# Reading skills are related to global, but not local, acoustic pattern perception

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Although reading ability has been related to the processing of simple pitch features such as isolated transitions or continuous modulation[1–3], spoken language also contains complex patterns of pitch changes that are important for establishing stress location[4] and for segmenting the speech stream[5]. These aspects of spoken language processing depend critically on pitch pattern (global structure) rather than on absolute pitch values (local structure)[6,7]. Here we show that the detection of global structure, and not local structure, is predictive of performance on measures of phonological skill and reading ability, which supports a critical importance of pitch contour processing in the acquisition of literacy.

We used psychophysical tasks to assess two different aspects of pitch change perception[8]. The first measured the ability to discriminate actual pitch values over time ('local' task); the second assessed the ability to discriminate contour patterns of rises and falls in pitch ('global' task). The measure of 'local' acoustic processing required subjects to detect differences between two pitch sequences that had the same pitch contour but differed in pitch at one point. The measure of 'global' acoustic processing required subjects to detect differences in the overall pitch contour. For this latter task, the comparison sequences were transposed in pitch to prevent the use of absolute pitch cues, so that only the pitch contour could be used to detect differences between these sequences (**Fig. 1**).

The tasks were administered to 30 student volunteers (aged 19–24 years) alongside measures of reading ability and intelligence. The National Adult Reading Test (NART)[9] provided a general measure of participants' reading skill, assessing the ability to name exception words (such as "ache"). Separate tests were also administered to assess orthographic and phonological skills involved in reading. In an adaptation of an orthographic recognition test (ORT)[10], subjects were required to discriminate real word targets (such as "rain") from pseudohomophone foils ("rane"). Because both items within a pair yield the same pronunciation, accurate performance depends upon the ability to visually recognize the correct spelling (orthography) of a written word. Phonological ability was assessed by measuring participants' speed and accuracy in reading aloud a list of non-words (such as "tegwop") (NWR)[10]. Non-words are conventionally used to measure phonological skill because they require subjects to decode a novel letter string using learned associations between letters and phonemes. In addition, a non-word repetition task was administered (REP) to assess representation and use of phonology without print, a skill that is related to reading ability[11]. For this test, pre-recordings of 6, 7 and 8 syllable nonsense words (30 total) were played, and subjects were required to repeat each word immediately upon hearing it. Responses were recorded and scored as correct if the item was accurately reproduced orally. Subjects were also administered the Raven's Advanced Progressive Matrices (RPM)[12] and Mill Hill Vocabulary Senior Scale Form (MHV)[12] as measures of nonverbal and verbal intelligence, respectively.

Distributions of scores on the various measures did not depart from normality as assessed by Kolmogorov–Smirnov $Z$ tests ($P > 0.05$), with the exception of the accuracy measure of non-word reading, where there were obvious ceiling effects. Performance on the 'global' and 'local' sequence tests was 69.7% correct (s.d. 12.3) and 75.3% correct (s.d. 10.4), respectively.

