error being present and attended (dual error and attended error) versus an error being absent (control) or unattended (unattended error, and unattended stimulus in dual error).

Experiment 3 responses were mapped differently from the preceding experiments - three physical responses (no error present, single error, dual error) were assigned to four experimental conditions (no error, language error, music error, dual error). Pilot testing participants expressed their decision making process in the three-choice task as being between four possible options for three physical responses. The task demand was therefore argued to be for four equiprobable options (25% per condition) and not three differentially probable responses, thereby making the experimental decision making process similar to that of earlier experiments.

However, a case can be made that a change in probabilities regarding the likelihood of an error being present or absent took place in Experiment 3. Syntax violations were present 75% of the time, with the remainder being control trials. Furthermore, the three-choice response mapping also added a layer of potential confound, with single errors (language or music) being mapped on the same button; dual errors (language and music) were mapped on another button. This led to the single error response being twice as likely as the dual error response to be correct if pressed.

Response probability effects may lead to higher P600/P3 amplitudes if a rarer stimulus is encountered (Polich, 2007), and therefore P600 amplitude differences for dual errors may have been
the product of stimulus probability. This is unlikely to be the sole contributor to condition-related differences, as controls were just as likely as dual errors and were significantly lower in P600 amplitude versus single errors. Despite this, the results for dual errors in Experiment 3 should be replicated in future research to confirm its veracity.

**Equivalence of language and music syntax violations.** Thirdly, the music and language violations might not be as equivalent as initially expected. Language syntax violations are still able to be syntactically repaired to a correct stated based on the incorrect syntactic form. For example, “The judge is reading out that laws” contains a syntactic number agreement violation but can still be repaired to a correct form “… reading out that law” of the judge reading a law aloud. This repair of the stimulus is based on the root word “law” and is possible to repair the presented word for a language syntax violation while retaining the semantic information of a law being read out. That said, the sentence remains ambiguous in its plurality – the sentence could also be reinterpreted as “reading out those laws” in the syntactic ambiguity created through the error.

In contrast, music harmonic errors comprise exclusively tonal information that violate musical tonal rules. A B major chord played in a C major tonality will nevertheless constitute an error, without any possibility of the listener extracting a correct syntactic form based on the error. There is no root word-like element to repair a progression if just examining the presented B major deviant chord. The violation of musical harmony therefore relies on the entire tonality of the progression to predict a sequence-ending root chord instead of element-by-element processing of a root word-like form as in language, and no repair of the specific element is possible if an error is encountered.

However, while it is difficult to disentangle the exact cognitive processes of syntax processing as being repair-based or prediction-based (Rohrmeier & Koelsch, 2012), current understanding suggests that language and music share a late stage of structural integration (Patel, 2012; Slevec & Okada, 2015; Tillmann, 2012) in the processing of a syntax violation. This may be based on the spreading activation of related lexical or musical elements based on prior stimuli (Patel, 2012), (re)analysis of structural aspects of the music or language progression (Koelsch, 2011a), or the
maintenance of a mental model as in information processing models of cognitive function (Slevc & Okada, 2015). These models of language and music processing all suggest that the overlap of language and music includes a repair stage involving the recognition of the syntax violation, then a reintroduction of the deviant stimulus into the context based on a predicted alternative syntactic form.

While no direct repair of the deviant musical chord is possible, it may be possible to replace the errant chord with the tonally-predicted one, thereby “repairing” it syntactically. This process of repair would more closely resemble a replacement process, similarly as the root word of the language syntax violation is substituted from unexpected syntactic form to an expected one. Therefore, despite the differences of language root word-based or music progression-based repair of the violating stimulus, the area of similarity between language and music proposed processing may lie in the expectation of an incoming stimulus, then the subsequent repair of a deviant stimulus as needed. The difference pathways of syntax building in language and music therefore may not result in different repair-related processes at the later stage, which is claimed to be indexed by the P600 (Patel, 2012).

If language and music syntax processing were differentiated along the time point of prediction and syntax repair, however, such an explanation would predict the differences observed in Experiment 1 response-alignment. Language syntax violations may require revision processes of the incoming deviant stimulus to repair the word into its predicted form (structural integration). This process may take a variable amount of time following the sensory and cognitive processing of the deviant stimulus, and lead to the observed response-aligned P600 component to language syntax violations. However, the musical context in the presented chord progression would have already generated a prediction of the progression-final critical chord. This would require no further reanalysis as the predicted form would either be present, or absent. The resultant P600-related activity would therefore be able to align itself to the onset of the chord, whereby an immediate assessment of chord congruency is made. Incongruent (syntax-violating) chords would be immediately recognised as such, and repair processes enacted to integrate the errant chord into a cohesive syntactic context. This would lead to a stimulus-aligned, not a response-aligned, P600 to music syntax violations.
In addition, the P600 amplitude effects seen in Experiment 1 helped support the similarity of strength in each domain’s syntax violation. The P600 effects helped consolidate the idea that syntax violations elicited comparable effects, whether in language or music. Coupled with the rigorous stimulus creation process, which included volume normalisation at the software level, unclear word pronunciation, PoDs, or uncommon word choices removed and re-recorded, and pilot testing helped ensure that the syntax violations were of similar type and strength. Therefore, while it is possible that the experimental material were different in strength or type, the data and rigorous creation process help support the idea that that is not the case.

Timing of syntax violations in simultaneous presentation. In Experiments 2 and 3, musical progressions were offset (delayed) to coincide with the PoD of the language sentence on a trial-by-trial basis. This meant that both streams of auditory stimuli had the exact point at which a deviance could originate, which conceptually increased the chance of shared syntax resource recruitment. One possible confound here is that musical deviance detection could simply be delayed until the word finished, thereby allowing for full concentration of the musical stimulus and its associated deviance. Pilot testing and experimental notes did not reveal this strategy to be considered viable. This is owing to the already slower RTs to music stimuli when presenting language and music progressions in isolation; further delaying RTs to wait for a clean music-only stimulus after the word would not be advised under those conditions.

