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The Contribution of Sensitivity to Speech Rhythm and Non-Speech Rhythm to Early Reading Development

Abstract

Both sensitivity to speech rhythm and non-speech rhythm have been associated with successful phonological awareness and reading development in separate studies. However, the extent to which speech rhythm, non-speech rhythm and literacy skills are interrelated has not been examined. As a result, five to seven-year-old English-speaking children were assessed on measures of speech rhythm sensitivity, non-speech rhythm sensitivity (both receptive and productive), reading attainment and phonological awareness. Hierarchical regression analyses revealed that productive non-speech rhythm was unable to predict variance in reading attainment independently of phonological awareness and speech rhythm sensitivity. Receptive sensitivity to speech rhythm and non-speech rhythm were both able to predict a significant amount of unique variance in reading attainment after controlling for each other and age, vocabulary, phonological awareness and short-term memory. The findings suggest that receptive sensitivity to speech rhythm and non-speech rhythm, while related to each other, also make contributions to reading attainment that are independent of each other. These findings provide only partial consistency with the general auditory processing deficit theory of reading difficulties, but are in line with the emerging theoretical claim that sensitivity to speech prosody may be implicated in successful literacy development.

Introduction

Few researchers would dispute that phonological awareness is strongly related to reading ability. It has been argued that phonological awareness skills directly influence the development of reading (Bradley & Bryant, 1983) and play a causal role in the acquisition of literacy (Goswami, 2002; Goswami, 1999, although see Castles & Coltheart, 2004). Ramus et al. (2003) found that 100% of their reading disabled sample displayed phonological processing deficits. The most influential explanation of such findings is the “phonological representations hypothesis” in which Snowling (2000) hypothesised that in human memory verbal material is stored in the form of a speech code, and that those with reading difficulties have faulty or underspecified representations of the phonological forms of words, which makes the access of these codes substantially more difficult. The phonological representations hypothesis was a development from Stanovich’s (1988) “phonological core-variable difference model” which suggests that poor readers differ from normal readers on all skills which tap into the phonological core deficit, such as phonological awareness tasks.

However, phonological awareness does not account for all the variation in children’s reading ability. It is also possible that phonological awareness deficits may be secondary to another underlying deficit, which occurs earlier on in child development (Chiappe, Stringer, Siegel, & Stanovich, 2002). Subsequently, several lines of enquiry have investigated other factors which may contribute to both reading and phonological development. One such skill is children’s sensitivity to speech rhythm or prosody, which refers to the supra-segmental features of speech such as stress, pitch, duration, and rhythm.

A New Conception of Reading Acquisition

Recently, Wood, Wade-Woolley, and Holliman (2009) argued that there is a failure to acknowledge the role of supra-segmental phonology in discussions of the development of children's segmental phonological representations and reading. The reason that this may be conceived as problematic is because suprasegmental phonology needs to be represented if polysyllabic words are to be successfully decoded. Models based on segmental phonological awareness only can account for decoding of individual syllables, but do not enable the realization of unfamiliar polysyllabic words, as the placement of lexical stress is unknown and can affect both vowel quality (thereby impacting on the application of segmental phonology) and word meaning (e.g., compare 'REcord' - the noun, to 'reCORD' - the verb).

Wood et al. (2009) reviewed the available evidence on prosodic sensitivity and reading and proposed four routes by which speech rhythm sensitivity may positively influence reading development.

In the first route, it was argued that infants' sensitivity to the supra-segmental features of speech (such as stress in particular; see Jusczyk, 1999) may facilitate spoken word recognition (Cutler, 1994), which in turn will affect vocabulary development (Newman, Bernstein Ratner, Jusczyk, Jusczyk, & Dow, 2006; Walley, 1993), which in turn facilitates reading development (Metsala & Walley, 1998). There is evidence of a spoken word recognition deficit in children with reading difficulties (e.g., Metsala, 1997), and Wood and Terrell (1998) found that although children with reading difficulties made significantly more errors than controls on a speech perception task, the difference became non-significant after controlling for vocabulary, which supports the assertion that spoken word recognition skills are related to reading through vocabulary development.

In a second pathway, Wood et al. (2009) argued that because speech rhythm centres on the production of the vowel within the syllable (Scott, 1998), sensitivity to it may highlight the location of vowels within words and therefore mark onset-rime boundaries. Children with sensitivity to speech rhythm should therefore have better rhyme detection skills, and consequently better reading attainment (Goswami & Bryant, 1990). Wood and Terrell (1998) found that children with reading difficulties showed deficits in both rhyme detection ability and a test of metrical stress sensitivity relative to controls, after controlling for vocabulary. Wood (2006a) also found that performance on a measure of stress sensitivity was related to rhyme detection skill in a sample of beginning readers.

In the third pathway, Wood et al. (2009) suggested that speech rhythm sensitivity may influence reading development by contributing to the acquisition of phonemic awareness. That is, as phoneme identification appears to be easier in stressed as opposed to unstressed syllables (Chiat, 1983), a child sensitive to speech rhythm may be able to manipulate stress and apply it to unstressed syllables to help them to clarify the identity of ambiguous phonemes. This, according to Kitzen (2001), is an important reading skill that is deficient in dyslexic samples and Wood (2006a) showed that sensitivity to speech rhythm was predictive of phoneme awareness.

These three pathways propose that the relationship between speech rhythm sensitivity and reading ability is mediated by vocabulary development, rhyme awareness, and phoneme awareness. However, a growing literature has also demonstrated links between speech rhythm and reading independently of these associations, perhaps displaying evidence of only partial mediation via these proposed pathways.

For instance, Whalley and Hansen (2006) used the ‘DEEdee task’ to assess prosody at the phrasal level in 81 eight to ten-year-old children. In this task the prosodic structure of a phrase was retained but each syllable was substituted by a meaningless syllable ‘dee’. Children were played an original phrase, which was then followed by two Deedee phrases, one of which matched the prosodic pattern of the original phrase and one of which did not. They had to decide which Deedee phrase matched the original phrase. For example, the phrase ‘Humpty Dumpty’ would match the Deedee phrase ‘DEEdee DEEdee’ and would not match ‘deeDEE deeDEE’. This task eliminated the potential contribution of phonemic information. They also assessed prosody at a word level where children had to discriminate between compound nouns ‘ice-cream’ and noun phrases ‘ice, cream’, which also differed only in terms of their prosodic features. It was found that phrase-level prosody predicted a significant amount of variance in reading comprehension after word reading accuracy, phonological awareness and general rhythmic sensitivity had been accounted for. Word-level prosody also predicted a significant amount of unique variance in word identification accuracy.

