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Situating language and music research in a domain-specific versus domain-general framework: A review of theoretical and empirical data

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Abstract

While many theoretical proposals about the relationship between language and music processing have been proposed over the past 40 years, recent empirical advances have shed new light on this relationship. Many features are shared between language and music, inspiring research in the fields of linguistic theory, systematic musicology, and cognitive (neuro-)science. This research has led to many and diverse findings, making comparisons difficult. In the current review, we propose a framework within which to organise past research and conduct future research, suggesting that past research has assumed either domain-specificity or domain-generality for language and music. Domain-specific approaches theoretically and experimentally describe aspects of language and music processing assuming that there is shared (structure-building) processing. Domain-general approaches theoretically and experimentally describe how mechanisms such as cognitive control, attention or neural entrainment can explain language and music processing. Here we propose that combining elements from domain-specific and domain-general approaches can be beneficial for advances in theoretical and experimental work, as well as for diagnoses and interventions for atypical populations. We provide examples of past research which has implicitly merged domain-specific and domain-general assumptions, and suggest new experimental designs that can result from such a combination aiming to further our understanding of the human brain.

1 | INTRODUCTION

Language and music are developed within a culture, they are specific to humans and important for most aspects of everyday life, such as communication, education, and social bonding. Language and music[1] relate to the innate, human-specific ability to acquire skills necessary to perceive and produce them within a given culture (Chomsky, 1965; Honing et al., 2015). Questions whether music is a language, as well as the use of first structuralist and then generative approaches from linguistics came up in systematic musicology of the 20th century (Monelle, 1992; Zbikowski, 2002). Advances in informatics, neuroscience, and cognitive science have led to more interdisciplinary approaches in language and music research. Recent research has looked for commonalities (Fitch & Martins, 2014; Koelsch, 2012, p. 244), seeing previous research with new eyes (e.g., Hockett, 1960; Lashley, 1951).

Language and music share basic 'design features', such as complexity, generativity, and universality (Jackendoff & Lerdahl, 2006; Koelsch, 2012; Lerdahl & Jackendoff, 1983). In other words, both language and music are complex systems of communication that can be broken down in simpler building blocks. These minimal, discrete blocks can be recursively combined to generate infinite possible structures. Furthermore, language and music depend on cultural transmission and their acquisition is thought to be based on innate learning abilities (e.g., Honing et al., 2015; Koelsch, 2012). Some features, like isochronicity and pitch organisation, are more prominent in music than in language, whereas propositional semantics and translatability are considered to be central in language, but their status in music is still under debate (Koelsch, 2012; Schlenker, 2017).

Our review of theoretical and empirical data will reveal the diverse approaches that have been developed, spanning theoretical linguistics and musicology, psycholinguistics, cognitive sciences and neurosciences. Although the interest in investigating the relationship between language and music has grown, the approaches have also diverged, making comparisons difficult. We argue that a common framework will help to identify commonalities in the data of previous research and also to design new paradigms.

The scope of this review is to outline theoretical frameworks and experimental evidence that suggest a connection between language and music, unfolding over two assumptions: (1) assuming that language and music share structure-building mechanisms and (2) assuming that structure-building mechanisms for language and music are part of domain-general mechanisms, such as prediction, cognitive control or dynamic attention. Both (1) and (2) have been investigated under similar principles: theory and experimental evidence, production and perception, typical and atypical populations. We review research that has assumed either explicitly or implicitly that processing (or structure-building) mechanisms in language and music are domain-specific or domain-general. More specifically, we argue that domain-specific approaches assume that mechanisms in language and music processing are specific to one or both domains, but independent of other general cognitive processes/mechanisms. Conversely, we argue that domain-general approaches assume that language and music processing rely on general cognitive mechanisms, such as low-level auditory processing, cognitive control, prediction, or dynamic attention. Apart from reviewing research separately (Sections 2 and 3), we will focus on research that combines specificity and generality, and propose directions for future research (Section 4). Although the term domain-specific has been used both for language and music research (e.g., Peretz and Coltheart (2003)), here we use it to describe approaches that implicitly assume shared structure-building for language and music that is independent of other domain-general mechanisms.

2 | DOMAIN-SPECIFIC APPROACHES

Section 2.1 presents a review of approaches that have theoretically described common structure-building mechanisms for language and music, independent from other general cognitive mechanisms. Section 2.2 provides examples of empirical research suggesting shared structure-building mechanisms.