It is possible that RTs and ERPs were processed sequentially in Experiments 2 and 3, where the critical word would be the initial focus, then the music. However, the Experiment 3 behavioural data suggest that RTs were very comparable between single language or single music errors, whereas dual errors were significantly higher in RT values compared to either of the single errors. Such a pattern of results suggests that instead of a sequential processing strategy for language first, then music, there was a concerted effort to process the deviance as soon as it occurred, whether in language or in music. Delays in RT were commonly associated with dual errors over single errors, which suggests that increased syntax processing cost led to an increased RT.
Type of language syntax violation. One way in which we could further investigate the diversity of syntax violations is to branch out from the plurality manipulations used here. In order to add variety to the types of syntax violations presented, one could manipulate subject- versus object-extracted (Fedorenko et al., 2009) sentences alongside plurality (Shen et al., 2013) manipulations. This should still elicit P600 effects, add heterogeneity to the stimulus set. Heterogeneity reduces the likelihood of sentences being predictable in the critical point of deviance. This could come in the form of a paragraph of text, pronounced sentence by sentence, with errors interspersed within the text.

It must also be noted that the sequence-ending nature of our stimuli may have led to the generation of associated components, which may have introduced confounding activity in the same time window such as the Closure Positive Shift (CPS; see Glushko, Steinhauer, DePriest, & Koelsch, 2016 for example). CPS may have contributed or constituted the effects we see in the data, and may appear to look similar to the effects observed here in the P600 component. The CPS occurs in line with variations in the predictability of prosody (speech and music timing) in a sequence, and produces a central or parietal activation similar in amplitude and timing to the P600. However, to do that requires a violation of the appropriate phrasing of a given sentence (Glushko et al., 2016). This factor was not manipulated at all in our stimulus set, which alongside the high predictability of our sentence structure and number of elements per sentence, reduces the likelihood that the CPS was elicited in the current experiment. Furthermore, the syntax violation conditions seen here elicited effects that were distinctly different from the control conditions, which suggests a consistent syntax-related effect unrelated to sequence closure. If closure were the main contributor, then we would expect the control conditions to also elicit CPS. This was not what we observed. However, future research can also minimise any potential confounds of the CPS by using mid-sequence syntax violations.

Number of elements in stimulus set. One additional aspect to the stimuli that could have impacted our RT findings in particular is that of the sequence length. A seven-word language sequence is suitable for all the syntactic violations used in the current project. However, a seven-
chord music sequence could have inadvertently introduced the RT-metric effect. This is because of the metric structure of music, which is often played in beats of four per musical interval, also called a bar. Seven chords would therefore constitute one-and-three-fourths of a bar, and the final eighth note may have contributed to a ~600 millisecond RT range for most music conditions. Such an effect, confounded by the stimulus, would’ve obscured any RT effects; the EEG data was seemingly unaffected, however. One counterpoint to this seven-chord sequence affecting syntax processing is that four to seven error-preceding chords have shown sufficient to produce P600s (Patel et al., 1998), and even two- and five-chord sequences were able to generate behavioural and P600 effects (Sammler et al., 2013). In particular, it appears that the sequence length in the above two studies was not inappropriate to elicit syntax violation processing, even when the sequences were odd-numbered. This suggests that the RT-metric effect may occur in specific contexts, and may not rely solely (or at all) on a seven-chord music sequence.

**Music control versus error chord repetition.** The music chord sequences used in the current project do play the canonical chord (the base chord of the sequence) at the first and middle chord of the sequence before the critical chord at the end. This was meant to a) set a canonical expectation of the base chord of the sequence at the very beginning, b) allow for a mid-sequence deviant such as seen in the language distractor conditions, and c) ensure that the untrained musical audience would recognise musical deviance despite their lack of musical knowledge.

However, one possible criticism presented is that of repetition. The playing of a chord twice over the sequence could prime the critical chord brain response to be habituated, reducing overall amplitudes with familiarity (Polich, 2007). This can be argued to happen more often in the case of earlier, more automatic components such as the P3a component. P600 may not be as affected as it relies less on sensory habituation to generate its associated change in amplitude, instead relying on syntax error processing (Patel, 1998).

Another issue related to music stimuli is related to acoustic changes in deviant chords resulting in physical (sensory) responses in brain response. This would constitute a confound of the P600
effects, where physical differences in control and deviant chords would be difficult to parse out from syntax-related differences. The experiments described in this project presented deviant chords that were extracted from control chords in other tonalities (B major ending-chord introduced to C major stem). This helped ensure that physical differences in control versus syntax violations would average out in the ERP; the B major chord as a control in a B major progression would then feature in a C major progression as a deviant chord, and the physical aspects of the B major would generate similar ERP components related to sensory processing. However, the B major in the deviant condition would have additional deviance-related P600 activity, which would then be captured. This may be something worth further controlling for in future research to help advance experimental controlling of acoustic differences.

**Experimental task.** Moreover, the experiments in this program of research employed a syntactic error detection task, where participants would process sentences and music progressions and assess them for syntax violations. Such a task has been successfully used in previous research (Koelsch et al., 2005; Schacht et al., 2014) to elicit syntax-related processing costs, but may not represent language processing in a more naturalistic comprehension task as in other research (Fedorenko et al., 2009). A simpler experimental task may therefore elicit P600-like responses that are not based on syntax processing per se, but rather on a simpler task-dependent target detection process. This is particularly relevant as the latency window of P600 components attained in the current project were earlier than expected across language and music, but especially so for the language syntax violations. Partial responsibility for that lies in the use of the PoD in measuring P600s. Measuring P600 components late in the word (where the error took place) would have led to an earlier latency window for an identical brain response measured at word onset.

Target detection processes may share similarities to oddball designs that elicit P3b (Polich, 2007), and may have elicited P3-like components that are qualitatively different to the processes related to sentence comprehension. There is a possibility that P3-like activations were elicited in the present program of research instead of P600-related activity. Whether this activity is similar or
differentiated is of recent and increasing debate (Brilmayer et al., 2017; Sassenhagen & Fiebach, 2018; Sassenhagen et al., 2014). However, an alternative proposition in the literature argues for the uniqueness of the P600 from P3 (Frisch et al., 2003; Osterhout & Hagoort, 1999), which may make task demand a matter of theoretical importance—simpler tasks may not elicit discourse-level language (and specifically syntax) processing.