Wood (2006b) used a ‘mispronunciations task’ to investigate whether children could recover the correct stress allocation from a mispronounced word and accurately identify the corresponding object from a line drawing of a house. There were four different kinds of mispronunciation, which variously affected the location of primary lexical stress and changed the nature of the vowels in the word. Wood found that performance on the ‘reversed metrical stress’ condition of this task (in which the stress pattern and reduced vowel location in the two syllable words was swapped, such that a word like ‘SOfa’ was pronounced as ‘s’FAR’) was the only word manipulation that was significantly associated with reading attainment in typically developing beginning readers. It was also found that this measure of speech rhythm sensitivity could account for a significant amount of variance in early spelling ability after phonological awareness has been accounted for.

Furthermore, Holliman, Wood, and Sheehy (2008) administered the mispronunciations task from Wood (2006b) to 44 primary school children (mean age 6;1), along with a battery of reading and phonological awareness assessments. It was found that speech rhythm sensitivity on this task predicted a significant amount of variance in reading attainment after age, vocabulary, and phonological awareness had been taken into account, indicating unique variance. Other studies have also demonstrated that speech rhythm sensitivity deficits remain in poor readers even after controlling vocabulary (e.g., Wood & Terrell, 1998).

Such studies suggest a fourth pathway in which there is an apparently direct relationship between speech rhythm sensitivity and reading attainment. However, it is likely that this relationship is mediated by another variable, such as fluency, comprehension, or morphological awareness. However, overall, it would seem that there is a coherent framework emerging for understanding how speech rhythm may contribute to reading development.

Speech Rhythm, Non-Speech Rhythm, and General Auditory Processing

One question raised by the above account is to what extent is sensitivity to rhythm in speech separate from sensitivity to rhythm generally, especially given the literature that has found links between non-speech rhythm sensitivity and reading proficiency. For example, Overy (2000) compared 6 children identified as ‘strong risk of reading difficulties’ with 16 children identified as ‘no risk of reading difficulties’ on a number of musical aptitude tests and found that the strong risk of reading difficulties group scored significantly lower on all the tests involving timing, and particularly on the rhythm copying task, which required children to copy a short rhythm after hearing it. Following this, Overy, Nicolson, Fawcett, and Clarke (2003) administered musical aptitude tests to 15 dyslexic boys (mean age 9.0) and 11 control boys (mean age 8.9). Three rhythm skills were assessed; in the ‘rhythm copying’ test a short rhythm played over headphones had to be copied by tapping a key on a computer keyboard, in the ‘rhythm discrimination’ test children were played two short rhythms over headphones and had to decipher whether they were the same or different and in the ‘song rhythm’ test children tapped the beat of happy birthday whilst singing the words. It was found that the dyslexic group scored lower on all of the non-speech rhythm tasks.

There is also longitudinal evidence of an association. David, Wade-Woolley, Kirby, and Smithrim (2007) administered a rhythm production task to 53 children in Grade 1, which involved moving to a beat by tapping with both hands, tapping with alternate hands, moving their legs, walking on the spot, and walking forward. This measure of motor rhythm was found to predict reading in all five subsequent grades. It was also found to account for an additional 9.0 percent of the variance in word reading after phonological awareness had been controlled, but only in Grade 5, and predicted unique variance in Grades 2, 3, and 5 after naming speed had been accounted for. The authors concluded that rhythm seems to be more important as the reading demands increase and that rhythm seems distinct from naming speed, but is subsumed by phonological awareness.

Such findings may be considered in terms of a domain-general dysfunction in processing temporal information (Tallal, 1980, 1984), which could be responsible for phonological processing deficits. Temporal processing refers to the perception of the temporal properties of the events, such as duration, sequencing, and rhythm. Farmer and Klein (1995, p. 480) stated “if a temporal processing deficit contributes to a difficulty with perception and discrimination of phonemes, recognition of those phonemes will not occur as easily and automatically as it would in a subject without a temporal processing deficit. Such an impaired recognition would undoubtedly lead to many of the problems described in children with a phonemic deficit who are at risk for reading problems”.

It should be noted that many researchers provided contrary evidence and dispute the relationship between temporal processing and reading (Chiappe et al., 2002). For instance, Boets, Wouters, van Wieringen, and Ghesquière (2006) compared pre-school children at high familial risk of dyslexia with those at low familial risk of dyslexia on a series of auditory processing tasks to assess the auditory temporal processing deficit hypothesis. While some of the auditory tasks were found to be significantly related to phonological awareness, there were no significant group differences on any of the auditory processing tasks. This is not unlike other research which has shown that only a subset of children with Specific Language Impairment (SLI) and reading difficulties have rapid auditory processing deficits (McArthur & Bishop, 2004). However, one possible explanation for this contrary evidence is that auditory processing deficits are evident only in a sub-sample of poor readers. This idea is supported by Bishop and McArthur (2005, p.328) who have argued that there is clearly no one-to-one relationship between temporal processing and reading difficulties and that “if auditory deficits are seen in only a subset of individuals, then one may mask genuine group differences by combining heterogeneous cases”. In fact, in a review by Ramus (2003) it was reported that approximately 40% of children with reading difficulties have accompanying auditory processing difficulties and such a “one-size fits all” explanation of reading difficulties has been challenged in the recent literature (Thomson, 2009).

Despite the controversial relationship between temporal processing and reading, it remains plausible that speech rhythm and non-speech rhythm may be related components of the same skill, both of which could be accounted for by a general auditory processing deficit. This, if found, may also explain how speech rhythm is related to reading independently of phonological awareness. However, as Thomson (2009, p.26) notes; “no study has yet convincingly linked observed non-speech auditory perceptual deficits to their purported speech equivalents”.