2.1 | Theoretical backgrounds shared between language and music

The parallel development of theoretical linguistics and systematic musicology, and subsequently generative linguistics and cognitive sciences through the 20th and early 21st centuries have continually highlighted properties of language and music that suggest the two systems share processing mechanisms. These properties, apart from the 'design features' mentioned previously, extend to the theoretical description of linguistic and musical structures. Similar to the development of generative linguistics (Boeckx, 2010; Chomsky, 1957, 1965, 1981), generative theories of musical structure highlight hierarchical organisation described in terms of expectation fulfilment, long distance dependencies (Huron, 2006; Meyer, 1956; Schenker, 1935), and phrase structure rules (Baroni et al., 1983; Granroth-Wilding & Steedman, 2014; Harasim et al., 2019; Lerdahl & Jackendoff, 1983; Longuet-Higgins & Lee, 1984; Rohrmeier, 2011; Steedman, 1984). Cross-pollination between the fields has led to the development of structure-building theories that describe language and music as one system (Rebuschat et al., 2011).

Several approaches have combined generative rules or theoretical concepts to describe shared language and music mechanisms at different levels of analysis, focussing, for example, on aspects of phonology and rhythm (summarised in Asano and Boeckx (2015)). Fabb and Halle (2012) provide a prosodic framework according to which stress is hierarchically organised in words and phrases. They describe stress organisation as a set of iterative rules, where words (and phrases) form a metrical grid of relationships of hierarchical importance. It is suggested that an adaptation of these rules can be applied to the computations necessary for metrical verse, both at the word and the line level (applied by Breen (2018)), and that these already well-defined rules can be applied to metrical organisation in music. The projected basic building block is timing slots; a beat pattern is recognised when these timing slots are grouped in specific ways. The rules proposed by Fabb and Halle are thought to be a part of a universal grammar (for language and music) and can account for all well-formed grids that can be produced in language and music.

Other unified approaches have focused on narrow-sense syntax and harmonic structure. One hypothesis states that language and music share the same structure-building operations for syntactic (language) and harmonic (music) structures, namely Merge (Identity Thesis, Katz and Pesetsky (2011)). This framework by Katz and Pesetsky is valuable because it highlights theoretical commonalities in structure-building mechanisms, especially with regard to long-distance dependencies in musical structures, and offers a beneficial comparison with the mechanisms of Lerdahl and Jackendoff's Generative Theory of Tonal Music (Lerdahl & Jackendoff, 1983). However, this framework has been criticised for the proposition to explain structural differences between language and music by the absence of a lexicon in music. Several frameworks of music perception specifically include a lexical component, either seen as a repertoire of all the pieces one has heard, referred to as 'musical lexicon' (Peretz et al., 2003) or as the meaning of a given piece with regard to the external world, to the listener's affect, or to the piece's own musical characteristics (Koelsch, 2011b; Schlenker, 2017, 2022). Roberts (2012) proposed that language and music share a computational system (in the sense of narrow-syntax and a simple algorithm like Merge), but rely on different lexicons and have different external and internal interfaces (Roberts, 2012). The similarities seen between language and music (either at the phonology/rhythm level or at the narrow syntax/harmony level) are due to their dependence on the same computational system.

2.2 | Empirical investigations of shared mechanisms in music and language processing

Empirical research investigating shared processing or structure-building mechanisms has focused both on typical and atypical populations. A hypothesis that reconciles findings from the two is the Shared Syntactic Integration Resources Hypothesis, which proposes that representation networks are distinct for language and music (and can thus be selectively impaired) while resources for linguistic and musical syntactic processing are shared (Patel, 2011). Exactly which syntactic mechanisms are shared still needs to be elucidated (Koelsch, 2011a; Perruchet & Poulin-Charronnat, 2013; Slevc & Okada, 2015).

Simultaneous processing of linguistic and musical material has been examined both behaviourally and neurophysiologically to disentangle aspects of syntactic processing in language and music. Behaviourally, either low accuracy or longer reaction times have been observed in simultaneous language and music syntactic processing with out-of-key notes and chords, with no interaction for acoustic and semantic manipulations (Fedorenko et al., 2009; Slevc et al., 2009). Similarly, less expected (and not out-of-key) chords worsened performance on lexical decision (Hoch et al., 2011). However, another study found a language-music interaction both for semantic and syntactic garden path sentences suggesting a shared general structural integration mechanism (Perruchet & Poulin-Charronnat, 2013). If language and music syntactic processing is independent, then additive effects would be seen in Event-Related Potential (ERP) paradigms, where syntactic incongruences elicit specific ERPs according to the processing stage. However, no additive ERPs where observed when processing music-syntactic and language-syntactic deviances: only the ERP associated with linguistic morphosyntax incongruences (LAN - Left Anterior Negativity) was observed, suggesting an interaction and sharing of syntactic processing resources for language and music (Koelsch, 2005). This interaction was observed only for syntax deviances, but not for semantic or acoustic deviances (Koelsch, 2005; Koelsch et al., 2007).

