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Perspectives on the rhythm–grammar link and its implications for typical and atypical language development

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Abstract

This paper reviews the mounting evidence for shared cognitive mechanisms and neural resources for rhythm and grammar. Evidence for a role of rhythm skills in language development and language comprehension is reviewed here in three lines of research: (a) behavioral and brain data from adults and children, showing that prosody and other aspects of timing of sentences influence online morpho-syntactic processing; (b) co-morbidity of impaired rhythm with grammatical deficits in children with language impairment; and (c) our recent work showing a strong positive association between rhythm perception skills and expressive grammatical skills in young school-age children with typical development. Our preliminary follow-up study presented here revealed that musical rhythm perception predicted variance in six-year-old children's production of complex syntax, as well as online reorganization of grammatical information (transformation); these data provide an additional perspective on the hierarchical relations potentially shared by rhythm and grammar. A theoretical framework for shared cognitive resources for the role of rhythm in perceiving and learning grammatical structure is elaborated on in light of potential implications for using rhythm-emphasized musical training to improve language skills in children.

Keywords

rhythm; music; syntax; prosody; children

What is the link between rhythm and grammar?

A potentially meaningful link between musical rhythm and linguistic grammar has received increasing attention.[1] Although many surface differences exist between the two domains,

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similarities also abound: rhythm and grammar are organized hierarchically with rule-based expectancies at multiple levels. A likely candidate mechanism for shared neural resources for rhythm and grammar is speech prosody: rhythmic variations in speech contain important cues to syntactic events as they unfold over time. Here, we review evidence for a substantial role of stimulus-driven rhythmic facilitation, and individual differences in domain-general rhythm skills shared between music and language, that may contribute to language acquisition and speech comprehension.

Prosody and syntax during typical language development

Speech prosody is characterized by changes in pitch, duration, and amplitude over time.[2] In natural language, prosody operates hierarchically at the clausal, phrasal, and lexical levels.[3] In linguistics, the term *grammar* refers to sets of rules or principles that give rise to a generative linguistic system.[4] Such grammar[b] contains several subcomponents, such as morphology (systematic patterning of sounds within words) and syntax (systematic patterning of words within phrases). There is no one-to-one mapping between prosodic and syntactic structure; however, prosodic cues do systematically signal aspects of syntactic structure. For example, in English, syllables are typically longer in the phrase-final position, and the edges of syntactic constituents may be marked by systematic changes in pitch.[5, 6] These interfaces between prosody and syntax lend support to the argument that prosody may facilitate the discovery of hierarchical relations in syntax, a mechanism referred to as “prosodic bootstrapping.”[7] Investigations into prosodic bootstrapping, as described in the remainder of this section, are grounded in the hypothesis that mapping between prosody and syntax may structure input into more parsible chunks, thus rendering analyses of the linguistic signal more efficient.[8]

Human infants exhibit sensitivity to aspects of prosody that are available prenatally (temporal envelope cues[9]); prosodic sensitivity becomes ever-more refined during the first year of life, and such sensitivity may provide language learners with a robust mechanism for processing linguistic input across the life span. Prosodic regularity facilitates memory of novel syllable pairs,[10] word segmentation,[11] word recognition,[12] word-form learning,[13] and fluent reading comprehension.[14] Sensitivity to rhythmic cues in the speech stream, such the temporal organization of stressed syllables, is present at birth[8, 15] and has been implicated as a facilitative mechanism for language acquisition. For example, the sensitivity of English-learning infants to regular trochaic word rhythm patterns has been robustly observed as a cue for word segmentation,[16–18] and early sensitivity to rhythm is predictive of later language abilities.[19] Infants are also sensitive to violations of prosodic cues to syntactic structure, exhibiting a listening preference for speech with pauses occurring at natural clause boundaries at 7–10 months[20] and at phrase boundaries at 6 months.[21] Prosodic cues to syntactic boundaries continue to be important for adults, where they facilitate segmentation

[b]A crucial aspect of describing language with respect to grammar is the recognition that natural language is both predictable (constrained) and generative (infinitely productive). For example, English speakers add the grammatical morpheme –s to nouns to mark them as plural: cats, dogs, tables. When new nouns enter the language, these nouns are marked as plural using the same marking: emails, blogs. Other examples of English grammatical morphology include verbal markers of tense (third person singular –s: he shops; past tense –ed: he shopped) and aspect (present progressive –ing: he is shopping). When new verbs enter the language, these verbs are systematically marked in the same way: he googles, he googled, he is googling.