It should be noted that this potential link between speech and musical rhythm is not supported by the neurological literature, which suggests that the two are independent systems. For instance, Peretz (1993) found that perception of musical syntax can be selectively impaired after brain damage without impairing linguistic syntax. McMullen and Saffran (2004) also commented that while damage to the left temporal lobe commonly results in language problems, damage to the right temporal lobe commonly results in amusia. However, according to Patel (1998, p. 39) this lack of relatedness could be explained by the “shared structural integration resource” (SSIR) hypothesis, which suggests that although the processing of linguistic and musical syntax may be cognitively distinct, both processes suffer a cost when elements of a sequence, albeit linguistic or musically, are forged into working memory. When this occurs and there is conflicting information between what is expected and what is actually there, both processes depend on the same set of shared neural resources in order to cover this cost, which would help explain the link between the two domains. Thus, the SSIR hypothesis suggests that the two domains may indeed be distinct and that domain similarity, when found, could be due to the shared neural resources that cover costs in syntactical processing tasks.

Rationale

A growing literature has demonstrated that sensitivity to the prosodic features of speech (such as stress) is related to reading development. However, to what extent is performance on measures of speech rhythm indicative of a specific form of phonological sensitivity, as opposed to being indicative of a more fundamental deficit in auditory processing? Further research is clearly warranted as we currently do not know whether speech rhythm sensitivity is related to non-speech rhythm sensitivity and whether speech rhythm can predict unique variance in reading beyond its relationship with non-speech rhythm. Many of the studies documented above found that prosodic sensitivity is predictive of reading even after phonological awareness has been accounted for and this suggests that prosody is not merely related to reading via the anticipated mechanisms of phonological awareness. It has been speculated that prosody may be related to reading in a similar way to musical, or non-speech rhythm. A study investigating the relationship between speech rhythm, non-speech rhythm, phonological awareness and reading, which can examine whether speech rhythm can predict reading independently of its association with non-speech rhythm, is necessary to inform the debate.

To assess this question, in the current study, in addition to the various reading and phonological awareness assessments, we employed two measures of speech rhythm; the mispronunciations task used in Holliman et al. (2008) and a revised mispronunciations task. It was felt necessary to include both versions of this task so that the concurrent validity of the revised task could be explored and to see whether the revised task followed the trend of the original task with respect to the other measures in this study. This study overcomes some of the limitations in the Holliman et al. (2008) study, as the revised mispronunciations task was simpler, included more distracter items with the same initial letter and phoneme, and a digit span test was administered to control for short-term memory. This study also employed two tests of non-speech rhythm using the rhythm copying task, which required children to reproduce a rhythm previously sounded, and the rhythm matching task, which required children to discriminate between two similarly sounding rhythms along the same-different paradigm.

This study will help to answer the following three research questions; *i)* is there a significant relationship between sensitivity to speech rhythm and sensitivity to non-speech rhythm, *ii)* can sensitivity to speech rhythm predict a significant amount of variance in reading attainment after non-speech rhythm and phonological awareness have been taken into account, *iii)* can non-speech rhythm predict a significant amount of variance in reading attainment after speech rhythm sensitivity and phonological awareness have been taken into account.

Method

Participants

All participants in this study (n = 102) were recruited from two combined schools in Buckinghamshire, UK, in the year 2006. The two schools were comparable in terms of their locality, number of students, age range, academic achievement as judged by their average point score on English, Mathematics, and Science, and on the number of pupils with special educational needs (SEN). Children were aged between 5 and 7-years-old (mean age = 6;7) and were in either Reception (n = 4), Year-One (n = 57), or Year-Two (n = 41) classes. Forty-six children were female and fifty-six were male. The mean standardised vocabulary score of the sample was 101.48 (SD =

10.33), and the mean word reading raw score was 29.82 (*SD* = 20.81), which equates to a reading age equivalent of 7;1. These tests are described in the Test Battery section. All participants were approached to participate only once both their parents and head-teachers had given their consent.

Test Battery

Word Reading

The British Ability Scales II Word reading subtest (Elliot, Smith, & McUlloch, 1996) was used as a measure of single word identification. It assessed the words that a child could accurately read out loud from a set of 90 presented in order of increasing difficulty. The test was administered according to the standardised instructions. It was reported in the British Ability Scales II that Cronbach's α reliability coefficient was between .88 and .98.

Vocabulary

To provide a measure of receptive vocabulary, children were assessed using the British Picture Vocabulary Scales II (Dunn, Dunn, Whetton, & Burley, 1997). Children heard a word spoken and selected the picture which best illustrated that word from a choice of four possible pictures. As the child progresses through the test, the words become increasingly difficult and the test is terminated when a child makes 8 or more failures in a set of 12. It was reported in the British Picture Vocabulary Scales II that Cronbach's α reliability coefficient was between .93 and .94.

Digit Span Test – Forward

The digit span subtest from the British Ability Scales II (Elliot et al., 1996) was used to provide a measure of children's short-term memory capacity. The administrator read some digits out loud and the child had to repeat the same digits in the correct order back to the administrator. The task was administered in accordance with the standardised instructions and children received one point for every item correctly repeated. As there were 36 test items a total score was obtained out of 36. It was reported in the British Ability Scales II that Cronbach's α reliability coefficient was between .87 and .96.

Rhyme Detection

The rhyme detection subtest of the Phonological Assessment Battery (PhAB; Frederickson, Frith, & Reason, 1997) was used to provide a measure of children's sensitivity to rhyme. Children heard three words from the administrator and then had to verbally identify the two rhyming words from the three provided (e.g., "made", "hide", and "fade"). The task began with three practice items followed by up to twenty-one test items of increasing difficulty. Children received one point for each correct answer. It was reported in the Phonological Assessment Battery that Cronbach's α reliability coefficient was .92.

Phoneme Deletion

This phoneme deletion assessment was taken from Wood (1999). Children heard a word spoken by the administrator and then had to repeat the word back but without either the first or last phoneme. In one subtest the first phoneme was deleted (e.g., 'try to say "car" without the /k/ sound') and in the other subtest the last phoneme was deleted. Prior to testing it was ensured that all children understood the concepts of 'first' and 'last'. For each subtest, four practice items were followed by the twelve test items and the subtests were presented in a counterbalanced order. Children received one point for each correct deletion made. Cronbach's Alpha reliability coefficient was $\alpha = 0.96$.