Apart from shared functional organisation, there is evidence that structural organisation may also be shared for language and music syntactic processing in the brain. Recent studies have shown that areas initially thought to be strictly dedicated to language processing (e.g., Broca's area) contribute to processing of other kinds of structure building activities, including music processing (Fedorenko et al., 2012; Hagoort, 2005; Ogg & Slevc, 2019; Sammler et al., 2011; Tillmann et al., 2006).

Earlier neuropsychological findings from individuals with brain injury had reported double dissociations between language and music processing (Frances et al., 1973; Luria et al., 1965; Tzortzis et al., 2000); however, recent neurophysiological studies are somewhat conflicting both relative to prior research and to each other (e.g., Chiappetta et al., 2022; Faroqi-Shah et al., 2020; Hébert et al., 2003; Patel et al., 2008). Individuals with Broca's aphasia did not detect harmonically ill-formed chord sequences, just as they did not recognise grammatically ill-formed sentences. They also failed to show a priming effect in music: harmonically expected chords were not processed faster than unexpected ones (Patel et al., 2008). However, these results, in almost identical experimental paradigms, were not replicated in a recent study (Faroqi-Shah et al., 2020). Individuals with aphasia did not judge harmonically ill-formed chord sequences as significantly worse than controls, and they showed a similar harmonic priming effect to controls (Faroqi-Shah et al., 2020). This latter result is consistent with the findings of a case study of a musician with agrammatic aphasia with spared musical structure processing (Slevc, Faroqi-Shah, et al., 2016). These findings suggest that previous musicianship might influence the observed data pattern and the related structural sharing.

To conclude, recent theoretical and experimental approaches have implied domain-specificity in the sense of shared processing mechanisms for language and music in varying degrees. Generativist approaches have been developed to describe linguistic and musical structure, focussing on hierarchical structure, innateness, and long-distance dependencies. In turn, they influenced experimental research aiming to investigate commonalities in language and music processing, resulting in the development of hypotheses regarding their representational and processing systems, particularly syntax.

3 | DOMAIN-GENERAL APPROACHES

Domain-general approaches assume that the perception and production of language and music rely on lower- or higher-level shared perceptual and cognitive processes, without the implication of a specific language-music processing mechanism. These processes include both low-level auditory rhythmic processing emerging early in life (Section 3.1), predictive processing and cognitive control (Section 3.2), the bases of transfer effects in musicians and bilinguals (Section 3.3), and entrainment and Dynamic Attention Theory (DAT) (Section 3.4). These approaches seek to clarify the processing of language and music by examining them through the lens of general cognitive abilities. In doing so, these approaches also propose alternative interpretations to findings reported in Section 2.2 and use examples from differences in cognitive skills between musicians and bilinguals on the one hand and differences between typical and atypical populations on the other.

3.1 | Rhythm and timing abilities early in life

Cutting-edge behavioural research in developmental psychology has demonstrated that humans are born with the ability to dynamically focus attention on elements in the auditory stream (Jones, 2019). For language, it seems that infants are sensitive to varying language-classes and their respective phonological organisation (Höhle et al., 2009; Jusczyk et al., 1999; Nazzi et al., 1998; Nazzi & Ramus, 2003). They can distinguish their native language from other languages not belonging to the same rhythm-family (e.g., French and Japanese), but not between languages sharing similar stress properties (e.g., English and Dutch) (Nazzi et al., 1998). Newborn infants incorporate their native language's stress patterns in their cry vocalisations (Mampe et al., 2009; Prochnow et al., 2019). Similarly, German-speaking 6-month-old infants prefer listening to stress patterns found in German (trochaic vs. iambic) (Höhle et al., 2009). German-speaking 4-month-old infants detect deviances in stress patterns not congruent with their native language (Friederici et al., 2007). When listening to pure tones resembling distinct stress patterns (trochee vs. iamb), French-speaking newborns showed greater brain activation in patterns inconsistent with the language to which they were exposed. This finding suggests greater processing costs for stimuli deviating from the native language's stress patterns (Abboub et al., 2016).

For music, infants are particularly sensitive to isochronous and metrical stimuli and this ability is refined by maturation and cultural exposure (Hannon & Trainor, 2007; Hannon & Trehub, 2005a). Electroencephalography measurements revealed that sleeping newborns detect structural temporal deviances (i.e., a set of rhythmic beats where the first beat, inducing the sense of a pulse, was omitted), as evidenced by a Mismatch Negativity component. This ERP was not present when other beats were omitted from the stream, or when only the deviant sequence was administered (Kujala et al., 2023; Winkler et al., 2009). Using a preferential looking paradigm, 6-month old infants were as probable to detect structural deviances in both simple ratio and complex ratio stimuli (in contrast to North American adults and adults from Balkan countries, who showed different preferences according to their cultural exposure (Hannon & Trehub, 2005a)). This culture-independent sensitivity was not present in 12-month old infants, just like for adults, but could be reversed in the infants via enhanced music exposure to complex-metre music (Hannon & Trehub, 2005b).

