**Using a developmental-ecological approach to understand the relation between language
and music**

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Abstract

Neurocognitive and genetic approaches have made progress in understanding language-music interaction in the adult brain. Although there is broad agreement that learning processes affect how we represent, comprehend, and produce language and music, there is little understanding of the content and dynamics of the early language-music environment in the first years of life. A developmental-ecological approach sees learning and development as fundamentally embedded in a child's environment, and thus requires researchers to move outside of the lab to understand what children are seeing, hearing, and doing in their daily lives. In this paper, after first reviewing the limitations of traditional developmental approaches to understanding language-music interaction, we describe how a developmental-ecological approach can inform not only developmental theories of language-music learning, but also contemporary neurocognitive and genetic approaches. We then make suggestions for how researchers can best use the developmental-ecological approach to understand the similarities, differences, and co-occurrences in early music and language input.

Using a Developmental-Ecological Approach to Understand the Relation between Language and Music

In the last decades, scientists have made significant progress in understanding language-music interactions using an array of neurocognitive and genetic approaches. Despite the tacit assumption in this work that the environment affects the structure of neural substrates and the expression of genes, details of early language-music input have been comparatively understudied. The developmental-ecological approach to investigating the dynamics of early language-music input is an important complement to neurocognitive and genetic approaches that can make headway on some of the challenges language-music research has faced.

In this paper, we describe how understanding the biological and functional relation between language and music requires a developmental-ecological approach (Adolph, 2019; Bronfenbrenner, 1979; West & King, 1987). First, we review the limitations of non-ecological approaches to studying language-music development. Then, we explain how a developmental-ecological perspective can complement neurocognitive and genetic approaches to language-music processing. Last, we make recommendations for conducting naturalistic developmental research on early language-music input from a developmental-ecological perspective.

Limitations of Non-Ecological Approaches to Investigating Language-Music Development

There is evidence within both music and language research that early experience affects later processing and behavior. Children's early music environment, measured via parent report, is correlated with musical processing and musical success (Brand, 1986; Putkinen et al., 2013; Williams et al., 2015), and the quality and quantity of language exposure affects language processing (Gruter et al., 2014). Researchers have also investigated the interaction of music and language across development. Much of this work uses measures of experience or ability,

such as years of music training or productive vocabulary at a certain age, to predict later brain activity and behavior. For example, some training studies have found that listening and learning how to play a musical instrument changes brain and behavioral responses to not only music stimuli, but language tasks as well (see Gordon et al., 2015, for review). Thus, early input, broadly defined, has been shown to affect how we respond to music and language, with some evidence of transfer across domains. This body of evidence has motivated domain-general, learning-based explanations for shared language-music processing (e.g., statistical learning theories such as Politimou et al., 2021, Schon et al., 2008, and Thiessen & Saffran, 2009; stimuli complexity theories such as Lebedeva & Kuhl, 2010; and familiarity-based theories such as Plantinga & Trehub, 2014).

However, the studies above treat early music and language experience as static, monolithic variables rather than continuous, complex streams that change across time. Asking a parent whether they have musical instruments at home (as some surveys do) is informative, but it ignores that the effect of instruments at home depends on the hour-to-hour and minute-to-minute dynamics of how infants interact with those instruments, and how that interaction in turn affects future neural activity and behavior. In order to understand the role of development and the environment in shared language-music processing, researchers need to move beyond summary measures of the environment and embrace the complex dynamics of how music and language input unfold over time.

The Developmental-Ecological Approach: Embracing the Dynamics of Development

The developmental-ecological approach (Adolph, 2019; Bronfenbrenner, 1979; West & King, 1987) builds on the view that an adult's brain and behavior is the product of interactions between the environment and biology throughout development. To understand the interaction between language and music processing in adults, researchers must not only study children's musical and language abilities in lab tasks, they also must observe how children use the input to

adapt to their environment in real time. Development must be observed outside of the lab because adults and children interact differently in structured tasks versus their daily routines (Tamis-LeMonda et al., 2017). Observations must be sampled across many families, both intra- and interculturally, because childrens' environments are inherently idiosyncratic and culture-dependent (Casillas et al., 2020; Montag, 2020). Datasets must follow development with frequent sampling and across longitudinal time because input interacts with development, such that what children see, hear, and touch is different at 6 months versus 12 months. For example, the visual field of a crawling baby is constrained compared to that of a walking baby (Kretch et al., 2014). Only by observing exactly how children engage with music and language across development--in the functional, social, and emotional context of their daily lives--can we understand the similarities and differences in how adults react to and engage with music and language.