It is therefore of theoretical importance that the tasks are comparable across domains, and both syntax-relevant in their implementation. Failing to do so would mean that a shared syntax resource as proposed in the SSIRH (Patel, 2012) would simply not be simultaneously taxed in Experiment 3. Furthermore, if tasks were not comparable across domains, then it is possible that the lack of response-alignment in music P600 may be attributable to the employment of a non-syntactic processing resource. This resource may well lack the response-alignment characteristics of the language P600 component seen in previous research (Sassenhagen et al., 2014).

However, two aspects of the data appear to support a comparable task being employed across language and music. Firstly, the similar pattern of a parietally-maximal P600 in the 300-500 millisecond window was elicited in both Experiments 1 and 2. This was replicated across language and music syntax violation conditions. Amplitude differences of the syntax violations were overall also comparable across language and music, with syntax-related increases to P600 amplitude in similar magnitudes. Furthermore, the combinatory increases of P600 amplitude in Experiment 3 were also indicative of shared resources being taxed simultaneously following a co-occurring language-music syntax violation. This provides circumstantial evidence demonstrating a similar task being imposed on participants for both domains.

That said, the design of the conducted experiments renders it challenging to ascertain exactly whether target detection or language/music comprehension took place in the current program of research. One way in which this can be clarified is the introduction of a word oddball task, where a target word is interspersed and responded to in a sentence. Sentence comprehension would therefore not be required in such a task, and a P3b-like response should result. Latency, amplitude, and
distribution of this component could be directly compared to the P600 elicited to syntax violations to determine their likeness. Due to the absence of such a task in the present program of research, it is unclear whether the P600 or a P3b is being elicited in the present task.

**Testing sample.** As part of the word-of-mouth recruitment strategy employed in the present project, there was a minority of participant overlap between experiments. This could have introduced familiarity or learning effects on the data collected for latter experiments, especially if the experiments were run one after the other in quick succession. However, this effect is minimised or likely to be negligible due to each experiment being timed at least three months apart at each point. Furthermore, experimental control and the differing task demands would further reduce the likelihood of such effects influencing the data in latter experiments; for example, participants in Experiment 2 stated that the instructed task forced them to listen purely to the attended condition (language or music), and paid no attention to the unattended stream. Participants who took part in Experiments 2 and 3 commented that Experiment 3 was extremely novel to them, as the task was different despite the stimuli used being identical in both experiments.

Another point to note regarding the testing sample is regarding the influence of individual differences in the language-music interaction. Formal training in music has distinct advantages in the language space along with the musical proficiency gained (Asaridou & McQueen, 2013). This meant that it was very important to ensure that musical training in the sample was to be kept at a minimum, so that the data could generalise to a non-musician sample. However, the operationalisation of a non-musician recruitment target was challenging. This was due to the extensive childhood experiences of most participants with music at some point, whether as a primary school group class or of an abortive two-month stint learning violin. In order to ensure we had large enough sample sizes with as little musical training as possible, the current project was populated with individuals who had not taken individual music classes in the last 10 years. Such a dearth of musical training would not constitute musical expertise, and thus would follow broad guidelines for nonmusicians lacking musical expertise (Besson & Faita, 1995) or no training outside school education (Guo & Koelsch, 2015). In other
studies, however, more strict criteria have been used where no formal music training or instrument playing is acceptable (Ungan et al., 2013).

The exclusion criteria employed in the current project may thus have been too liberal in accepting participants, as it is unclear how much musical training is required to constitute the acquisition of the musician advantage. Previous research appears to generally compare musical experts to untrained individuals (see Asaridou & McQueen, 2013 for a review). It is possible that the inclusion of individuals who were trained more than 10 years ago could constitute a musically-trained sample, and may have confounded the extent to which the findings in the current project can generalise to the non-musician population. It is unlikely that this is the case, but future research can investigate this.

**Individual differences.** Individual differences also exist between how language is processed in the brain (Tanner & van Hell, 2014). In a study by Tanner and van Hell (2014), the grand average ERP to syntax errors in language constituted a N400-P600 brain response, which represents a negative-electric response around 400 milliseconds after encountering the error followed by a positive-electric response at 600 milliseconds. However, individual ERP responses demonstrated a broad heterogeneity of brain responses, with some individual ERPs seemingly lacking the N400 or the P600 component. This lack of one or the other ERP component suggests that a negative-positive biphasic ERP response is not reliably elicited in individual ERPs, though the overall grand average may suggest that (Tanner & van Hell, 2014). Further research replicated this N400-P600 continuum (Tanner, Inoue, & Osterhout, 2014), and may be influenced by individual motivation, and the age of arrival at a second language environment among other variables. These studies highlight the influence of the individual differences that exist between participants, which may constitute the presence or absence of a given component. It is therefore important to keep in mind that some heterogeneity of ERP components is possible, and even expected, in language syntax ERP research.

**Experimental power.** A power analysis was performed for a repeated-measures experiment such as we were conducting, with the P600 component as the main effect size measured. This
produced a recommended testing sample of 22 participants. Experiment 1 had a notably smaller sample size than the recommended; this decision to keep that number was made in consultation with a member of the supervisory panel, Dr Urte Roeber, where a preliminary analysis at 16 final datasets showed that we had achieved statistical significance at that point. However, the calculations of sample sizes themselves are called into question, as little information exists to reliably set ‘gold standard’ sample sizes for the specific designs, tasks, stimuli, and components of a given experiment. There are significant challenges in performing power calculations for sample size in the ERP field, with precious few articles providing the prerequisite information needed to get a rudimentary assessment for sample sizes (Larson & Carbine, 2017). Therefore, future work can assist by providing variances and correlations among repeated measures. This added rigour would better help future sample size calculations.

**Impact of working memory.** One potential confound that we did not control for is the impact of individual working memory. In particular, the effects of distractors (see Causse et al., 2016) may be still present in individuals with a high capacity to handle a strenuous attended task, whereas individuals with less capacity may well lose a distractor effect if the task is intense enough. This would be in line with Tillmann’s (2012) postulation that verbal working memory is implicated in shared integration resources in language and music. It is possible to measure and compare these effects as a covariate in future studies.