3.2 | Predictive processing and cognitive control

Recent advances in predictive processing have argued for a prominent role of prediction in language and music processing. The framework of active inference (Friston, 2009) has been used to interpret findings in music neuroscience, in which acoustic irregularities and music-syntactic irregularities both elicit brain responses. The responses to these irregularities are further investigated in terms of whether participants were anticipating irregular stimuli, that is, in terms of how bottom-up and top-down information shapes predictive processing (Koelsch et al., 2019). Another approach has focused on integrating previous hypotheses regarding rhythm perception and (motor) production within the predictive processing framework, according to which, findings showing an implication of brain motor areas during beat perception and music listening are explained with models of active inferencing and predictive processing (Patel & Iversen, 2014; Proksch et al., 2020).

In response to approaches claiming that language and music share syntactic integration processing resources (Patel, 2003) or structural integration processing resources (Hoch et al., 2011; Perruchet & Poulin-Charronnat, 2013), Slevc and Okada (2015) suggested that what is shared is domain-general cognitive control. They propose that previous findings showing an interaction between language-syntactic and music-syntactic processing, but no interaction between language-semantic and music-syntactic processing can be explained by task difficulty and/or strength of violation. This requires more or less cognitive control resources and can interpret these interference effects (Slevc & Okada, 2015). More recent work also supports that language and music share hierarchical cognitive control, a neurocognitive mechanism responsible for selecting, maintaining and inhibiting goals with hierarchical and temporal organisation (Asano et al., 2021). In Asano et al.'s proposal, interference and facilitation experimental paradigms (with simultaneous processing of hierarchical language and music stimuli) can be explained within a shared hierarchical cognitive control mechanism. Furthermore, a processing pathway between cortical and subcortical areas is proposed, which could also involve the processing of action syntax, that is the organisation of hierarchically complex motor actions (Asano et al., 2021). A recent meta-analysis of neuroimaging studies in language, music, and action perception has shown a wide brain network including both cortical and subcortical regions serving for domain-general predictive coding (Siman-Tov et al., 2019).

3.3 | Transfer effects in musicians and bilinguals

There has been considerable research on potential transfer of memory and attention skills in individuals that have extensive training in language (acquisition of more than one language—bilinguals) or music (musicians), as an example of investigating the nature of language and music skills (D'Souza et al., 2018; Slevc & Miyake, 2006; Tierney & Kraus, 2014).

3.3.1 | Hypotheses for transfer effects between linguistic and musical skills

Different accounts have explained effects of a transfer of skills between trained abilities and performance on tasks not related to the training (far-transfer effects) (Bigand & Tillmann, 2022), in terms of the cognitive, neural, and behavioural mechanisms involved. The OPERA account states that the mechanisms for music/speech processing Overlap (O), while music requires greater Precision (P) in information encoding. Furthermore, music training is related to Emotional (E) processing and is connected with reward-based learning, it is highly Repetitive (R) and requires Attentional (A) mechanisms (Patel, 2014). The OPERA hypothesis has influenced other similar hypotheses which focus on different aspects of processing and possible transfer effects. Miendlarzewska and Trost (2014) have suggested that the way that transfer is possible is through neural entrainment mechanisms, which are trained during music training. Fujii and Wan (2014) propose an addition to OPERA stipulating that the shared neural mechanisms for sound envelope processing, and the ability to entrain (in perception and production) to a beat (Synchronization and Entrainment to a Pulse—SEP), are features that could explain far-transfer effects. Other accounts have posited that music training can either amplify common auditory processing abilities through rigorous auditory music training, or can enhance domain-general cognitive abilities which in turn have an impact on language skills (Besson et al., 2011). Strait and Kraus (2014) propose that musicians with intensive training are ideal for investigating auditory learning. The Precise Auditory Timing hypothesis states that the rigorous training in auditory timing can explain transfer effects between music training and language skills (Tierney & Kraus, 2014).

3.3.2 | Empirical evidence for transfer of language and music skills

Studies have investigated whether rigorous (language or music) training leads to the enhancement of domain general abilities, such as executive function (EF), working memory, and auditory sustained attention. In Slevc, Davey, et al. (2016), EF (inhibition, updating, task-switching) was assessed in a large sample of musicians and non-musicians. Regression analysis showed that music skills had a significant effect on EF task performance; however, only the updating task (i.e., n-back task), and not the switching or inhibition tasks, correlated positively with the music ability tasks (Slevc, Davey, et al., 2016). Another study found an advantage for working memory within musicians in comparison to nonmusicians, but no effect with regard to inhibitory control (D'Souza et al., 2018). A similar advantage for working memory within children receiving daily music-based activities and attending a music-based school curriculum has also been shown (Saarikivi et al., 2019). In a meta-analysis, the effect of musicianship was explored in terms of individuals' long-term, short-term and working memory, taking into consideration all modalities. Musicians seem to generally out-perform non-musicians with regard to both auditory/non-verbal but also verbal memory and less so in visuospatial memory (Talamini et al., 2017). Auditory selective attention has also been found ameliorated in a small sample of musicians versus non-musicians (Strait et al., 2010).