Some areas of language learning research have productively embraced the developmental-ecological approach. For example, in the 1970s, Roger Brown used a combination of diary studies and tape recordings to describe early syntax and semantic development (1973). The CHILDES database (MacWhinney & Snow, 1990) is a corpus of transcribed and tagged speech to children in both lab and naturalistic settings that has been used to create models of child language learning (e.g., Mintz, 2003). More recently, there has been a renewed interest in collecting day-long, longitudinal audio/visual recordings to describe the nuances of language input in first years of life (e.g., Bulgarelli & Bergelson, 2020, Casillas et al., 2020, Roy et al. 2015, Sullivan et al, 2021, Tamis-LeMonda et al., 2019). This work has led to novel findings, such as the role of context (Roy et al., 2015) and temporal structure (Casillas et al., 2020) in language development.

In contrast, scientific efforts to understand the early music environment largely do not stem from a developmental-ecological perspective, in part because this work has approached music input as an extracurricular, optional enrichment activity (e.g., Schellenberg, 2005).

Researchers rarely record music in the daily lives of babies, but instead assess beliefs about and frequency of music engagement through surveys (Brand, 1985; Brand, 1986; Custodero et al., 2003; Custodero & Johnson-Green, 2008; Dai & Schader, 2002; deVries, 2009; Mehr, 2014; Politimou et al., 2021; Steinberg et al., 2020; Valerio et al., 2012; Williams et al., 2015), individual and group interviews (Barrett, 2009; Barrett, 2011; Cho, 2015; Custodero, 2006; deVries, 2009; Young, 2008), and diary studies (Barrett 2011, Barrett, 2009; Custodero, 2006).

In the last two decades, some music researchers have begun to take an interest in direct observational research of the musical environment, through live observations (Barrett, 2009; 2011), lab recordings (Falk & Kello, 2018), and field recordings (Barrett, 2009; 2011; Custodero, 2006). This body of work has revealed that parents do value music in interactions with their children (Cho, 2015; Dai & Schader, 2002; Mehr, 2014), that music is used in routines, for social bonding, and in identity formation (Barrett, 2009; 2011), and that infants and children encounter music from a wide variety of sources (e.g., toys, singing, recordings; Young, 2008). Recently, day-long at home recordings have shown that infants are frequently exposed to live and recorded music, that the distribution of sources of music input is not uniform, and that critical features of music input impact singing development (Costa-Giomi & Benetti, 2020; Mendoza & Fausey, in press). Thus, there is increasing evidence that the developmental-ecological approach will lead to novel insights into early music processing.

What Language-Music Researchers Stand to Gain from the Developmental-Ecological Approach

In addition to advancing developmental research on language-music interaction, the developmental-ecological approach will also address challenges faced by researchers investigating these questions from non-developmental perspectives.

Brain Imaging

Neuroimaging studies comparing brain activity during language and music tasks generally find significant overlap across domains in Broca's area and its right-hemisphere homologue (Chiang et al., 2018; Koelsch et al., 2002; Kunert et al., 2015; Maess et al., 2001). However, the observation of overlapping activation does not necessarily allow for the conclusion of shared neural processing; rather, distinct co-located networks for language and music could underlie the observed overlap (Peretz et al., 2015).

This interpretation challenge can be addressed by investigating the early life experiences that lead to observed patterns of activation. Specifically, data from observational studies of the early language-music environment can be used to predict brain activation in imaging studies. For example, our understanding of how the brain employs statistical learning (Frost et al., 2019) to make sense of language and music would be advanced by developmental-ecological studies that directly measure an individual's frequency of exposure to specific stimulus patterns, and correlate these statistics to their brain activity. This approach would be particularly powerful in a longitudinal context, allowing researchers to track the reciprocal shifts between changing stimulus frequencies and neural encoding of these patterns over the course of development.

Behavioral Interference Paradigms

Behavioral interference paradigms (e.g., Fedorenko et al., 2009; Kunert et al., 2016; Perruchet & Poulin-Charronnat, 2013; Slevc et al., 2009; Steinbeis & Koelsch, 2008) play participants a language sequence (sentence or phrase) overlaid with a music sequence (melody or chord progression). Typically, the structure of the language and/or music sequences are manipulated (e.g., by introducing a syntactic error or an out-of-key note), and then participants are asked to make a judgment regarding one of the sequences (e.g., sentence comprehension). Overall, these studies demonstrate reciprocal interference: structural disturbances in one domain impact structural processing in the other domain.