5.5. **Future Research Directions**

The P600 literature base is still developing, especially with respect to comparing P600 in language and music. However, with the onset of new analyses and research questions regarding the cross-domain syntactic interaction, alongside new perspectives that suggest a broader intersection of neural mechanisms such as P3 employed in both simple and complex stimuli, there exist a number of new avenues for future research to develop on existing ideas.

Based on the theoretical speculation earlier regarding the possible elicitation of P3a-like activations in non-musician samples, one research question that comes from the present program of
research pertains to the potential effects of formal musical training on the characteristics of the P600 to musical syntax violations. One possible explanation to the lack of music response-alignment to the syntax-related P600 component could be based on musical expertise. A lack of music P600 response alignment may suggest that non-musician may not have the requisite explicit structural knowledge to consciously integrate the error into its syntactic context, instead relying on an implicit understanding of music to process the perceived syntax violations. Such differences in language and in music based on expertise may lead to a different recruitment of P600-generating neural networks, which would lead to our observed findings in Experiment 1. However, a musician sample would have high proficiencies in recognising both language and music syntax.

One possible future experiment could involve the same design as Experiment 1 but with musically-trained as well as untrained participants; this would allow the comparison of the effects of musical expertise on response-alignment. If prior formal training in music affects response-alignment of the music P600, recruiting P3b-like response-aligned resources with expertise, then musicians’ musical syntax error P600 components should exhibit response-alignment like their language P600 equivalents. P600 latency increases as RT increased would represent a qualitative difference of the musically-proficient individuals’ ability to process music compared to non-musicians, and demonstrate the modulating effect of expertise on P600 behaviour. In contrast, the failure to detect response-alignment in even the musical brain would suggest that there is an enduring qualitative difference in the music versus language P600 component regardless of expertise, and refute a claim of expertise on P600 response-alignment. P600 may therefore reflect the recruitment of a common resource through P600 elicited amplitudes relative to controls, but also express the domain-specific differences between how this resource is recruited through P600 response-alignment.

Two claims in the SSIRH allow for a potential future direction of research regarding the shared nature of language and music processing: of shared resources being syntax-specific, as well as of the P600 component as reflecting that shared resource (Patel, 2012). There is evidence of a semantic language violation producing a P600 amplitude increase (Faustmann et al., 2007; Martín-
Loeches, Nigbur, Casado, Hohlfeld, & Sommer, 2006; Van Herten, Kolk, & Chwilla, 2005), which suggests that P600 may be responsive to more than just syntax specifically. As we have found combinatorial effects of P600 amplitude increases to language and music syntax, a potential direction to pursue is with language semantic violations with musical syntax violations. There already exists some behavioural evidence to suggest combinatorial effects of language semantics with musical syntax (Hoch et al., 2011; Perruchet & Poulin-Charronnat, 2013). For example, Perruchet and Poulin-Charronnat showed interactions of musical syntax with a semantic garden path manipulation (2013), akin to what was implemented in earlier syntactic garden path manipulations (Slevc et al., 2009).

These garden paths (e.g. “After the trial the attorney advised/advised that the defendant was likely to commit more crimes.”; “The old man went to the river bank/the bank to withdraw his net which was empty.”) produced comparable impairments to syntactic equivalents, which combined with unattended musical syntax violation impairments to generate significantly increased reading times compared to language semantic violations without the accompanying musical violations (Perruchet & Poulin-Charronnat, 2013). Such a finding provided evidence for the idea that language semantic processing may be shared with musical syntax in the same way that language syntax is. A subsequently proposed shared process of semantic and syntactic integration suggests that the P600 represents integration of any error into a context (Brouwer et al., 2012).

Another future experiment could utilise challenging semantic manipulations in language that require complex integration into a sentential context, such as the semantic garden path, alongside syntactic manipulations of a similar nature. Listening to chunks of words in a self-paced reading time task, participants would read visually-presented sentences whilst musical chords are played, but ignored, chunk-by-chunk. The SSIRH postulates that the shared resources between language and music are syntax-specific, and semantic garden path manipulations would therefore not interact with processing costs or electrophysiological responses caused by musical syntax. However, as this was not the case with prior behavioural research (Perruchet & Poulin-Charronnat, 2013), an electrophysiological point of comparison may reveal a) a language-semantic P600 effect b) that is
amplified by an unattended musical syntax error similar to the combinatorial effects of dual errors in Experiment 3.

P600 amplitude increases with increased behavioural impairments would further show the functional co-occurrence observed in the present program of research, and extend the syntax-to-syntax relationship to that of a semantic-syntactic manipulation. This extension to a semantic manipulation would challenge the syntax-specificity of the language-music relationship as outlined in the SSIRH. Instead, a more general resource as suggested by the P600-as-P3 hypothesis would be more consistent in explaining those findings as processing cost increases to multiple aspects of language, not limited to syntax alone. Such an extension of the findings in the current program of research would help alleviate a limitation in the current program of lacking an active control condition. Error-free controls as implemented in the experiments of the present program of research served to provide a comparison for the effects of syntactic violations. However, the design did not control for the effects of attention-based changes to behaviour or P600 amplitude change. The inclusion of semantic, intensity (or loudness), and timbre errors (Koelsch et al., 2005) into the overall comparisons could help clarify the specific effects of linguistic syntax with musical equivalents.

Thirdly, the utilisation of emerging analyses can help further understand the electrophysiological dynamics underlying P600 responses in language and music syntax. Recent studies have compared changes in the time-frequency decomposition in EEG to expose similarities in how language morphosyntactic violation P600 behaves relative to a P3 face detection task (Brilmayer et al., 2017), which was particularly similar in the theta and delta bands of the EEG. Another recent study has used a similar morphosyntactic language manipulation to elicit P600, which was then compared to P3 by machine learning (MVPA); this found that language syntax P600 is discernible to a machine trained to recognise P3 data (Sassenhagen & Fiebach, 2018). Both studies highlight how these new analyses can elucidate the ways in which musical syntax P600 alongside a P3 task can be compared, and demonstrating a similarity of response between a syntactic and non-syntactic (P3) condition. Other alternatives also exist, such as the use of a cluster-based permutation
analysis to show distinct regions of brain responses independent of human biases. This non-hypothesis-driven approach may reveal new areas of interaction in the data that have missed the rigid, hypothesis-driven approach applied here.