The 'Mispronunciations' Task

This speech rhythm sensitivity assessment was taken from Wood (2006b). It first checked that children could accurately identify 17 common words from a line drawing of a cartoon house by pointing to the correct picture; this was the baseline score. All of the objects had two syllables and carried primary lexical stress on the first syllable, and a reduced vowel in the second syllable (i.e. sofa). In the experimental condition of this task, the words were mispronounced. The metrical stress of each word was reversed so that the first vowel became reduced and the second vowel became fully articulated. For example, instead of the normal pronunciation of the word “parrot” (‘pærət) it was pronounced /pə‘rɒt/.As with the baseline condition of this task, in the reversed stress condition of this task, children had to point to the picture that went with the word they had just heard from line drawing of a house. Following one practice item, an overall score out of 16 was obtained. In terms of presentation, the correctly pronounced words and the mispronounced words were recorded beforehand and were then played through speakers to children during this task. The internal reliability of items used in the task was $\alpha = 0.87$. See Appendix A for a complete list of the target items, their phonetic transcription, and the phonetic transcription for the mispronounced forms.

The Revised ‘Mispronunciations’ Task

This speech rhythm assessment was based upon the original mispronunciations task used by Wood (2006b) but was adapted to overcome some of the more problematic aspects of the task format, for instance, this task was simpler and had more distracter items that began with the same letter sound and phoneme. Nineteen words from the common lexicon of children aged between 5 and 7-years-old (one practice item and 18 test items) were selected from the children’s printed words database (http://www.essex.ac.uk/psychology/cpwd/). In the baseline condition for each trial, children were shown four pictures of two syllable words, each of which started with the same letter and sound (i.e. singer, skateboard, swordfish, seagull) and they had to identify which picture out of a possible four was sounded through the mechanical speaker by pointing to it. Similar to the 'Mispronunciations' Task above, these correctly pronounced words and the mispronounced words were recorded beforehand and were then played through a mechanical speaker to children during this task. The word frequency of the target and distracter items in the test were matched as closely as possible. All of the target words carried primary lexical stress on the first syllable, and the vowel in the second syllable included a reduced vowel (i.e., singer above). However, in the experimental condition the words were mispronounced. The metrical stress of each word was reversed so that the first vowel became reduced and the second vowel became fully articulated. For example, instead of the normal pronunciation of the word "singer" ('sɪŋə) it was pronounced "sn'ger" (səŋ'ɜː). It should be noted that the decision to include only items in this task which contained a schwa in their final syllable was a conscious decision, as this is a highly common form of vowel reduction in British English pronunciation, and therefore one that children will have encountered very frequently. We therefore acknowledge that there are other forms of vowel reduction that were not manipulated and assessed in this task, and that this may be seen as a limitation of it. Prior to participation under this experimental condition, children were instructed that they would hear words that 'were not said properly' and then have to point to the picture that best went with that word from a choice of four pictures available. Children received one-point for each correct answer and an overall score out of 18 (as the first one was a practice trial) was obtained. If errors were made on the practice item 'spider', children were only instructed what the correct item was and what the utterance sounded most similar to, but were not told why. To avoid memory effects, the order of test conditions (baseline or experimental) was counterbalanced and were administered one week apart. The internal reliability of the experimental condition of this task was $\alpha = 0.82$. See Appendix B for a complete list of the target items and distracter items used in this task along with their word frequency per million and their phonetic transcription.

Rhythm Copying

This productive assessment provided a measure of children's non-speech rhythm skills using one form of musical aptitude test based on Overy et al. (2003). Children were seated at a laptop computer with an administrator and were played a short rhythm twice over headphones, with particular time intervals between beats. They were then required to copy this sequence as accurately as possible using the spacebar on the keyboard to represent beats. The computer measured the time interval between each of their copied beats and if this interval was within 20% of the true time interval they scored that time interval correctly and received one point. The actions of the child were observed by an administrator who could restart the task should any mishaps occur. Upon completion, the data for each child, including the length of intervals between all tapped beeps on all trials, was also observed by the researcher to ensure that the computer scoring was working appropriately. Following a fairly simple practice trial, the test trials were repeated at an increasing level of difficulty, with rhythms ranging from two to seven beeps in duration. There were a total of 21 time intervals so children obtained a score out of the 21 on this task. The internal reliability of items used in the task was $\alpha = 0.602$.

Rhythm Matching

This receptive assessment, also based on Overy et al. (2003), provided a measure of children's non-speech rhythm skills using another form of musical aptitude test.

Children were seated at a computer with an administrator and were played two sets of rhythms over headphones. They had to decide whether the second rhythm matched the first, by saying either “same” or “different” so that the administrator could select the appropriate option on the computer screen. Children received one point for each rhythm correctly identified as “same” or “different”. Following a fairly simple practice trial, the trials were repeated at an increasing level of difficulty, with rhythms ranging from two to seven beeps. There were a total of twelve test trials so children obtained a score out of twelve on this task. The internal reliability of items used in the task was $\alpha = 0.193$.

Results

Table 1 below shows the mean scores children obtained for all the assessments in this study.

Table 1 about here

It can be seen from Table 1 that participants scored in the middle range on both of the phonological awareness measures (the phoneme deletion task and the rhyme detection task) and the non-speech rhythm measures (the rhythm copying task and the rhythm matching task). It should be noted given that the rhythm matching task involved a forced choice procedure, that the mean score of 7.49 was above that expected by chance and that the difference between expected and observed frequencies was significant, $\chi^2(1, N = 102) = 11.333$, $p = 0.001$. It can also be seen that while participants obtained a high mean score on the baseline condition of the original mispronunciations task (15.58 from a possible 16) a relatively low mean score was obtained on the stressed reversed condition of this task (9.69 from a possible 16). This difference between baseline and experimental conditions was significant, $t(101) = 15.484$, $p < 0.001$. Similarly, while participants obtained a high mean score on the baseline condition of the revised mispronunciations task (17.57 from a possible 18) a relatively low mean score was obtained on the stressed reversed condition of this task (12.55 from a possible 18) which was also expected. The difference between baseline and experimental conditions was significant, $t(101) = 13.173$, $p < 0.001$. It should also be noted given that the revised mispronunciations task involved a forced choice procedure, that the mean score of 12.55 was above that expected by chance and that the difference between expected and observed frequencies was significant, $\chi^2(1, N = 102) = 94.157$, $p < 0.001$.