Similarly, the 'bilingualism advantage' regarding enhanced cognitive skills in bilinguals has been extensively investigated, with recent meta-analyses showing mixed findings: although there seems to be a small marginal effect of bilingualism in executive functions (Gunnerud et al., 2020; Nichols et al., 2020), publication bias also has affected reporting of results (de Bruin & Della Sala, 2019).

Other attempts have assessed whether specific auditory-related skills (e.g., pitch/contour/loudness discrimination) extend to specific language- and music-related skills. Adult and children musicians have an advantage in a variety of speech tasks including: sensitivity in detecting changes in prosody, lexical pitch discrimination, vowel duration, metrical speech discrimination (Besson et al., 2011). They also have better skills at second language learning (phoneme discrimination) (Milovanov & Tervaniemi, 2011; Slevc & Miyake, 2006). However, in a systematic review investigating the effect of children's music education in other cognitive aspects, the authors found conflicting results regarding typically developing children's reading and writing skills, associated with diverse research methodology and lack of consistency in literacy and academic attainment assessments (Jaschke et al., 2013). A later meta-analysis showed that music training had a positive effect on phonological awareness (Gordon et al., 2015).

In conclusion, investigations of near- and far-transfer of skills due to extensive music training (comparing musicians and non-musicians), because of their cross-sectional design, cannot suggest a directly causal relationship between music training and other skills. Other variables like individual variability, musical predisposition, intelligence, higher engagement in training or higher musical sophistication in the environment are latent in these studies. Behavioural, genetic, and neurophysiological longitudinal studies need to be conducted to elucidate the nature of skill transfer due to music training.

3.4 | Entrainment and dynamic attention

3.4.1 | Theories of entrainment and dynamic attention

Language and music are organised rhythmically and this is evidenced in the acoustic signal. Smaller elements (pitch heights, phonemes) are grouped together resulting in establishing a systematic alteration of strong-weak parts, turning into the extraction of a regular pulse (described as metrical grids in 1.1). The frequency of modulations in amplitude has been investigated, especially with an interest in the neural responses to the speech/musical signal. The spectrum of speech modulation (for a small set of language corpora) ranges between 4 and 5 Hz, while the spectrum of music modulation (for a small set of musical genres) ranges from 1 to 2 Hz (Daikoku & Goswami, 2022; Ding, Patel, et al., 2017). The similarities in metrical organisation and the assumption that critical information is conveyed in specific time frequencies (Pellegrino et al., 2011) have increasingly motivated the investigation of the relationship between metre perception and attention.

Several approaches have been developed with regard to auditory processing of sound information, ranging from models of neuronal entrainment to rhythmic environmental sounds (Schroeder & Lakatos, 2009), to beat-based accounts of rhythmical processing (Large & Snyder, 2009), to dynamic attention theories (Jones, 2019; Jones & Boltz, 1989). We report two theoretical approaches, one influenced by language/speech (attentional bounce hypothesis) and one influenced by music processing (DAT) (Jones, 2019; Jones & Boltz, 1989; Pitt & Samuel, 1990; Port, 2003).

With the 'attentional bounce hypothesis', Pitt and Samuel (1990) explain how selective attention could play a part in speech processing and more specifically in phoneme detection. They found better phoneme detection when the stimuli could be metrically predicted by the phonemic context. More recent research on word-level has shown that syllable detection depends on the rhythmic context (stressed vs. unstressed syllable) both for real words and pseudowords regardless of linguistic rhythm class (syllable-timed vs. stress-timed) (Arvaniti & Rathcke, 2015; Quené & Port, 2005). Attention allocation has been theoretically explored in speech production as well; when participants are asked to match short phrases to a metronome, they align the perceptually most salient parts of the phrase (i.e. vowels) to the beat of the metronome (what they refer to as 'harmonic timing effect') (Port, 2003).

DAT stipulates that events evolving over time can have either a hierarchical or a non-hierarchical organisation (Jones, 2019; Jones & Boltz, 1989). Hierarchically organised events have an internal organisation in which smaller events are nested into bigger ones. This property of sequential organisation of events defines how attention is allocated. For hierarchical events, attention can be future-oriented; as hierarchical events have points of higher importance, attention can be oriented to those points and not locally from one point to the next in the stream. Non-hierarchical events with no internal organisation require a constant (albeit lower in energy) allocation of attention. The general attending hypothesis, recently developed within the DAT framework, has implications for neurophysiological functioning. It postulates that cortical oscillations automatically (involuntary) phase-couple with external rhythmical events and that certain oscillations voluntarily can be heightened (or suppressed) to selectively attend to specific stimuli (Jones, 2019). This states that attention is rhythmical; it is allocated via internal oscillators that have their own inherent frequency, is coupled with the external oscillator via exogenous entrainment, and finally generates expectations via endogenous entrainment regarding future important events in the stream (Jones, 2019).