In doing so, future research could challenge not only syntax-specificity as claimed in the SSIRH (Patel, 2012), but also affirm the claims of the P600-as-P3 hypothesis to extent P600 beyond syntax as a member of the P3 family (Sassenhagen et al., 2014). By separately employing an attended detection task, identifying errors alongside error-free controls in both a musical syntax and face detection task, the time-frequency spectrum of P600 and P3 could be compared to assess aspects of similarity in the theta and delta bands. Qualitatively different spectral dynamics of frequency-band power and coherence change should be observed. That same EEG data could be run with MVPA to identify patterns in the P3 response, which would result in the algorithm being trained to recognise that specific pattern in EEG data. Applying this P3-trained algorithm to musical syntax P600 would provide a bias-free and computationally intensive comparison of the musical syntax P600 versus P3. If P600 is a member of the P3 family, then P3-trained MVPA would successfully classify P600 trials as seen in previous work (Sassenhagen & Fiebach, 2018). Like the time-frequency analyses, MVPA classification of P600 using P3 data would also challenge the SSIRH’s language-music perspective, yet also provide support for the P600-as-P3 hypothesis. Both analyses of the same data would thus provide converging evidence to support or challenge the SSIRH and the P600-as-P3 hypotheses, using the P3 as a third point of comparison to provide differentiated predictions between each hypothesis.

5.6. Conclusions

The findings of the present program of research lead to three conclusions. Firstly, response-alignment has shown that P600 does not behave exactly in music as in language. This implies somewhat domain-specific recruitment of the P600-related neural networks, and has implications for both the SSIRH and P600-as-P3 hypothesis, as both would predict P600 response-alignment in both
domains. Future work is needed to better understand why this qualitative difference occurs between language and music.

Secondly, we found similarities in P600 elicitation when undergoing similar task conditions. P600 was only elicited in an attended syntax error in both directions (Experiment 2), verifying the shared attentional characteristics of syntax processing across domains. P600 effects were accompanied by significantly increased RTs in attended language syntax violations, and non-significant RT results in attended syntax violations versus controls in music; the musical RT patterns in this case may be explained by a metric preference in control trials that encourages adherence to 600ms, which coincided with as-fast-as-possible syntax violation RTs.

Thirdly, a separate experiment (Experiment 3) showed the effect of dually-attended syntax errors generating combinatory P600 amplitude increases alongside RT impairments, and that these P600 amplitudes and RT increases were significantly higher than those of single errors in either domain. These findings suggest that there is still a strong case for overlapping neural resources underlying language and music as indexed by the P600, despite some observed differences in the behavioural results of Experiment 2.

The present program of research has also demonstrated a novel combination of methodological and analysis elements, which are centred around the use of an attended syntax processing task. Doing so elicits the attention-dependent P600, which can be processed using emerging analyses (such as response-alignment analyses) in further understanding the language-music relationship. Interestingly, the conscious processing of syntax seems to result in increased attentional load and task demand, reducing the effect of unattended syntax errors on the attended task. Lastly, the use of the PoD is a novel application of creating precise trial-by-trial epochs of the ERP. This method of epoch creation seems to focalise P600 components that appear to resemble P3b in latency and distribution. The present program of research has shown the advantages of task demand and methodological aspects that can be implemented in future work.
In addition, these findings have theoretical implications that extend beyond syntax in both domains, while using music as a compelling alternative point of comparison alongside language in understanding the nature of their purported shared resources and higher cognitive processes in general. Future research can use a suite of new analyses including spectral data from the time-frequency decomposition, alongside typical ERP comparisons of the language P600 with musical P600 and the P3. The findings from the present program of research contribute to the literature by generating a new point of difference in P600 response-alignment, as well as broad similarities of P600 attention-dependence, distribution, amplitude change, and latency across domains.

In summary, the claims of shared resources as put forth by the SSIRH as well as the P600-as-P3 hypothesis provide the context for our findings of differentiated, yet largely similar processing of syntax in language and music. Underlying syntax-related processes across domains may rely on more general processes as indexed by the P3 family of responses (P600-as-P3 hypothesis) or be language- and music-specific (SSIRH). However, neither perspective has the ability to further investigate this question without the cognitive processes as indexed by the P600. The P600 correlates with RT impairment at the behavioural level. It displays similar patterns of response across language and music, and reflects the increased deviance of dual errors. Lastly, the response-alignment analyses demonstrate the sensitivity displayed in the P600 component to further examine cross-domain differences beyond the ERP. It is for these reasons that the under-researched P600 is an ideal ERP component for future research in the investigation of the language-music interaction, and potentially inquire new proposed links to general processes instead of a language and music syntax-specific process.
References


Carrus, E., Pearce, M. T., & Bhattacharya, J. (2013). Melodic pitch expectation interacts with neural
responses to syntactic but not semantic violations. *Cortex, 49*, 2186–2200. doi:10.1016/j.cortex.2012.08.024


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Tillmann, B. (2012). Music and language perception: Expectations, structural integration, and


# 6. LIST OF APPENDICES

Appendix A: Participant Questionnaire

**Questionnaire**

An examination of shared neural resources in language and music

<table>
<thead>
<tr>
<th>Participant’s code:</th>
<th></th>
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<tbody>
<tr>
<td>Date:</td>
<td>Time:</td>
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</tbody>
</table>

- **Sex**
  - [ ] Male
  - [ ] Female

- **Age**
  - ....

- **Sight**
  - [ ] Normal
  - [ ] Corrected
  - [ ] Impaired

- **Hearing**
  - [ ] Normal
  - [ ] Corrected
  - [ ] Impaired

- **Dominant hand**
  - [ ] Right
  - [ ] Left

- **Native Language**
  - .................................................................

- **Which other languages are you fluent in?**
  - .................................................................

- **Musical Influences**
  - Have you primarily listened to tonal Western music throughout your life (pop, classical, country, rock, blues, jazz, etc.)?
    - [ ] Yes
    - [ ] No

- **Formal Training**
  - Have you had formal training on a musical instrument?
    - [ ] Yes
    - [ ] No

Please specify your formal musical training:
*Note: “Individual” means years of one-on-one private lessons; “group” means years of training with one teacher and several students simultaneously (e.g., school class).