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of words that occur at the edges of prosodically contoured syntactic constituents better than for words that occur in the middle of such constituents.[22] Adult listeners successfully infer hierarchical syntactic structure in novel linguistic input when such structures are signaled by prosodic cues (e.g., pitch and duration) that systematically correspond to boundaries within syntactic structure, but fail to infer identical structure when convergent prosodic cues are unavailable.[23] Furthermore, prosodic cues help listeners to resolve syntactic ambiguities (i.e., in the sentence "While the parents watched, the child sang a song," the pause between "watched" and "the child" signals to the listener that "the child" is the beginning of a new clause rather than the object of the first clause).[24, 25]

Brain evidence that rhythm modulates syntactic processing

Further information about possible brain mechanisms shared between rhythm and morpho-syntactic processing comes from studies conducted with brain imaging methods. Perception of syntax is reflected in a late positive event-related brain potential (ERP) component called the P600 and can be compared across experimental conditions containing syntactic ambiguities or violations versus expected syntax.[26] A series of studies by Kotz and collaborators investigated modulations of the P600 while typically developing (TD) adult participants listened to sentences with varying temporal and syntactic characteristics. In particular, rhythmically regular auditory sentences in German facilitated syntactic ambiguity resolution[27] and detection of syntactic violations;[28] furthermore, attention to the metric structure of sentences enhanced the P600 response.[29] Interestingly, the P600 to syntactic violations also can be modulated by presenting words in a sentence with highly temporally predictable, isochronous timing.[30]

Converging support for shared neural resources between rhythm and syntax is also evident from recent functional magnetic resonance imaging (fMRI) studies of jazz musicians where improvisation and detection of rhythmic deviations in music are associated with activation of areas typically involved in linguistic syntax[c], including the left inferior frontal gyrus.[31,32] Taken together, these findings in adults with typical language skills suggest overlap of brain networks for syntactic and rhythmic skills, and motivate further investigation of how rhythm and syntax relate in the time period of language development. This link may not be restricted to co-occurring rhythmic and syntactic cues during speech. For instance, an intriguing study used musical rhythms to invoke auditory rhythmic stimulation in alternating blocks of trials and spoken sentences, and found that children with both typical and atypical language development were better able to detect syntactic violations in sentence trials that were heard after a block of musical stimuli that had regular (versus irregular) rhythms.[33]

Musical and speech rhythm in specific language impairment

Difficulties with timing and rhythm have long been noticed in language disorders.[34] In specific language impairment (SLI), a common language disorder that is characterized by deficits in grammar and, for some children, in vocabulary,[35] some aspects of musical and speech rhythm also appear to be affected.[36] Children and adults with SLI (ages 11–78 years)

[c]Future fMRI work examining language and rhythm processing within the same study is needed to understand the anatomical and functional mapping of these shared resources.

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within a single extended family showed weaker perception and production of musical rhythms relative to age-matched controls, but no deficit in pitch perception or production.[37] School-age children with SLI (ages 7–11 years) showed deficits in judging rise time and duration (both acoustic cues to rhythm) of tone pairs[38] and paced tapping to a metronome.[39] Conversely, some researchers have not found group differences; 6- to 8-year-old SLI children were not different in paced tapping[40] from TD peers. Reports on the ability to carry out prosodic imitation tasks are mixed: young children with SLI (ages 4–6 years) had difficulty imitating prosodic contours of sentences,[41] although older children with SLI showed normal performance when asked to imitate prosody.[42] Some studies assessing other aspects of speech prosody production have not found significant deficits in SLI.[43,44] Yet there is evidence from both English and Italian that young children with SLI more frequently tend to omit weak syllables compared to their TD peers,[45, 46] relevant because grammatical morphemes, such as the plural “s”, often occur on weak syllables.

Studies examining prosody perception shed light on the relevance of rhythm to language skills in SLI and suggest that rhythm has functional significance in SLI, in addition to being one of the constellation of co-morbid auditory and motor deficits in SLI.[47,48] Young children with SLI seem to have trouble perceiving prosodic fluctuations in speech[49, 50] that signal syntactic function and mark grammatical morphemes.[51] If weaker sensitivity to prosodic cues is one of the core deficits in SLI, then would exaggerating prosodic cues aid children with SLI in language acquisition? Interestingly, evidence has been found both in favor[52] and against[53] this hypothesis.