A major challenge in designing interference paradigms (that also applies to some brain imaging experiments) is the matching of conditions between domains. For instance, Fedorenko et al. (2009) manipulated sung materials in terms of “linguistic complexity” by comparing subject- and object-extracted relative clauses, and “musical complexity” by comparing in- versus out-of-key notes. Understanding the distributions of language-music structures in early input will help theoretically motivate methodological decisions regarding condition matching. For example, a better understanding of the developmental trajectory of the frequency with which individuals are exposed to subject- vs. object-extracted relative clauses as well as in- vs. out-of-key notes would help to equalize difficulty in experimental manipulations.

Associations between Language and Music Skills

Researchers use cross-sectional and training studies to measure associations and transfer between music and language abilities. Cross-sectional designs compare participants with musical training with those without (e.g., Anvari et al., 2002; Banai & Ahissar, 2013; Cohrdes et al., 2016; Francois & Schon, 2011; Hausen et al., 2013), while training paradigms test language skills before and after musical training (e.g., Bolduc, 2009; Bolduc & Lefebvre, 2012; Dege & Schwarzer, 2011; Douglas & Willats, 1994; Forgeard et al., 2008; Francois et al., 2012; Moreno et al., 2011; Schon et al., 2008). In general, these studies show positive associations between musical training and performance on language processing tasks, with converging evidence from observations of training-related neuroplasticity (e.g., Chobert et al., 2012; Hyde et al., 2009; Schlaug et al., 2005). However, transfer effects between music and language remain a site of debate (see for example, Bigand & Tillmann, 2021; Román-Caballero et al., 2021; Sala & Gobet, 2020). Studies that employ training regimes to explore the causal links between language and music skills often fail to fully consider pre-existing differences between groups, and these differences complicate the path between musical training and improved language processing (Swaminathan & Schellenberg, 2020; Vuvan et al., 2020; Wesseldijk et al., 2021).

One way to develop clearer interpretations of cross-sectional and training studies is to understand the developmental-ecological pathway of language and music learning in early life. Because training studies often start at school-age, understanding the variability in music and language input before that time point can help researchers better match participants across experimental conditions. More broadly, cross-sectional and training studies implicitly assume that some music and language abilities only begin to develop when formal training starts. By describing language and music experience in the earliest years of life, researchers can measure the naturalistic “training” of language and music in infants and children, and thus understand the fully ontological pathway both within and between language and music.

Genetic Approaches

Researchers have also investigated the genetic factors that drive neural and behavioral expressions of language and musicality. Within this approach, researchers seek to identify specific genotypes (individual genes or networks of genes) that are correlated to target phenotypes (behaviors or brain activity). Twin and family aggregation studies have shed light on the contribution of genetics to musical aptitude and achievement (Wesseldijk et al., 2020), congenital amusia (Peretz et al., 2007), and specific language impairment (Bishop & Hayiou-Thomas, 2008). Studies have also identified the role of specific genes in language and musicality (e.g., FOXP2, Vargha-Khadem et al., 2005; CNTNAP2, Whitehouse et al., 2011). For example, studies of genome-wide associations (GWAS) have revealed multiple genes to be correlated to reading and speech (Reader et al., 2014) and rhythmic (Niarchou et al., 2020) abilities. This genetic approach can help make progress on the question of language-music interaction through the identification of genetic predictors common to both language and music behaviour (Wesseldijk et al., 2021).

Genetic approaches, too, can benefit from a better understanding of the early language-music environment. All genetic methods, from twin studies to GWAS, rely on researchers defining the phenotype to explore, which is fraught with difficulty. For example, the

criteria that researchers use to define Specific Language Impairment affect the strength of heritability (Bishop & Hayiou-Thomas, 2008). Phenotype definition will benefit from the bottom-up approach of describing the early language-music environment. The utility of the bottom-up creation of phenotypes can be seen in bilingualism research, where descriptions of early bilingual environments has led to a more nuanced understanding of how to define, measure, and study bilingualism and its cognitive outcomes (Byers-Heinlein et al., 2019). By describing the early language-music environment, we can develop a more valid spectrum of language-music phenotypes to use in genetic (and neurocognitive) research.