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Individual (years)</th>
<th>Group (years)</th>
<th>Age started – ended</th>
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Are you still musically active (formal or recreational activities)?
- Yes
- No

If YES, how many hours/week (on average) do you do music? .................

If NO, how long has it been since you did musical activities? .................

Musical Activity

Last night’s sleep
- Good
- Ok
- Bad

Today’s concentration
- Good
- Ok
- Bad

Course Credit
- Yes
- No, movie ticket lucky draw

Habits

<table>
<thead>
<tr>
<th>Smoking</th>
<th>Yes</th>
<th>No</th>
<th>How much per day?</th>
<th>When last?</th>
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<tr>
<th>Alcohol</th>
<th>Yes</th>
<th>No</th>
<th>How much per day?</th>
<th>When last?</th>
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<tr>
<th>Caffeine</th>
<th>Yes</th>
<th>No</th>
<th>How much per day?</th>
<th>When last?</th>
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<tr>
<th>Medication that affects nervous system (excluding contraceptives)</th>
<th>Yes</th>
<th>No</th>
<th>How much per day?</th>
<th>When last?</th>
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If yes (type?): ..........................................................................................
## Appendix B: Language Stimuli

### Table B6.1

**List of language stimuli**

<table>
<thead>
<tr>
<th>Sentence Type</th>
<th>Sequence Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct</td>
<td>The mouse is creeping into those crates.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The mouse is creeping into that crates.</td>
</tr>
<tr>
<td>Correct</td>
<td>The pilot is sitting inside that cockpit.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The pilot is sitting inside those cockpit.</td>
</tr>
<tr>
<td>Correct</td>
<td>The doctor is working for that clinic.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The doctor is working for those clinic.</td>
</tr>
<tr>
<td>Correct</td>
<td>The koala is hanging from that offshoot.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The koala is hanging from those offshoot.</td>
</tr>
<tr>
<td>Correct</td>
<td>The technician is tinkering with that radio.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The technician is tinkering with those radio.</td>
</tr>
<tr>
<td>Correct</td>
<td>The judge is reading out those laws.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The judge is reading out that laws.</td>
</tr>
<tr>
<td>Correct</td>
<td>The lawyer is strutting towards that courtroom.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The lawyer is strutting towards those courtroom.</td>
</tr>
<tr>
<td>Correct</td>
<td>The dolphin is swimming towards that boat.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The dolphin is swimming towards those boat.</td>
</tr>
<tr>
<td>Correct</td>
<td>The mosquito is buzzing around those rats.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The mosquito is buzzing around that rats.</td>
</tr>
<tr>
<td>Correct</td>
<td>The engineer is drilling into that rock.</td>
</tr>
<tr>
<td>---------</td>
<td>----------------------------------------</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The engineer is drilling into those rock.</td>
</tr>
<tr>
<td>Correct</td>
<td>The girl is skipping towards those classrooms.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The girl is skipping towards that classrooms.</td>
</tr>
<tr>
<td>Correct</td>
<td>The sloth is climbing up that trunk.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The sloth is climbing up those trunk.</td>
</tr>
<tr>
<td>Correct</td>
<td>The accountant is strolling towards that cubicle</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The accountant is strolling towards those cubicle</td>
</tr>
<tr>
<td>Correct</td>
<td>The frog is leaping from that stone</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The frog is leaping from those stone</td>
</tr>
<tr>
<td>Correct</td>
<td>The florist is tidying up those bouquets.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The florist is tidying up that bouquets.</td>
</tr>
<tr>
<td>Correct</td>
<td>The squirrel is scurrying towards those acorns.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The squirrel is scurrying towards that acorns.</td>
</tr>
<tr>
<td>Correct</td>
<td>The counsellor is writing up several reports.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The counsellor is writing up this reports.</td>
</tr>
<tr>
<td>Correct</td>
<td>The butcher is slicing up those steaks.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The butcher is slicing up that steaks.</td>
</tr>
<tr>
<td>Correct</td>
<td>The cockroach is scuttling towards that hole.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The cockroach is scuttling towards those hole.</td>
</tr>
<tr>
<td>Correct</td>
<td>The bird is swooping towards that worm.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>Incorrect Sentence</td>
</tr>
<tr>
<td>-----------------</td>
<td>--------------------</td>
</tr>
<tr>
<td>The bird is swooping towards those worm.</td>
<td>The barista is taking down that order.</td>
</tr>
<tr>
<td>The barista is taking down those order.</td>
<td>The producer is stomping towards those set.</td>
</tr>
<tr>
<td>The carpenter is cutting into these log.</td>
<td>The snake is slithering up that tree.</td>
</tr>
<tr>
<td>The swimmer is swimming against that tide.</td>
<td>The swimmer is swimming against those tide.</td>
</tr>
<tr>
<td>The lion is sprinting after that gazelles.</td>
<td>The boy is singing for those girls.</td>
</tr>
<tr>
<td>The ape is swinging from those bars.</td>
<td>The drunk is wandering towards that hospital.</td>
</tr>
<tr>
<td>The butterfly is fluttering towards several flowers.</td>