Moreover, most of the studies cited here have compared group performance between TD children and those with SLI, but an individual differences approach, such as that employed by Weinert,[36] provides relevant complementary information. As a group, children with SLI were less able to use prosodic cues when learning an artificial language, but a subset was able to use these cues efficiently to learn grammar, and their grammar learning correlated with musical rhythm sensitivity. Other data identified different subsets of children with SLI with prosodic difficulties at the discourse level and others at the word and phrase level.[54] Recent work[55] showed that, in adults, music expertise (measured as hours of lifetime practice) predicted variance in acquiring complex syntax rules in an artificial language. But because rhythm skills were not isolated, this facilitation of musical experience on language learning could also be due to shared resources for processing harmonic/tonal relations and linguistic syntax,[56,57] rather than a specific influence of rhythm abilities on grammar acquisition.

To summarize, thus far we have presented evidence that prosody is important for speech segmentation and grammar acquisition during development, as well in adult language comprehension. Behavioral and electroencephalography (EEG) evidence attest to listeners’ reliance on regular prosodic cues while they parse and store morpho-syntactic information and perceive violations of grammatical expectancies or ambiguities online. The SLI literature points to co-morbid rhythm and grammar deficits, with some divergence depending on task demands (prosodic cues to syntax appears to be more affected than prosody imitation/production). However, few studies have employed an individual differences approach to examine the relation between trait-like grammar and rhythm abilities

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in children, especially in children with typical language development. The next two sections describe our recent findings on this line of research.

Music rhythm perception and expressive grammar skills: individual differences in typical language development

Our recent study[1] investigated whether individual differences in rhythm abilities could predict variability in grammar skills in children. Rhythm perception skills were tested in TD 6-year-old children (n = 25; age range 5.9 to 7.1 years, mean age = 6.5 years) with a children's version of the Beat-Based Advantage (BBA) test developed for the study (BBA is based on the adult paradigm by Grahn and Brett[58]) and the standardized test Primary Measures of Music Aptitude (PMMA[59]). Expressive grammar was measured with the Structured Photographic Expressive Language Test (SPELT-3[60]), in which children are shown pictures and asked specific questions that are formulated to elicit answers in particular grammatical constructions. The results showed that children's performance on a Rhythm Composite measure, calculated by combining the BBA and PMMA scores, was strongly predictive of grammatical competence (Rhythm Composite versus SPELT-3 scores: $r = 0.73$, $p < 0.001$; see Figure 1). Additional analysis controlling for non-Verbal IQ, socio-economic status, and music experience showed that the association between rhythm and grammar remained significant ($r = 0.70$, $P < 0.001$). These findings are striking given that the task requirements were quite different (detecting subtle differences in musical rhythms versus generating language). A possible interpretation is that children who are better at differentiating musical rhythms also tend to be more sensitive to fluctuations in speech prosody that mark syntactic elements, and thus they have a measurable language acquisition advantage. Further study is needed to determine if individual differences in speech rhythm sensitivity or other processes, such as verbal working memory and hierarchical sequencing, also contribute to these effects.

An exploratory look at syntactic categories related to musical rhythm

Here we report a preliminary follow-up study that analyzes the items from data collected in a study by Gordon and colleagues,[1] to identify how proficiency in certain grammatical skill areas may be most relevant to rhythm discrimination skills. For this analysis, items from the SPELT-3 were separated into the following eight categories[d] based on the grammatical structure targeted by the probe: (1) complex syntax: subordinate, infinite, complement, and relative clauses; (2) transformations: interrogatives, negation, and passive; (3) aspect: present and past progressive, modal auxiliaries; (4) copulas: present and past forms of copula *to be*; (5) prepositional phrases: *on, under, behind, next to*; (6) nominal morphology:

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[d]Two considerations are important to keep in mind. First, as with expressive language tests in general, on the SPELT-3 children's incorrect responses cannot be linked to specific vulnerabilities in comprehension, production, or both. To administer the SPELT-3, an examiner shows a child a picture and delivers a verbal probe, thus requiring children to comprehend the probe as well as produce an appropriate response. Presumably, comprehension of the probe must occur to yield accurate production; thus, children's correct responses are reflective of both accurate comprehension and production. Second, the SPELT-3 is a global tool and was not designed to differentiate subtle differences in a child's grammatical performance in one given area versus another, due in part to the small number of items of each type on the test. Thus, the exploratory approach presented here is best viewed as an initial attempt in unpacking the relation between various aspects of grammatical skill and musical rhythm, which will be investigated further in future studies using a wider range of instruments for contrasting particular aspects of grammatical skill.