Table 2 below shows the correlation matrix for all the variables included in this study.

Table 2 about here

It can be seen from Table 2 that the revised stress mispronunciations task was strongly correlated with word reading ($r = 0.63$, $p < 0.001$) and the phonological awareness measures (rhyme $r = 0.56$, $p < 0.001$ and phoneme deletion $r = 0.54$, $p < 0.001$). This was not surprising given the growing amount of evidence linking speech rhythm to phonological awareness and reading ability. The revised stress mispronunciations task was found to be correlated with the original stress mispronunciations task ($r = 0.58$, $p < 0.001$) as expected. The non-speech rhythm tasks were both significantly correlated with the reading and phonological awareness measures, although the relationship was not as strong as the relationship between speech rhythm and these skills. In terms of the relatedness between speech and non-speech rhythm, the revised mispronunciations task was significantly correlated with the receptive non-speech rhythm measure ($r = 0.36$, $p < 0.001$), but not the productive non-speech rhythm measure ($r = 0.17$, $p = 0.095$). Moreover, the two non-speech rhythm measures were not significantly correlated ($r = 0.19$, $p = 0.063$) and this may have been due to the relatively poor internal reliabilities of the tasks or the fact that one measure was based more on reception (rhythm matching task) and the other on production (rhythm copying task). Lastly, there was a strong positive relationship between the phonological awareness measures and word reading, which was also anticipated given the well-documented link between these skills.

Note that in the following regression analyses speech rhythm sensitivity was measured using the revised mispronunciations task. Also, a composite measure of phonological awareness was constructed by obtaining z-scores for each of the two phonological awareness measures (the phoneme deletion task and the rhyme detection task) and then adding these scores together. The data was also inspected to ensure that it met the assumptions for a hierarchical regression analysis.

In the first analysis, a hierarchical regression was conducted to see whether speech rhythm sensitivity could account for a significant amount of the variance in reading attainment after phonological awareness and non-speech rhythm sensitivity had been accounted for.

The results from the regression analysis showed that phonological awareness was able to account for 62.5 percent of the variance in reading attainment when entered at step one, R^2 change = 0.625, $F(1, 100) = 166.667$, $p < 0.001$. Receptive non-speech rhythm sensitivity (the rhythm matching measure) was able to account for 1.9 percent of the variance in reading attainment at step two, R^2 change = 0.019, $F(1, 99) = 5.140$, $p = 0.026$, and productive non-speech rhythm sensitivity (the rhythm copying measure) was able to account for 0.1 percent of the variance in reading attainment at step three, R^2 change = 0.001, $F(1, 98) = 0.148$, $p = 0.701$. However, speech rhythm sensitivity accounted for a further 3.2 percent of the variance in reading attainment at step four, R^2 change = 0.032, $F(1, 97) = 9.676$, $p = 0.002$. Thus, performance on the revised mispronunciations task was able to predict a significant amount of unique variance in reading attainment after phonological awareness and non-speech rhythm sensitivity had been taken into account.

In the second analysis, a hierarchical regression was conducted to see whether receptive non-speech rhythm sensitivity (using the rhythm matching task) could account for a significant amount of the variance in reading attainment after phonological awareness and speech rhythm sensitivity had been accounted for.

After phonological awareness had been controlled, speech rhythm sensitivity was able to account for 3.8 percent of the variance in reading attainment at step two, R^2 change = 0.038, $F(1, 99) = 11.149$, $p = 0.001$. However, receptive non-speech rhythm sensitivity accounted for a further 1.2 percent of the variance in reading attainment at step three, R^2 change = 0.012, $F(1, 98) = 3.658$, $p = 0.059$. Thus, performance on the receptive non-speech rhythm task could not predict a significant amount of unique variance in reading attainment after phonological awareness and speech rhythm sensitivity had been taken into account, although it was only marginally non-significant.

In the third analysis, a hierarchical regression was conducted to see whether productive non-speech rhythm sensitivity (using the rhythm copying task) could account for a significant amount of the variance in reading attainment after phonological awareness and speech rhythm sensitivity had been accounted for.

After phonological awareness and speech rhythm sensitivity had been controlled, productive non-speech rhythm sensitivity accounted for 0.2 percent of the variance in reading attainment at step three, R^2 change = 0.002, $F(1, 98) = 0.480$, $p = 0.49$. Thus, performance on the productive non-speech rhythm task was unable to predict a significant amount of unique variance in reading attainment after phonological awareness and speech rhythm sensitivity had been taken into account.

Based on the strength of the associations in the three analyses, a more robust analysis was undertaken to see just how strongly speech rhythm (and receptive non-speech rhythm) was related to reading. Therefore, another hierarchical regression analysis was conducted to see whether speech rhythm sensitivity could predict variance in reading after age, vocabulary, phonological awareness, short-term memory, productive non-speech rhythm, and receptive non-speech rhythm had all been accounted for. This order of entry was based as far as possible on the proposed routes from speech rhythm sensitivity to word reading in the model by Wood et al. (2009). It was also investigated whether receptive non-speech rhythm could account for unique variance in reading attainment after controlling for these variables because the associated p-value approached significance in an earlier regression (see Table 3 below).

Table 3 about here

It can be seen from Table 3 that performance on the productive non-speech rhythm sensitivity measure was unable to predict any additional variance in reading attainment after age, vocabulary, phonological awareness, and short-term memory had been accounted for. However, performance on the receptive non-speech rhythm sensitivity was able to account for an additional 1.8 percent of the variance in reading attainment at step six, R^2 change = 0.018, $F(1, 95) = 5.532$, $p = 0.021$. Interestingly, performance on the speech rhythm sensitivity task was still able to predict an additional 2.1 percent of the variance in reading attainment at step seven after age, vocabulary, phonological awareness, short-term memory, productive non-speech rhythm, and receptive non-speech rhythm had been accounted for, R^2 change = 0.021, $F(1, 94) = 6.828$, $p = 0.01$.