<td>The butterfly is fluttering towards this flowers.</td>
</tr>
<tr>
<td>Correct</td>
<td>Syntactic Error</td>
</tr>
<tr>
<td>----------------------------------------------</td>
<td>------------------------------------------------------</td>
</tr>
<tr>
<td>The artist is climbing up those stairs.</td>
<td>The artist is climbing up that stairs.</td>
</tr>
<tr>
<td>The usher is gesturing towards those seats.</td>
<td>The usher is gesturing towards that seats.</td>
</tr>
<tr>
<td>The crocodile is crawling into that swamp.</td>
<td>The crocodile is crawling into those swamp.</td>
</tr>
<tr>
<td>The elephant is lumbering towards that pond.</td>
<td>The elephant is lumbering towards those pond.</td>
</tr>
<tr>
<td>The eagle is diving towards several rabbits.</td>
<td>The eagle is diving towards that rabbits.</td>
</tr>
<tr>
<td>The milkman is walking towards several streets</td>
<td></td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The milkman is walking towards this streets</td>
</tr>
<tr>
<td>---------------</td>
<td>-----------------------------------------</td>
</tr>
<tr>
<td>Correct</td>
<td>The postman is running from those dogs.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The postman is running from that dogs.</td>
</tr>
<tr>
<td>Correct</td>
<td>The merchant is driving towards those markets</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The merchant is driving towards that markets</td>
</tr>
<tr>
<td>Correct</td>
<td>The student is reciting from those textbooks.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The student is reciting from that textbooks.</td>
</tr>
<tr>
<td>Correct</td>
<td>The officer is marching with those soldiers.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The officer is marching with that soldiers.</td>
</tr>
<tr>
<td>Correct</td>
<td>The penguin is waddling on that shore.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The penguin is waddling on those shore.</td>
</tr>
<tr>
<td>Correct</td>
<td>The dog is bounding in those fields.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The dog is bounding in that fields.</td>
</tr>
<tr>
<td>Correct</td>
<td>The bull is stomping towards those stands.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The bull is stomping towards that stands.</td>
</tr>
<tr>
<td>Correct</td>
<td>The turtle is paddling into that ocean.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The turtle is paddling into those ocean.</td>
</tr>
<tr>
<td>Correct</td>
<td>The kangaroo is hopping into that forest.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The kangaroo is hopping into those forest.</td>
</tr>
<tr>
<td>Correct</td>
<td>The model is posing for those cameras.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The model is posing for that cameras.</td>
</tr>
<tr>
<td>Correct</td>
<td>The</td>
</tr>
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<td>---------</td>
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</tr>
<tr>
<td>Syntactic Error</td>
<td>The</td>
</tr>
<tr>
<td>Correct</td>
<td>The</td>
</tr>
<tr>
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<td>Correct</td>
<td>The</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>Correct</td>
</tr>
<tr>
<td>-----------------</td>
<td>---------</td>
</tr>
<tr>
<td>The medic is attending to these wound.</td>
<td>The climber is heading for those mountains.</td>
</tr>
<tr>
<td>The salesman is rushing towards that customers.</td>
<td>The cyclist is pedaling up that slope.</td>
</tr>
<tr>
<td>The runner is striding towards those path.</td>
<td>The diplomat is chatting with several ministers.</td>
</tr>
<tr>
<td>The chef is chopping up that onions.</td>
<td>The waiter is serving up these plates.</td>
</tr>
<tr>
<td>The customer is paying for these product.</td>
<td>The actor is performing for this crowd.</td>
</tr>
<tr>
<td>The butler is helping out that guests.</td>
<td></td>
</tr>
<tr>
<td>Correct</td>
<td>The assistant is carrying down that bag.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The tradesman is rushing into those store.</td>
</tr>
<tr>
<td>-----------------</td>
<td>------------------------------------------</td>
</tr>
<tr>
<td>Correct</td>
<td>The elder is yelling out these commands.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The elder is yelling out this commands.</td>
</tr>
<tr>
<td>Correct</td>
<td>The client is waving towards that buyer.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The client is waving towards those buyer.</td>
</tr>
<tr>
<td>Correct</td>
<td>The lecturer is laughing at this joke.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The lecturer is laughing at these joke.</td>
</tr>
<tr>
<td>Correct</td>
<td>The chimp is dangling from those beams.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The chimp is dangling from that beams.</td>
</tr>
<tr>
<td>Correct</td>
<td>The cat is hissing at those burglars.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The cat is hissing at that burglars.</td>
</tr>
<tr>
<td>Correct</td>
<td>The pig is trotting into that barn.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The pig is trotting into those barn.</td>
</tr>
<tr>
<td>Correct</td>
<td>The steward is focusing on those passengers.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The steward is focusing on that passengers.</td>
</tr>
<tr>
<td>Correct</td>
<td>The valet is looking at that superstar.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The valet is looking at those superstar.</td>
</tr>
<tr>
<td>Correct</td>
<td>The president is speaking at this meeting.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The president is speaking at these meeting.</td>
</tr>
<tr>
<td>Correct</td>
<td>The mayor is signalling towards those buildings.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The mayor is signalling towards that buildings.</td>
</tr>
</tbody>
</table>