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pronoun case agreement, plural –s; (7) verbal morphology: third-person singular –s, past tense –ed, irregular inflections; (8) inflectional morphology: plural –s, third-person singular –s, past tense –ed.

The category inflectional morphology was comprised of the items from verbal morphology and a subset of the items from nominal morphology (plural –s). Skill areas containing fewer than six items (prepositional phrases and copula) were excluded from further analysis. Only verbal morphology and inflectional morphology contained items that probed uniformly categorical structures; the other categories contained items that were determined to probe similar grammatical constructs. For example, the aspect category contained items eliciting both the present and past progressive (*is walking* or *was walking*), as well as aspect-marking modal auxiliaries (*will walk*). Participants were near ceiling in nominal morphology and aspect categories. These findings represent what is known about grammatical development in the greater population: for TD children, measurements of grammaticality are negatively skewed, an asymmetry that increases over the course of language acquisition.[60]

The categories complex syntax and transformation contained items that were slightly more diverse than the items contained in the aforementioned categories. Complex syntax category contained all multi-clausal items, such as relative clauses and complement clauses. The transformation category contained interrogative, passive, and negation items. The creation of these two categories was motivated theoretically. Although all syntax is hierarchically structured, complex sentences are multi-clausal and thus introduce additional layers of structural dependency.[61] Sentence 1, shown in Figure 2, (“The boy read the book”) is an example of simple syntax, in that it contains a single clause, whereas sentence 2 (“The boy read the book that his mother gave to him”) is an example of complex syntax, in that it contains two clauses, one of which is structurally dependent on the other.

Variability in the production and comprehension of complex syntax has been noted in TD children beyond the age when they have largely mastered other grammatical operations, such as inflectional morphology.[62] Research has indicated that, for TD children, working memory, but not short-term memory, may correlate with the comprehension of both complex sentences in both spoken and written language.[63] Theoretically, efficient domain-general rhythmic processing could facilitate the parsing, storage, and retrieval of syntactic constituents; we thus predicted that rhythm would correlate with items requiring the production of complex syntax.

The transformation category (adapted from the theoretical linguistics literature, in which a transformation is considered a derivational process from underlying to surface structure[4]) included all items requiring participants to reorganize the syntactic constituents of the probe. For example, sentence 1 is representative of canonical English subject-verb-object word order. Sentence 3 (“What did the boy read?”), shown in Figure 2, can be described as a transformation of this canonical word order, in which the direct object has been fronted to form an interrogative. Critically, the complex syntax items also require participants to reorganize information in a probe; however, the items in the transformation category are uni-clausal, as opposed to those in the complex syntax category.

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Given evidence that auditory working memory may facilitate hierarchical syntactic processing,[64] we hypothesized that transformation category items would be associated with musical rhythm discrimination skills. It should be noted that while interrogatives, passives, and negation all involve a reorganization of the syntax in the probe, the relationship between the items in the category is quite abstract and does not account for differences in the emergence of these aspects of syntax over the course of development. Thus, the hypothesis that items in this category would correlate with rhythm was highly exploratory.

Two alternative sets of predictions for the remaining categories were formulated. On the one hand, according to a developmental approach to grammatical acquisition, TD six-year-old children have largely mastered the structures probed in these categories, producing very few errors in obligatory contexts.[62] We predicted that due to this hypothesized lack of variability (Table 1), the following categories would not correlate with musical rhythm: nominal morphology, inflectional morphology, verbal morphology, and aspect. However, given a younger age group, one might make different predictions regarding the strength of the relation between these different grammatical categories and rhythmic acuity. On the other hand, the recent literature shows transfer of music training to language skills;[65] music training enhances sensitivity to acoustically subtle variations in the speech signal[66] (such as deviations in voice onset time and duration[67]). Therefore, it is also possible that individual differences in musical (rhythm) skills would reflect variance in auditory processing such that grammar skills are globally affected across categories, even within the group of 6-year-old children who are TD.