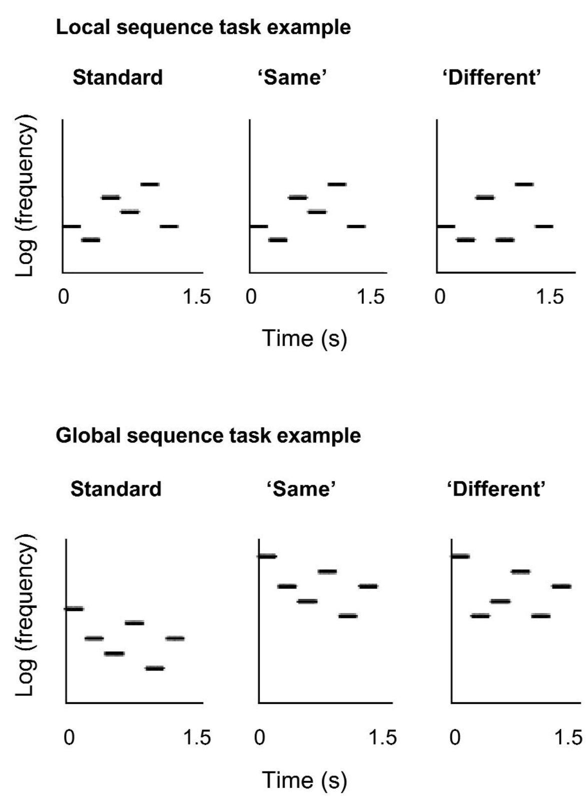


**Fig. 1.** Examples of the auditory sequences. Pairs of six-element sequences were presented, with within-pair intervals of 1 s. Forty different pairs of sequences were administered; one example of each type is shown. Sequences were composed of pure tones (250 ms duration; 20 ms gating windows), with pitches taken from an atonal scale and with the octave divided into seven equally spaced logarithmic steps ('notes'). Starting pitches varied from 250 to 354 Hz, and each sequence spanned exactly five notes. Differences altered one random note (avoiding the first and last notes) and were always two notes higher or lower than the original note. For the 'local' task, this change maintained the overall pattern of rises and falls between the notes, whereas for the 'global' task, this was always violated. Stimuli were delivered in a soundproof booth through Sennheiser HD 265 headphones (Wedemark, Germany) at 72 dB SPL. Ethical approval was attained from the local Research Ethics Committee for the University of Newcastle upon Tyne. Informed consent was obtained from all subjects.

**Table 1. Pearson product moment correlations between the study measures.**

| | Local | Global | NART | ORT | NWR time | REP | RPM |
|---|---|---|---|---|---|---|---|
| Global | 0.45* | | | | | | |
| NART | 0.25 | 0.47** | | | | | |
| ORT | 0.35 | 0.45* | 0.64** | | | | |
| NWR time | 0.13 | 0.50** | 0.57** | 0.69** | | | |
| REP | 0.11 | 0.50** | 0.47** | 0.39* | 0.29 | | |
| RPM | 0.36* | 0.57** | 0.27 | 0.31 | 0.32 | 0.36* | |
| MHV | 0.18 | 0.23 | 0.64** | 0.40* | 0.16 | 0.37* | 0.37* |

$^*P < 0.05$; $^{**}P < 0.01$ (two-tailed).

**Table 2. Semi-partial correlations between the 'local' and 'global' tasks and the reading and phonological measures.**

| | NART | ORT | NWR time | REP |
|---|---|---|---|---|
| Local | 0.01 | 0.15 | –0.12 | –0.15 |
| Global | 0.35* | 0.27 | 0.41* | 0.38* |

Semi-partial correlations show the unique variance predicted in each dependent variable (NART, ORT, NWR, REP) by a specific independent variable, after accounting for inter-correlations between the other independent variables in the regression (local, global, RPM and MHV). $^*P < 0.05$; $^{**}P < 0.01$.

We ran Pearson product moment correlation analyses to determine the statistical association between the study measures (**Table 1**). Apart from the verbal intelligence measure, all of the study measures correlated significantly ($P < 0.05$) with performance on the global sequence task. In contrast, the only measures that correlated significantly with the local sequence measure were the RPM test of nonverbal intelligence and the global sequence measure. The correlation between the local measure and ORT was close to statistical significance (at $P < 0.05$ level).

Semi-partial correlations were run between each of the phonological and reading measures (dependent variables (DVs): NART, NWR, REP, ORT) and the auditory and intelligence measures (independent variables (IVs): global, local, RPM, MHV). These correlations showed the unique variance in a DV that could be accounted for by each IV after accounting for correlations between the IVs. Performance on the global sequence task could account for unique variance in the non-word repetition, non-word reading time and the NART measures, accounting for 14.4%, 16.8% and 12.3% of the variance on each measure, respectively (**Table 2**). In contrast, the local sequence measure did not account for unique variance in any of these measures. Notably, performance on neither the local nor global measures could account for unique variance in performance on the measure of orthographic skill. This suggests that the associations between global pitch processing and reading component skills are restricted to the phonological domain.

These results can be explained in terms of a strong covariance between speech prosody perception, the acquisition of phonological representations of language and the development of reading skill. Contour perception measured in infancy[13,14] could provide a framework for understanding how acoustic perception constrains the development of phonological skill and literacy acquisition.

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**Competing interests statement**

*The authors declare that they have no competing financial interests.*

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