262
<table>
<thead>
<tr>
<th>Correct</th>
<th>The</th>
<th>broker</th>
<th>is</th>
<th>trudging</th>
<th>into</th>
<th>that</th>
<th>conference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Syntactic Error</td>
<td>The</td>
<td>broker</td>
<td>is</td>
<td>trudging</td>
<td>into</td>
<td>those</td>
<td>conference</td>
</tr>
<tr>
<td>Correct</td>
<td>The</td>
<td>policeman</td>
<td>is</td>
<td>asking</td>
<td>for</td>
<td>that</td>
<td>notepad.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The</td>
<td>policeman</td>
<td>is</td>
<td>asking</td>
<td>for</td>
<td>those</td>
<td>notepad.</td>
</tr>
<tr>
<td>Correct</td>
<td>The</td>
<td>monkey</td>
<td>is</td>
<td>picking</td>
<td>up</td>
<td>those</td>
<td>bananas.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The</td>
<td>monkey</td>
<td>is</td>
<td>picking</td>
<td>up</td>
<td>that</td>
<td>bananas.</td>
</tr>
<tr>
<td>Correct</td>
<td>The</td>
<td>scientist</td>
<td>is</td>
<td>testing</td>
<td>out</td>
<td>that</td>
<td>idea.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The</td>
<td>scientist</td>
<td>is</td>
<td>testing</td>
<td>out</td>
<td>those</td>
<td>idea.</td>
</tr>
<tr>
<td>Correct</td>
<td>The</td>
<td>designer</td>
<td>is</td>
<td>drawing</td>
<td>up</td>
<td>those</td>
<td>plans.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The</td>
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<td>is</td>
<td>drawing</td>
<td>up</td>
<td>that</td>
<td>plans.</td>
</tr>
<tr>
<td>Correct</td>
<td>The</td>
<td>man</td>
<td>is</td>
<td>jogging</td>
<td>towards</td>
<td>that</td>
<td>park.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The</td>
<td>man</td>
<td>is</td>
<td>jogging</td>
<td>towards</td>
<td>those</td>
<td>park.</td>
</tr>
<tr>
<td>Correct</td>
<td>The</td>
<td>thief</td>
<td>is</td>
<td>sneaking</td>
<td>into</td>
<td>this</td>
<td>bank.</td>
</tr>
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<td>Syntactic Error</td>
<td>The</td>
<td>thief</td>
<td>is</td>
<td>sneaking</td>
<td>into</td>
<td>these</td>
<td>bank.</td>
</tr>
<tr>
<td>Correct</td>
<td>The</td>
<td>clerk</td>
<td>is</td>
<td>budgeting</td>
<td>for</td>
<td>this</td>
<td>party.</td>
</tr>
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<td>Syntactic Error</td>
<td>The</td>
<td>clerk</td>
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<td>for</td>
<td>these</td>
<td>party.</td>
</tr>
<tr>
<td>Correct</td>
<td>The</td>
<td>handler</td>
<td>is</td>
<td>attending</td>
<td>to</td>
<td>those</td>
<td>singers.</td>
</tr>
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<td>The</td>
<td>handler</td>
<td>is</td>
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<td>to</td>
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</tr>
<tr>
<td>Correct</td>
<td>The</td>
<td>architect</td>
<td>is</td>
<td>planning</td>
<td>with</td>
<td>this</td>
<td>group.</td>
</tr>
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<td>Syntactic Error</td>
<td>The</td>
<td>architect</td>
<td>is</td>
<td>planning</td>
<td>with</td>
<td>these</td>
<td>group.</td>
</tr>
<tr>
<td>Correct</td>
<td>The</td>
<td>farmer</td>
<td>is</td>
<td>marking</td>
<td>out</td>
<td>those</td>
<td>crops.</td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The farmer is marking out that crops.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------</td>
<td>--------------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct</td>
<td>The guard is staring at those boys.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The guard is staring at that boys.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct</td>
<td>The painter is sketching with this pen.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The painter is sketching with these pen.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct</td>
<td>The director is chatting with this intern.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The director is chatting with these intern.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct</td>
<td>The auditor is swearing at those workers.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The auditor is swearing at that workers.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct</td>
<td>The author is scripting with that pencil.</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Syntactic Error</td>
<td>The author is scripting with those pencil.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Correct</td>
<td>The craftsman is splicing out those wires.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The craftsman is splicing out that wires.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct</td>
<td>The baker is preparing for this banquet.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The baker is preparing for those banquet.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct</td>
<td>The bride is booking up those venues.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The bride is booking up that venues.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct</td>
<td>The therapist is practicing for that session.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Syntactic Error</td>
<td>The therapist is practicing for those session.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct</td>
<td>The editor is editing for that website.</td>
<td></td>
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<td>Syntactic Error</td>
<td>The editor is editing for those website.</td>
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<td>The botanist is smiling with those awards.</td>
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<td>The brewer is pointing out those barrels.</td>
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<td>The labourer is shifting up those pallets.</td>
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<td>The banker is ranting about those clients.</td>
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<td>The singer is skipping into that theatre.</td>
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<td>The pharmacist is arriving at these warehouse.</td>
<td>The husband is storming into that café.</td>
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<td>The husband is storming into those café.</td>
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<td>The concierge is bolting from those hotel.</td>
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<td>The bellboy is scrambling up that ramp.</td>
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<td>The drycleaner is proud of those shirts.</td>
<td>The drycleaner is proud of that shirts.</td>
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<td>The curator is hanging up those paintings.</td>
<td>The curator is hanging up that paintings.</td>
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<td>The guide is calling towards that tourist.</td>
<td>The guide is calling towards those tourist.</td>
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<td>The developer is coding for this program.</td>
<td>The developer is coding for these program.</td>
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<td>The geologist is digging into those canyons.</td>
<td>The geologist is digging into that canyons.</td>
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<td>The goldsmith is crafting with those tools.</td>
<td>The goldsmith is crafting with that tools.</td>
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<td>The grower is pruning with this saw.</td>
<td>The grower is pruning with these saw.</td>
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<td>The gunsmith is wiping down this weapon.</td>
<td>The gunsmith is wiping down these weapon.</td>
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<td>The stylist is designing for that show.</td>
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<th>Syntactic Error</th>
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<td>The stylist is designing for those show.</td>
<td>The handyman is drilling into those boards.</td>
<td>The handyman is drilling into that boards.</td>
<td>The historian is taking down those events.</td>
<td>The historian is taking down that events.</td>
<td>The trainer is shouting at this athlete.</td>
<td>The trainer is shouting at these athlete.</td>
<td>The analyst is looking up those files.</td>
<td>The analyst is looking up that files.</td>
<td>The spy is skulking along that alley.</td>
<td>The spy is skulking along those alley.</td>
<td>The jockey is surging towards those stalls.</td>
<td>The jockey is surging towards that stalls.</td>
<td>The journalist is typing with that keyboard.</td>
<td>The journalist is typing with those keyboard.</td>
<td>The kitchenhand is peeling with that peeler</td>
<td>The kitchenhand is peeling with those peeler</td>
<td>The librarian is scanning for those novels.</td>
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<td>The</td>
<td>locksmith</td>
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<td>The plumber is throwing away those pipes.</td>
<td>The machinist is filing down that screw.</td>
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<td>The examiner is reading through those papers.</td>
<td>The publisher is printing for this comic.</td>
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<td>The presenter is drawing on that whiteboard.</td>
<td>The worker is trudging along those hallways.</td>
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<td>The chaplain is talking to this teacher</td>
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<td>The patient is coughing into that napkin.</td>
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<td>The researcher is working with those numbers.</td>
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<td>The camper is exploring around that cabin.</td>
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<td>The scout is slinking behind those hills.</td>
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<td>The miller is grinding down these crops.</td>
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<td>The miller is grinding down this crops.</td>
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<td>Correct</td>
<td>The foreman is chuckling at those jokes.</td>
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<td>Correct</td>
<td>The dressmaker is tailoring for that bridesmaid</td>
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