Furthermore, when receptive non-speech rhythm and speech rhythm sensitivity are entered at different (reverse-order) steps, we can see that while sensitivity to speech rhythm was able to account for an additional 2.6 percent of the variance in reading attainment at step six, R^2 change = 0.026, $F(1, 95) = 8.053$, $p = 0.006$, performance on the receptive non-speech rhythm sensitivity measure was able to predict an additional 1.3 percent of the variance in reading attainment at step seven, after age, vocabulary, phonological awareness, short-term memory, productive non-speech rhythm, and speech rhythm had been accounted for, R^2 change = 0.013, $F(1, 94) = 4.362$, $p = 0.039$.

It can also be seen that speech rhythm sensitivity relates quite strongly to reading attainment, Beta = 0.187, $t(94) = 2.613$, $p = 0.01$, so too does receptive non-speech rhythm sensitivity, Beta = 0.133, $t(94) = 2.089$, $p = 0.039$, although age and phonological awareness also made a unique contribution. It should also be noted that the same pattern of results was observed when the original mispronunciations task was entered in place of the revised mispronunciations task in the above analyses.

Discussion

In this study, no relationship was found between speech rhythm sensitivity (using the revised mispronunciations task) and the productive non-speech rhythm sensitivity measure ($r = 0.17$). However, a significant relationship was found between speech rhythm sensitivity and the receptive non-speech rhythm sensitivity measure ($r = 0.36$). Neither the speech rhythm sensitivity measure nor the receptive non-speech rhythm sensitivity measure yielded a demonstrable association with the productive measure of non-speech rhythm sensitivity, perhaps highlighting a distinction between the processes involved in receptive and productive rhythm. The correlations suggest some degree of similarity between the processing of speech and non-speech rhythm at the receptive, perceptual level, but this relationship cannot be extrapolated to the production of rhythm, although the productive task clearly involves perception too. It is possible that the processes involved in the reception and the production of rhythm differ, and seems possible that good production of rhythm can co-occur with poor perception of rhythm (and vice versa). Perhaps children's performance on the productive non-speech rhythm measure would have been more related to spelling given the productive nature of these tasks; however, a measure of spelling was not included in this study. It is also regrettable that no productive speech rhythm measure was included in this study. Therefore, the findings only provide partial support for a relationship between the two domains.

Despite the significant relationship between speech rhythm sensitivity and receptive non-speech rhythm sensitivity, the regression analyses were indicative of different, unique relationships between these two types of rhythm and children's reading development. For instance, speech rhythm sensitivity was found to predict a significant amount of the variance in reading attainment after age, vocabulary, phonological awareness, short-term memory, productive non-speech rhythm, and receptive non-speech rhythm had been accounted for. Moreover, receptive non-speech was also able to account for significant variance in reading attainment once age, vocabulary, phonological awareness, short-term memory, productive non-speech rhythm, and speech rhythm sensitivity had been accounted for. Taken together, these findings suggest that despite a significant zero-order correlation, both speech rhythm sensitivity and receptive non-speech rhythm sensitivity make an independent contribution to reading development, and therefore provide only partial support for a general auditory processing deficit theory of reading difficulties. It could be for instance, that the poor readers in this sample may have had a co-occurring general auditory processing deficit. An accompanying auditory processing deficit is present in a subgroup of the population of poor readers, and this would compromise the processing of both speech, and non-speech rhythm in these children. The findings could also perhaps be explained in terms of the “shared structural integration resource” (SSIR) hypothesis put forward by Patel (1998) whereby the processing of speech and non-speech rhythm are considered to be cognitively distinct, but that both processes depend on the same set of shared neural resources when elements of a speech or non-speech sequence are forged into working memory. However, if either of these theories hold, we would have expected a stronger relationship between performance on the productive non-speech rhythm measure and the other assessments in this study (e.g. reading, speech rhythm, and receptive non-speech rhythm), but this was not the case. This may perhaps suggest that the two types of rhythm may involve different processes and contribute to reading in different ways. However, due to the fact that the receptive non-speech rhythm measure had such poor internal reliability, and due to some inherent limitations to the productive non-speech rhythm measure, these findings should be interpreted with some degree of caution.

The results from this study have contributed to the growing amount of literature finding that prosodic sensitivity can account for variance in reading attainment after controlling for individual differences in phonological awareness (Holliman et al., 2008; Whalley & Hansen, 2006; Wood, 2006b), which is a key finding. Some might have argued that speech rhythm sensitivity is predicting reading attainment because the mispronunciations task(s) can be seen as a form of phonological awareness measure. However, as the results show, speech rhythm sensitivity predicted a significant amount of variance in reading attainment after phonological awareness had been accounted for. While this study only included two measures of phonological awareness (i.e., phoneme and rhyme awareness), this raises the idea that sensitivity to speech rhythm may contribute to reading development not just through the anticipated mechanisms of phonological awareness development.

Perhaps in line with the model from Wood et al. (2009), the relationship between speech rhythm sensitivity and reading might be mediated by some other, unknown variable via the fourth pathway. Holliman et al. (2008) argued in accordance with Kuhn and Stahl (2003) that sensitivity to the rhythmic/prosodic features of speech, such as stress, are implicated in both the reading comprehension and reading fluency process. It seems plausible that these processes could mediate the observed relationship between stress sensitivity and word reading, in a manner that does not necessarily depend purely on phonological skills, which could explain the findings here. Another explanation for the relationship between speech rhythm and reading independent of phonological awareness is that speech rhythm could be related to reading via its link with morphology, although morphology was not assessed in the present study. Current reading models typically deal with monosyllabic words (Protopapas, Gerakaki, & Alexandri, 2006) where stress sensitivity has little importance. However, when we are decoding multisyllabic words, stress rules become very important and the location of stress can change depending on the suffix of that word. For example, Wade-Woolley (2007) showed that in words ending in ‘ity’ or ‘tion’ there is a stress shift to the syllable immediately before that suffix. For instance, in the word ‘electric’ the stress is on the ‘lec’ syllable, but in the word ‘electricity’ there is a stress shift and the stress moves immediately before the suffix on ‘tri’. The same principle applies to the suffix ‘tion’ (e.g., operate and operation). However, some suffixes e.g. ‘ness’ do not result in a stress shift. For example, the location of stress in the words ‘happy’ and ‘happiness’ falls on the ‘ha’ syllable in both cases. It has been demonstrated that morphological knowledge (stress accuracy) in the production of words with rhythmic suffixes, undergoes development in school-aged children (see Jarmulowicz, 2006) and researchers such as Wade-Woolley have argued that poor readers may be less sensitive to stress in oral language and be less aware of morphological rules when decoding multisyllabic words. This speculation might explain how sensitivity to stress (speech rhythm) can predict word reading after phonological awareness has been controlled. If this explanation were the case, we might expect that if morphology were entered into a hierarchical regression model before stress sensitivity that the amount of variance accounted for by stress sensitivity would reduce, or disappear. In support of this explanation, Clin and Wade-Woolley (2007) found in a group of eight to thirteen-year-old children that prosodic sensitivity could no longer predict a significant amount of variance in reading once morphological awareness was accounted for. However, it remains unknown whether these results would be replicated in a sample of younger children whose morphological awareness is less developed.