We tested correlations between the above-described categories of items on the SPELT-3 versus the rhythm composite, d'(a measure of response sensitivity[68]) from the BBA for beat-based rhythms, and $d'$for non-beat-based rhythms, while co-varying age (since raw scores were used from the sum of subsets items, it was not possible to convert to age-normed standard scores). Correlations significant at $p < 0.05$ are reported here. As predicted, noun morphology, verbal morphology, and aspect did not significantly correlate with the music rhythm measures, possibly due to TD children's relative mastery of certain syntactic structures by age six years. Further in line with our predictions, rhythm composite correlated with both complex syntax ($r = 0.44$, $P = 0.03$) and transformation ($r = 0.42$, $P = 0.04$)[e] (Fig. 3A–B). For the BBA, the correlation between beat-based (simple rhythms) and complex syntax trended toward significance ($r = 0.39$, $P = 0.06$; Fig. 3C).

A limitation of this preliminary study is that the restricted variability in this particular TD sample precludes a broader (and possibly more informative) examination of morphological and syntactic categories that may be related to rhythm skills. Future studies should include a broader age range to better understand what portion of variance in each grammatical category can be accounted for by rhythm perception.

[e]Although the separation of items into complex syntax and transformation was theoretically motivated, one might argue that they converge to a greater extent with each other than theydiverge. Indeed, these two categories correlated with each other ($r = 0.45$, $P = 0.03$) and when merged into a single category, also correlated with rhythm composite ($r = 0.51$, $P = 0.01$), beat-based rhythms ($r = 0.40$, $P = 0.05$) and trended towards correlation with non-beat-based rhythms ($r = 0.36$, $P = 0.09$).

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To summarize, the item analysis was carried out to examine whether subsets of items on the SPELT-3 were related to musical rhythm skills and were possibly driving the correlations reported in Gordon *et al*.[1] The complex syntax and transformation categories were positively correlated with musical rhythm perception skills, in accordance with a framework of domain-general rhythm facilitating grammatical acquisition. Since items in the transformation category required children to reorganize the syntactic constituents of the probe, it is likely that the underlying mechanism of the association between rhythm and this category cannot be solely explained by facilitation of processing surface-level acoustics. Interestingly, the ability to discriminate beat-based rhythms was associated with performance on grammar items characterized by their complex syntax (i.e., subordinate, infinite, complement, and relative clauses) and likely benefit from prosodic cues. Both of these seemingly diverse constructs also rely on hierarchical, rule-based relations that unfold over time.[57]

Conclusion: mechanisms for shared rhythm and grammar and future directions

The relevance of speech rhythm cues and rhythm processing for grammatical acquisition has been reviewed here along with our re-analysis of extant data showing that variance in musical rhythm perception in 6-year-old TD children predicts global grammatical performance and, in particular, is associated with mastery of complex sentence structure. This converging evidence for a role of rhythm in language can be considered in a framework of dynamic attending theory,[69] in which neural oscillations synchronize with temporally organized stimuli, and generate temporal expectancies for upcoming events by directing attention to specific points in time. Studies of both speech perception and production in adults suggest that temporal expectancies increase attention toward the timing of stressed, or accented, syllables.[70] These temporal and metrical patterns in words and sentences appear to affect word segmentation and lexical access[71,72] and syntactic processing, by entraining endogenous attentional fluctuations to periodicities in the speech signal.[30] In typical language comprehension, rhythm works in conjunction with syntax and semantics to allow the listener to predict when and what important parts of the speech signal are coming up.[30,73] Thus, in language disorders such as SLI, an inability to use rhythm efficiently could interfere with grammatical acquisition.

This interpretation assumes some degree of domain-general rhythm, in which musical rhythm and speech prosody use shared cognitive resources[74,75] and individual differences in domain-rhythm skills account for language outcomes. The literature to date has not yet differentiated whether shared mechanisms for rhythm and grammar connections are bolstered also by underlying differences in auditory working memory[76] or hierarchical processing,[57] as suggested by our findings of an association between music rhythm skills and complex syntax. Previous studies of syntax in language and music have focused on shared resources for harmonic (musical syntax) processing, which is also organized into rule-based hierarchies.[57,77] Correlational data suggest that musician children outperform their non-musician peers on morphological rule formation[78] and detection of syntactic incongruities.[56] Future studies using random assignment to music training, and specifically

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investigating the improvement of rhythm skills as a mediating mechanism, are necessary to evaluate a causal influence of rhythm on grammar outcomes in children with typical and atypical language development.