3.4.2 | Evidence for entrainment and dynamic attention in typical populations

Neural oscillations have been found to be remarkably important for sensory processing in general (Lakatos et al., 2019) and there is evidence of their role in tracking both speech and music over time (Harding et al., 2019). The acoustic characteristics of speech suggest that speech can be described in different timescales (notably 30–50 Hz for phonemic information, 4–7 Hz for syllabic information, 1–2 Hz for lexical/phrasal information) and it is thought that neuronal activity interacts with these timescales (Giraud & Poeppel, 2012). More specifically, what has been evidenced is that four oscillatory bands seem to underlie speech and language perception: low gamma band (25–35 Hz), beta band (15–20 Hz) theta band (4–8 Hz), and delta band (1–3 Hz) (Giraud & Poeppel, 2012; Goswami, 2022). Rhythmic (amplitude-related), phonetic, morphemic, and phrasal information is tracked during listening, even when prosodic cues are extracted (Ding et al., 2016; Ding, Melloni, et al., 2017; Luo & Poeppel, 2007). Similarly, there is evidence on neuronal entrainment (delta-theta bands) on a melodic and rhythmic level in music (Ding, Patel, et al., 2017; Doelling & Poeppel, 2015). Cortical tracking of rhythm properties in language and music has been shown for the same pool of participants (Harding et al., 2019).

3.4.3 | Atypical rhythm processing

Evidence of neuronal entrainment to rhythmic stimuli influenced research investigating atypical neuronal entrainment, as well as possible difficulties in rhythm perception for populations with developmental language and literacy disorders, such as developmental dyslexia (DD). According to recent research, these impairments are based on atypical neuronal sampling, that is, atypical theta-band brain oscillations thought to be responsible for syllabic processing (Temporal Sampling Framework) (Colling et al., 2017; Di Liberto et al., 2018). Another stipulation is that individuals with DD show atypical low-gamma oscillations, atypical hemispheric lateralisation, and atypical coupling between the bands during speech processing. Individuals with DD were found to have greater entrainment to higher frequencies of the stimuli, suggesting an over-sampling of phonetic information, and this performance had negative correlations with verbal working memory measures (Lehongre et al., 2011).

Accounts of atypical neuronal entrainment in DD fit well with long-standing hypotheses regarding a temporal processing deficit both for DD and developmental language disorder (DLD) (e.g., Rapid Temporal Processing Hypothesis - Tallal (1976) and Temporal Sampling Framework Hypothesis - Goswami (2011)). The Temporal Sampling Framework hypothesises that the poor phonological (and subsequently core language) skills observed may not result just from a temporal processing difficulty in processing rapidly presented stimuli (as in the Rapid Temporal Processing hypothesis), but from a difficulty in detecting suprasegmental speech elements (evidenced in the amplitude modulation envelope which also contributes to lexical and sentential prosody) (Goswami et al., 2002). These elements are thought to be linked to processing of the rhythmical and timing properties of speech, suggesting a deficit for the higher-level perception of language and music that leads to difficulties in phonology and syntax/semantics. Numerous studies across different languages have been carried out with children and adults with DD and DLD, showing that difficulties in detecting amplitude modulation in these populations (even in non-verbal, music-like materials) were correlated with performance on a variety of phonological, core language, and memory tasks (Corriveau et al., 2007; Corriveau & Goswami, 2009; Cumming, Wilson, & Goswami, 2015; Cumming, Wilson, Leong, et al., 2015; Goswami et al., 2002). Apart from detecting amplitude modulations, children with DD and DLD were found to have impaired performance on rhythm perception tasks and rhythm production (tapping) tasks, which were all correlated with measures of phonological awareness and language abilities (Colling et al., 2017; Corriveau & Goswami, 2009; Goswami, 2011; Thomson & Goswami, 2008).