In spite of the fact that the revised speech rhythm sensitivity task had undergone lots of changes to overcome previous criticisms, there is at least one methodological limitation which may help to explain the strong relationship found between speech rhythm and reading. In this study there was no measure of problem solving ability or intelligence. The metrical stress sensitivity task can be seen as a ‘problem solving’ task and it could be that the task demanded a specific problem solving skill that may be absent or less developed in those with poorer reading ability. It could therefore be problem solving which is mediating the link between metrical stress and reading, and this could also have been involved in the unique variance too. However, vocabulary was accounted for, and this measure is very highly correlated with general IQ.

Another limitation of this task concerns the discrepancies between the foil items in relation to the target items. For instance, the target items included a disproportionately high number of agent nouns in comparison to the foil items, there was not an equal ratio of target items in comparison to foil items that ended in a schwa vowel or in an open syllable, and the type of affixes and compound words was not controlled for in any way. It could therefore be argued that correct answers could have arisen from some implicit awareness of the target item similarities. However, while the authors acknowledge that other factors could have been controlled for in this task, it was essential to control for the most important problematic aspects of this task, which might underlie the observed relationship between speech rhythm and reading. For instance, one of the major criticisms of the original task was that few items began with the same phoneme as the target item and therefore phonemic sensitivity, rather than stress sensitivity could help children to solve this task (Holliman et al., 2008). We therefore had to ensure that all distracter items began with the same phoneme and initial letter. In doing so, we then had to decide how to select distracter items. Knowing that vocabulary has been argued to mediate the link between speech rhythm and spoken word recognition (Walley, 1993) we thought it was essential to match them on frequency of occurrence in children of this age. It was extremely difficult to find words with a similar initial letter and phoneme that are matched on word frequency. However, had we matched distracters on all other factors noted above, it would have meant the matching of items in terms of their familiarity and initial phoneme relative to the target items was even more difficult, if not impossible, to achieve and we felt that this was the most important thing to control theoretically.

There is also at least one limitation with the non-speech rhythm measures. The only aspect of rhythm that was manipulated in this task was the duration of gaps between beeps. However, in other studies, different aspects of non-speech rhythm are manipulated and investigated. For instance, Patel, Peretz, Tramo, and Labreque (1998) considered musical, non-speech rhythm to consist of pitch, duration, and intensity and in their assessment of music, length, rate, frequency, and timing were manipulated. Perhaps the relatively weak association found between productive non-speech rhythm and the various rhythm and reading measures could be due to the fact that only a single aspect of musical, non-speech rhythm (duration between beeps) was investigated. If the assessment of non-speech rhythm had manipulated length of beeps, tones, and intensity which may well have made it more comparable with the speech rhythm task, a link may have been found.

It is becoming clear that prosodic sensitivity in the form of stress sensitivity is related to reading development independent of phonological awareness and musical rhythm, but how it is doing this is less clear. One line of enquiry might consider in depth precisely what is being manipulated or assessed in these ‘stress sensitivity tasks’. A study which included a great number of prosodic tasks and investigated the link between them might shed light as to what precisely is predicting reading in the mispronunciations’ task. Another line of enquiry might investigate whether stress sensitivity can predict other aspect of reading over time (other than just word reading in this study) such as reading comprehension, reading fluency and spelling. This has not been done in this entirety and such a study would tell us a lot about the predictive power of metrical stress sensitivity in the development of all areas of literacy. It could be for instance, that metrical stress is related to word reading via its relationship with reading comprehension. Further research investigating the relatedness or speech rhythm and non-speech rhythm should use more equivalent, and more reliable tasks to assess these skills. This was one of the short-comings of this study. It also seems necessary to consider the relative productive/receptive nature of tasks.

The findings from this study may have practical implications for early education; for instance, given that speech rhythm may facilitate spoken word recognition (Cutler, 1994) and subsequent vocabulary development from a very early age (e.g., Newman, Bernstein Ratner, Jusczyk, Jusczyk, & Dow, 2006; Walley, 1993), it is possible that measures of speech rhythm sensitivity may provide an early indication of later reading difficulties that can be used before the emergence of reading itself. The strong links found between receptive speech and non-speech rhythm, phonological awareness and reading in the current study may be consistent with the idea that developing children's sensitivity to speech and non-speech rhythm through rhythm games and poetry for example, could have important implications for later reading acquisition. However, it is important to note that prior to any kind of rhythmic intervention, future research would have to establish that rhythmic sensitivity precedes reading acquisition and then demonstrate that the link between rhythmic sensitivity and reading is causal. If the observed relationship still holds, then rhythmic capacity could potentially be used as part of a screening battery at the preschool stage to predict who is likely to experience difficulty in learning to read.

Conclusion

The regression analyses showed that speech rhythm and receptive non-speech rhythm could predict a significant amount of variance in reading attainment after age, vocabulary, phonological awareness, short-term memory, and non-speech (or speech) rhythm had been accounted for. This shows that although metrical stress is unquestionably related to phonological awareness, it can also predict reading independently of this association. Receptive non-speech rhythm was also able to do this, although more caution is expressed with respect to this finding due to such poor internal reliability associated with the receptive non-speech rhythm task. In summary, the results demonstrate a relationship between speech and receptive non-speech rhythm, but also an independent relationship between these processes and reading development, which provides only partial consistency with the general auditory processing deficit theory of reading difficulties affecting both speech and non-speech domains.

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Appendix A

Table A1. Stimuli and phonetic transcription for mispronunciations task.