Recommendations for Conducting Developmental-Ecological Research on the Early Language-Music Environment

In the past two decades, there has been a surge in naturalistic work in developmental psychology (Adolph et al., 2016; Bulgarelli & Bergelson, 2020; Sullivan et al., 2020; Yoshida & Smith, 2008) which has yielded several insights on the design and interpretation of naturalistic data (see Mendoza and Fausey, 2021, for an introduction to thinking through decisions surrounding who, what, where, and how to build and code large, naturalistic corpora). Here, we give recommendations specific to studying the early language and music environment in tandem, from a developmental-ecological perspective.

Identify Theoretical Assumptions behind Coding Schemes

One benefit of naturalistic work is that it surfaces previously unattended theoretical assumptions that impact research design and analyses. For example, a survey item such as “My child rarely makes music” (Politimou et al., 2018) relies on the parent’s lay definition of music and music-making. This item inherently assumes that the parent’s definition of music is the same as the child’s and the researcher’s. In contrast, research based on observation of children’s music-making requires the a priori creation of coding schemes that explicitly state what “music” and “music-making” are. When coding for bouts of music, researchers could define music by its rhythmic properties, pitch properties, context of production, etc. These definitions

have different theoretical assumptions about what infants perceive as music input (versus language or environmental noise). For example, a parent chanting “Come here, baby” in infant-directed speech might be coded as music because of its pitch and rhythm properties, but not in a context-of-production framework. These three definitions of music are all valid, but the resulting data from choosing one over the other must be interpreted with the limitations and assumptions of the underlying theory in mind.

Study Language and Music as Both Analogous and Distinct

When studying music and language, researchers often treat the domains as analogous, and thus port theoretical and experimental frameworks from one domain to the other. Although this approach can be informative, observational naturalistic research also gives us the opportunity to study each domain in its own context. For example, we know that North American infants receive the majority of their language input from a single source (the primary caregiver; Sperry et al., 2019). One might translate this language framework to music by measuring the proportion of music input from the primary caregiver versus other people. Then, one might compare the language and music source distributions. A necessary complementary approach is to also take into account potential qualitative differences in sources of music and language, such as the North American cultural practice of listening to recorded music. Accordingly, one should explore not only live sources of music, but also recorded sources (see Mendoza & Fausey, 2020 for this analysis).

The usefulness of studying language and music input as both analogous and distinct can be seen in psychological research on signed and spoken languages. Some research focuses on analogies between signed and spoken languages (Petitto et al., 2000), whereas other work describes how functional differences between signing and speaking underly unique features of both (Senghas, 2010). This has led to a nuanced understanding of the neurocognitive mechanisms that subserve languages in different modalities. Using analogous and distinctive frameworks in tandem can also address the historical tendency to study the language and

music of predominantly white, WEIRD communities (Baker et al., 2020; Jacoby et al., 2020; Schwab & Lew-Williams, 2016). By looking for both differences and similarities in music and language input across cultures and communities, researchers can embrace a non-hierarchical approach to cross-cultural research.

Collaborate

Language and music studies each exist at a nexus of interdisciplinary contact between behavioral scientists, humanists, and artists. Scholars trained in different disciplines will thus bring contrasting values, theories, and methods to questions that bridge these two domains. For scientists whose training is predominantly experimental, the developmental-ecological approach offers an exciting opportunity to leverage the methodological expertise of colleagues trained in qualitative and observational research. For example, there is a rich history of qualitative and quantitative observation within musical corpus studies (Shanahan, in press) and linguistics (Brown & Levinson, 2018). Experimentalists should build on the theory and logistical insights from this past work and launch new interdisciplinary collaborations. Finally, researchers should embrace opportunities to investigate language-music interactions via secondary analysis of existing naturalistic developmental datasets (e.g., Cirelli et al., 2020; Gilmore et al., 2015).

Conclusion

To fully understand the gene-brain-environment dynamics that give rise to language-music cognition in adulthood, we must have a clearer understanding of the dynamics of the environment in early development. Language-music researchers universally acknowledge that children learn about language and music implicitly, but tend to skirt important questions about how this learning unfolds over time and how the learning process influences downstream processing throughout the lifespan. The developmental-ecological approach offers a path for specifying developmental trajectories and mechanisms that will in turn advance theories of language-music interaction.

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