The difficulties with rhythm perception skills observed in neurodevelopmental disorders led to the stipulation of the Atypical Rhythm Risk Hypothesis (Ladányi et al., 2020), which posits that infants and children with atypical rhythm skills are at greater risk for developmental speech/language deficits (covering DLD, DD, Attention-Deficit Hyperactivity Disorder, and stuttering). Furthermore, it acknowledges comorbidity between disorders that have a primary speech/language deficit and disorders with a primary motor deficit, predicting that rhythm might be a diagnostically useful risk factor for all atypical conditions with and without a primary linguistic deficit. It also predicts that correlations observed phenotypically, that is all the correlations described above, could be partially explained by shared genetic architecture for rhythm and language skills (Ladányi et al., 2020; Pagliarini et al., 2020). A correlation between rhythm perception tasks and phonological and morphosyntactic language skills, as well as literacy skills, has been shown in typically developing younger and older children in an array of studies (Gordon et al., 2014; Lee et al., 2020; Politimou et al., 2019; Swaminathan & Schellenberg, 2020; Tierney & Kraus, 2014; Woodruff Carr et al., 2014).

4 | COMBINING APPROACHES AND FUTURE DIRECTIONS

We have shown that work so far adopts different assumptions regarding the nature of the underlying phenomena and investigates language-music processing either in terms of a shared language-music processing mechanism (referred to here as 'domain-specific' mechanisms, with domain combining both language and music) or under the umbrella of domain-general cognitive mechanisms. This leads to parallel research lines with few opportunities to intersect explicitly. We argue that combining domain-specific and domain-general approaches in language and music research can be beneficial for future research and we will give examples from the language and music field and from other fields.

In this section we will: first, provide examples of recent research in which an implicit combination of domain-specific and domain-general assumptions has been adopted (Section 4.1) and second, describe similar future implementations (Section 4.2).

4.1 | Recent language-music research combining approaches

Below, we summarise research with approaches that can be interpreted as combining domain-specific assumptions for shared language-music processing (e.g., syntax-related neurophysiological responses, metrical hierarchical structure) and domain-general assumptions (e.g., dynamic processing of auditory material) within the same experimental design. These investigations cover mostly stimulation/priming effects, in which either the stimuli themselves are metrically manipulated, or rhythmic/musical primes are presented before an experimental language task.

By controlling word onsets to manipulate rhythmic delivery of the words, Schmidt-Kassow and Kotz (2008) showed altered neural responses being aligned to match the created metrical expectations, that is at the next timed slot. Processing of metrical and syntactic violations in speech seem to share resources; combining the two produced an under-additive effect in terms of ERPs (Schmidt-Kassow & Kotz, 2009). When manipulating stress patterns and syntactic complexity, a facilitation in complex syntax comprehension was observed when accompanied by metrical regularity (Roncaglia-Denissen et al., 2013). In recent work, prosodic elements of complex structures for ambiguity resolution were investigated by hypothesising the involvement of neuronal entrainment mechanisms (Hilton & Goldwater, 2019). The authors showed that accuracy on subject and object relative clause comprehension was ameliorated when a superimposed beat matched the metrical structure of the sentences. This effect was shown also when participants heard the sentences and were also asked to actively induce a beat matching the sentence metrical structure by tapping on a drum pad (Hilton & Goldwater, 2019).

Other studies have investigated the effect of musical rhythmic cueing and priming on speech processing. Phoneme detection in pseudowords was faster when preceded by rhythmic cues that matched the word's syllabic structure in terms of stress patterns (Cason & Schön, 2012). This finding was further explored in a phoneme detection task with real sentences and reaction times were faster when the sentence stress pattern was an exact match to the preceding cue in comparison to a mismatch or irregular pattern (Cason et al., 2015). Rhythmic priming using short musical excerpts that had strong regular, metric structures has been found beneficial for school-aged children's grammaticality judgements on subsequently presented, naturally spoken sentences (not metrically matched to the musical primes) both in typically developing children and in children with DLD and DD (Bedoin et al., 2016; Chern et al., 2018; Przybylski et al., 2013). A similar effect has been found for sentence repetition in DLD children (Fiveash et al., 2023). Children with cochlear implants seem to have benefitted more strongly from a short intervention programme targeting syntactic comprehension when these were interleaved by rhythmic (vs. non-rhythmic) primes within each therapy session, thus providing some first evidence for rhythmic non-linguistic interventions (Bedoin et al., 2018). A rhythmic march-like prime enhanced neurophysiological measures that are associated with syntactic processing (P600) in basal ganglia patients (Kotz et al., 2005), as opposed to a separate study not using primes (Kotz et al., 2003).

4.2 | Future directions

In this section, we introduce two directions that can be implemented by combining domain-specific approaches with domain-general approaches into one framework, allowing for the development of novel targeted hypotheses with more complex experimental designs. By using one framework including domain-specific and domain-general approaches in language and music research both approaches are enriched bidirectionally taking advantage of methodologies from cognitive neuroscience, generative linguistics, and systematic musicology.