Baseline Word	Phonetic Transcription	Stress Reversal Condition
Money (practice)	‘mʌni	mə'ni:
Sofa	‘səʊfə	sə‘fɑ:
Paper	‘peɪpə	pə‘pɑ:
Teddy	‘tedi	tə‘di:
Carpet	‘kɑ:pɪt	kə‘pet
Parrot	‘pærət	pə'rɒt
Garden	‘gɑ:dən	gə‘den
Shopping	‘ʃɒpĭŋ	ʃə‘pɪŋ
Jumper	‘dʒʌmpə	dʒəm'pɜ:
Table	‘təɪbəl	tə‘bɔ:l
Camera	‘kæmrə	kəm‘rɑ:
Mirror	‘mɪrə	mə'rɔ:
Candle	‘kændəl	kən‘dɔ:l
Cushion	‘kʊʃən	kə‘ʃɒn
Flower	‘flaʊə	flə‘wɑ:
Blanket	‘blæŋkɪt	blən‘ket
Trumpet	‘trʌmpɪt	trəm‘pet

Notes: Jumper was added as an additional item to those used by Wood (2006b)

Appendix B

Table A2. Phonetic transcription and word frequency per million for all target and distractor items.

Target Words and Freq.	Phonetic Transcription	Stress Reverse Condition	Distracter Item 1 and Freq.	Distracter Item 2 and Freq.	Distracter Item 3 and Freq.
spider (93)	‘spaɪdə	spə'dɜ:	swinging (83)	snowman (62)	sandwich (83)
baker (93)	‘beɪkə	be'ɪkɜ:	beetles (83)	branches (93)	bottles (93)
barrel (10)	‘bærəl	bə'rel	bracelet (10)	burglars (10)	ballet (10)
builder (21)	‘bɪldə	bəl'dɜ:	blackbird (31)	biscuit (21)	bookcase (21)
butcher (41)	‘bʊtʃə	bə'tʃɜ:	baseball (52)	badgers (31)	boiling (52)
butter (175)	‘bʌtə	bə'tɜ:	breakfast (196)	bottle (186)	basket (186)
carrot (21)	‘kærət	kə'rɒt	clipboard (10)	cutting (10)	camel (21)
cleaner (83)	‘kli:nə	klə'nɜ:	crying (72)	counting (62)	cupboard (93)
cooker (31)	‘kʊkə	kə'kɜ:	carrots (31)	cowboy (31)	crayons (31)
jumper (114)	‘dʒʌmpə	dʒəm'pɜ:	jewels (114)	jolly (103)	jacket (93)
mirror (41)	‘mɪrə	mə'rɔ:	married (41)	mushrooms (31)	marbles (52)
painter (21)	‘pentə	pən'tɜ:	panda (31)	penguin (21)	peanuts (21)
parrot (83)	‘pærət	pə'rɒt	pattern (72)	pumpkin (62)	pocket (62)
plaster (52)	‘plɑ:stə	pləs'tɜ:	pencil (52)	penny (41)	pizza (41)
rubber (10)	‘rʌbə	rə'bɜ:	rhino (31)	raining (10)	robot (21)
ruler (10)	‘ru:lə	rə'lɜ:	rowing (10)	robin (31)	rainbow (21)
sailor (10)	‘seɪlə	sə'lɔ:	swimmer (10)	smiling (10)	scarecrow (21)
singer (10)	‘sɪŋə	səŋ'ɜ:	swordfish (10)	skateboard (10)	seagull (10)
tiger (52)	‘taɪgə	tə'gɜ:	tissue (31)	tractor (31)	twenty (31)

Notes: The word frequencies in parentheses are per million. ‘Spider’ was the practice item.

Table 1.

Summary statistics for children on all measures used in this study

Task	Mean	Std. Deviation
Original Mispronunciations task baseline / 16	15.58	0.67
Original Mispronunciations task experimental / 16	9.69	4.06
Revised Mispronunciations task baseline / 18	17.57	0.68
Revised Mispronunciations task experimental / 18	12.55	3.92
Rhythm Copying / 21	9.24	3.86
Rhythm Matching / 12	7.49	1.82
Word Reading raw score / 90	29.82	20.81
Rhyme Detection / 21	10.91	6.79
Phoneme Deletion / 24	11.75	8.20
Digit Span / 36	18.16	3.87
Vocabulary	67.65	13.11

Table 2.

Correlation matrix between age, reading, phonological awareness, speech rhythm, and non-speech rhythm

Variables	1	2	3	4	5	6	7	8	9
1. Age									
2. BAS Word Reading	.59***								
3. Digit Span Test	.26**	.41***							
4. Vocabulary	.51***	.51***	.37***						
5. Rhyme Detection	.40***	.69***	.54***	.59***					
6. Phoneme Deletion	.54***	.76***	.37***	.45***	.69***				
7. Rev Misp.	.43***	.63***	.36***	.40***	.56***	.54***			
8. Orig Misp.	.45***	.62***	.39***	.30**	.57***	.55***	.58***		
9. Rhythm Copying	.23*	.31**	.34**	.34**	.34**	.32**	.17	.16	
10. Rhythm Matching	.22*	.46***	.39***	.32**	.35***	.44***	.36***	.3**	.19

Notes: Rev Misp., Revised Mispronunciations Task; Orig Misp., Original Mispronunciations Task.
**p*<.05, ***p*<.01, ****p*<.001

Table 3.

Hierarchical multiple regression analysis predicting word reading from age, vocabulary, phonological awareness (PA composite, rhyme and phoneme), short-term memory, non-speech rhythm, and speech rhythm sensitivity (at different steps)

Variable	B	SE B	β	ΔR^2
1. Age	0.519	0.160	0.222**	0.345***
2. Vocabulary	-0.028	0.115	-0.018	0.058**
3. PA composite	5.915	0.962	0.522***	0.268**
4. Digit Span Test	-0.149	0.361	-0.028	0
5. Rhythm Copying	0.165	0.339	0.030	0
6. Rhythm Matching	1.516	0.726	0.133*	0.018*
7. Mispronunciations	0.991	0.379	0.187*	0.021*
6. Mispronunciations				0.026**
7. Rhythm Matching				0.013*

Notes: **p*<.05, ***p*<.01, ****p*<.001