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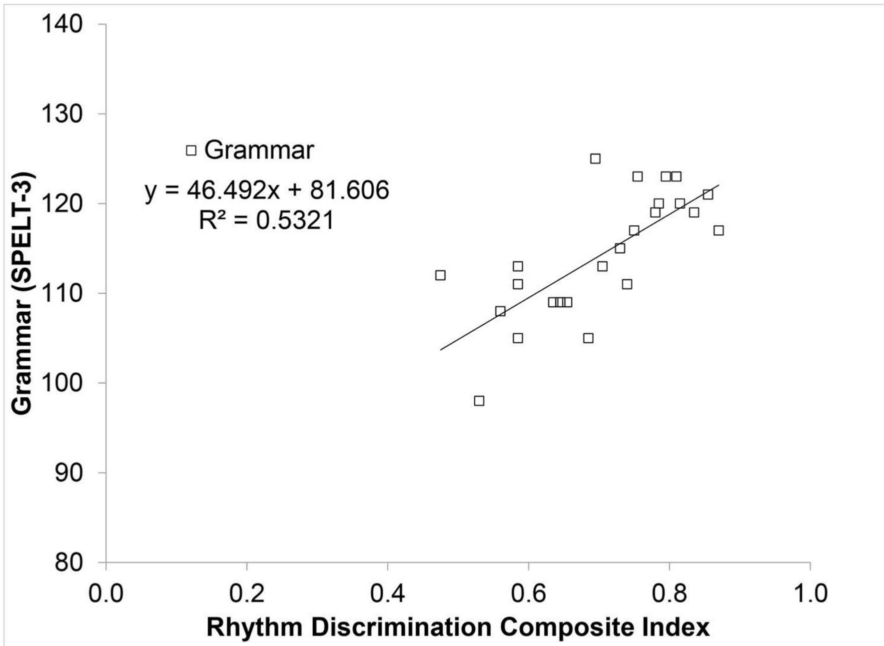

Figure 1.
Scatterplot showing correlation between expressive grammar skills and discrimination of musical rhythms. Reprinted from Gordon *et al.*[1] with permission.

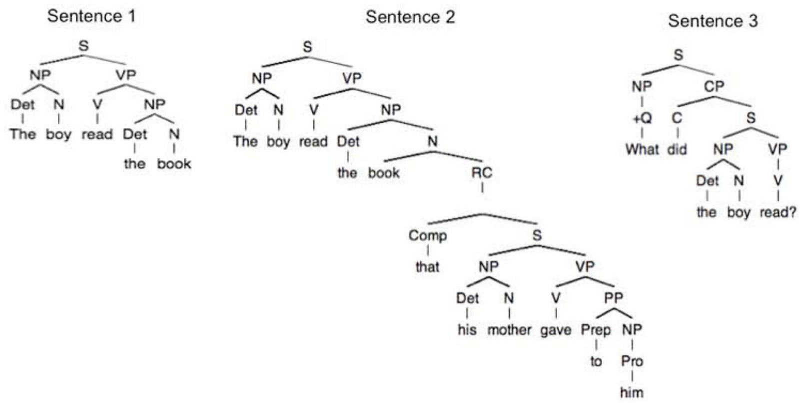

Figure 2.
Sentence examples of simple syntax, complex syntax, and transformation.

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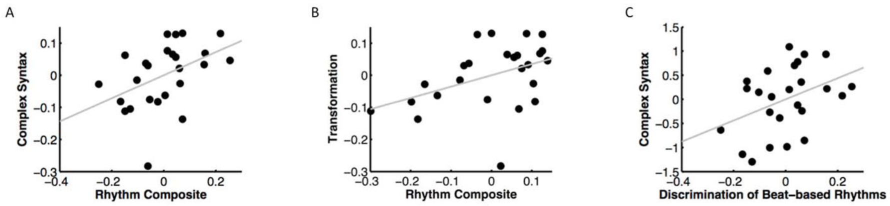

Figure 3.

Scatterplots showing correlations between musical rhythm versus items from the SPELT-3 reflecting complex syntax (panel A) and transformation (panel B). Panel C shows a scatterplot for correlation between discrimination of beat-based musical rhythms versus percent of correct items on the SPELT-3 requiring production of complex syntax. Age is controlled for in all plots.

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Table 1

Musical rhythm and categorized SPELT-3 items

	Complex syntax	Transformations	Nominal morphology	Verbal morphology	Inflectional morphology	Aspect
Number of items	12	11	9	6	6	8
Group mean (SD)	9.6 (1.61)	9.52 (1.55)	8.4 (.76)	5.32 (.85)	5.68 (.56)	7.8 (.65)
Percent correct (SD)	81% (13%)	86.5% (14%)	93% (8%)	89% (14%)	94.7%(1%)	97.5% (8%)
Group median	10	10	9	6	6	8