Processing of syntactic complexity in language and music can be investigated by testing potential limitations in memory or processing capacities, predictive processing, and dynamic (rhythmic) attention (similarly as proposed by Slevc & Okada, 2015). Such a design would assume a shared language-music mechanism for structure-building and would test it with possible domain-general cognitive limitations. For example, experiments of language- and music-syntactic complexity involving simultaneous processing can incorporate conditions where language-music processing is taxed by other cognitive demands. To our knowledge, such hybrid models that explore the limits of shared language-music processing with general cognition in terms of both executive functions and dynamic attention have been scarcely developed, which could lead to new paths to typical and atypical language processing models (e.g., Murphy et al. (2022)). Another example would be to continue the exploration of experimental work showing benefits in processing metrically regular linguistic information, both in typical and atypical populations (Hilton & Goldwater, 2019; Kotz & Gunter, 2015; Schmidt-Kassow & Kotz, 2008), revealing how dynamic attention possibly underlies the processing of hierarchical information. These questions can also be enriched by studying not only typical populations, but also language deficits in developmental and acquired language disorders. By investigating shared structure-building mechanisms for language and music in aphasia and DLD, the limits of such mechanisms can be tested in atypical populations and can be informed by possible domain-general explanations. Questions regarding syntactic complexity and deficit in aphasia and DLD may be elucidated by investigating harmonic/syntactic and rhythm perception in depth and by also including accounts of memory, dynamic attention, and prediction (Chiappetta et al., 2022; Faroqi-Shah et al., 2020; Haro-Martínez et al., 2021; Slevc, Faroqi-Shah, et al., 2016). Investigating in depth non-linguistic/music deficits in DLD will provide new insights on the nature (and comorbidities) of the disorder for research and diagnostic purposes (Ladányi et al., 2020).

The second direction results from investigations of music/rhythm processing deficits in populations with language disorders (e.g., aphasia and DLD) and the benefits of short-term rhythmic/music intervention effects as alternative or addition to linguistic interventions. Theoretical frameworks of transfer effects between language and music processing (e.g., OPERA) have already been developed, therefore there is already a theoretical basis for the design and implementation of large-scale intervention trials, where music training can be tested against cognitive training. Different aspects of training can unveil which elements of music can be beneficial for skill transfer, as opposed to cognitive training (e.g., singing vs. rhythm vs. working memory training). For example, a musical intervention with focus on rhythm perception and production could be implemented in young children with DLD similar to other music training studies recruiting typically developing children and dyslexic children (Flaugnacco et al., 2015; Overy, 2003; Tierney & Kraus, 2013). Hypotheses mentioned in Section 3.3.1 have already argued that attentional mechanisms, entrainment to a pulse, and repetitiveness are key elements for transfer between music and language skills. Questions could target whether music training containing the above skills can have positive effect compared to no therapy, cognitive training, or other arts-based activities, but also whether music training can have a similar effect to language intervention.

5 | CONCLUSIONS

In the present paper, we have reviewed several theoretical frameworks and empirical investigations addressing potential connections between language and music, revealing the breadth of approaches. With this in mind, we have aimed to present past work within one framework. In the first section, we presented theories and experiments which assume language and music structure-building as domain-specific. In other words, we presented theories and experiments which assume that structure-building mechanisms are specific for language and music, as opposed to general cognition. These theories and experiments describe their mental representations, as well as the rules that describe their organisation in terms of quasi-modular systems that may share aspects of processing resources (Patel, 2011). In the second section, we presented theories and experiments which consider language and music processing as domain-general, by focussing on cognitive skills such as prediction, executive functions, and dynamic attention. We presented novel approaches in predictive processing for language and music processing, as well as theories regarding mechanisms of hierarchical cognitive control. We presented dynamic approaches of attention in which temporal processing and rhythm perception and production become a central ability. In order to investigate their hypotheses, both domain-specific and domain-general approaches have strengthened their claims based on experimental evidence on production and perception in typical and atypical populations.

In the third section, we showed that adopting a framework for placing language-music research can be implemented in a twofold way. First, incorporating elements from both approaches results in novel hypotheses which tackle long-standing domain-specific theoretical issues, such as processing syntactic complexity via domain-general mechanisms such as dynamic attention or cognitive control, in both typical and atypical populations. Research investigating domain-general mechanisms involved in the deficits reported in language disorders such as aphasia and DLD can clarify the nature of the disorders but also provide a wider clinical image for diagnostic purposes, including music-based or domain-general deficits. Second, based on rhythmic priming effects shown for language tasks and on theories around transfer effects between language and music, novel non-linguistic interventions can be designed and tested for near- and far-transfer effects on both short- and long-term facilitation.

In conclusion, we believe that acknowledging domain-specific and domain-general approaches in language-music research can promote the systematic comparison between the two and advance our understanding of both typical and atypical brain functioning, for music, language and beyond (i.e., other hierarchical systems). This framework can be beneficial for future research investigating both fundamental research and potential connections to clinical and rehabilitation research.

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ENDNOTE

[1] The inherent ability to perceive and produce music has also been referred to as musicality (Honing et al., 2015).

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