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Acoustic Features of Oral Reading Prosody and the Relation With Reading Fluency and Reading Comprehension in Taiwanese Children

Wei-Lun Chung[a] and **Gavin M. Bidelman**[b]

[a] National Taipei University of Education, Taiwan [b] School of Communication Sciences and Disorders, The University of Memphis, TN

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ABSTRACT

Purpose: The study aimed to examine whether oral reading prosody—the use of acoustic features (e.g., pitch and duration variations) when reading passages aloud—predicts reading fluency and comprehension abilities.
Method: We measured vocabulary, syntax, word reading, reading fluency (including rate and accuracy), reading comprehension (in Grades 3 and 4), and oral reading prosody in Taiwanese third-grade children (N = 109). In the oral reading prosody task, children were asked to read aloud a passage designed for third graders and then to answer forced-choice questions. Their oral reading prosody was measured through acoustic analyses including the number of pause intrusions, intersentential pause duration, phrase-final comma pause duration, child–adult pitch match, and sentence-final pitch change.
Results: Analyses of variance revealed that children's number of pause intrusions differed as a function of word reading. After controlling for age, vocabulary and syntactic knowledge, and word reading, we found that different dimensions of oral reading prosody contributed to reading rate. In contrast, the number of pause intrusions, phrase-final comma pause duration, and child–adult pitch match predicted reading accuracy and comprehension.
Conclusions: Oral reading prosody plays an important role in children's reading fluency and reading comprehension in tone languages like Mandarin. Specifically, children need to read texts prosodically as evidenced by fewer pause intrusions, shorter phrase-final comma pause duration, and closer child–adult pitch match, which are early predictive makers of reading fluency and comprehension.

In recent years, cross-linguistic research has increasingly focused on relationships between prosody and reading. Awareness of prosodic patterns at the word level (e.g., lexical stress or lexical tone), independent of awareness of individual sounds (i.e., phonological awareness), predicts word reading in English (Goswami et al., 2010; Holliman et al., 2008; Jarmulowicz et al., 2007; Whalley & Hansen, 2006) and Mandarin (Chung & Bidelman, 2021; Chung et al., 2017). This suggests that individuals good at monitoring word-level prosody better segment words into syllables, map letters onto sounds via grapheme–phoneme correspondence, and then more accurately sound out English words. Prior work has also shown they distinguish homophonic syllables (e.g., *shōu* "receive," *shóu* "ripe," *shǒu* "hand," *shòu* "sell") and better pronounce Chinese characters. These findings align with notions that word-level prosody forms an important mediator to word reading through phonological awareness (Wood et al., 2009; Zhang & McBride-Chang, 2010).

Interestingly, sensitivity to word prosody also accounts for broader reading comprehension abilities (Chung & Bidelman, 2021; Whalley & Hansen, 2006), suggesting local prosody sensitivity transfers beyond the word level. To elucidate the mechanism(s) of the relationship between prosody and reading comprehension, the role of sentence-level

Correspondence to Wei-Lun Chung: wwlchung@mail.ntue.edu.tw.
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prosody is also important to consider. For example, sentence-level prosody (e.g. intonation) is one way listeners chunk a spoken sentence into phrases. Adjacent phrases are separated from each other through an intonational phrase boundary (IPB) signaled by pitch change, lengthening, or pause (Selkirk, 2011). Indeed, listeners process sentences faster when intonation coincides with syntactic boundaries, as compared to when they do not (Kjelgaard & Speer, 1999). Several studies also revealed that individuals use IPBs to disambiguate sentences in spontaneous speech (Kraljic & Brennan, 2005; Schafer et al., 2000; Snedeker & Trueswell, 2003) and silent reading (Breen, 2014; Fodor, 1998; Webman-Shafran, 2018). Together, IPBs help individuals segment sentences into phrases, assist the analyses of syntactic structure, help resolve syntactic ambiguity, and decipher meaning in sentences.

Given that IPBs play an important role in sentence processing, Mandarin speakers also rely on IPBs and then interpret a sentence (e.g., *bàbà kàndào nǎinǎi kūle*) in different ways. Some speakers could insert an IPB between words *nǎinǎi* and *kūle* and interpret the sentence as "Dad saw grandma and started crying." On the other hand, others could insert an IPB between words *kàndào* and *nǎinǎi* and interpret the sentence as "Dad saw grandma crying." Interestingly, Mandarin readers do not separate adjoining Mandarin words using spaces as shown in English. That is, they need to decode Chinese characters (e.g., eight characters correspond to eight spoken syllables: *bàbàkàndàonǎinǎikūle*), map those sounds onto spoken words in their mental lexicon, and then group adjacent Chinese characters to words (*bàbà kàndào nǎinǎi kūle*) through statistical cues of character combinations (Yen et al., 2012; Zang et al., 2016). Although Mandarin words are not physically segmented by spaces as in English, Mandarin uses the same punctuation marks (i.e., commas and periods) in printed texts similar to English. Based on previous research (Benjamin & Schwanenflugel, 2010; Miller & Schwanenflugel, 2008; Schwanenflugel et al., 2004), the current study examined global prosodic variations (signaled by pauses and pitch change) across, between, and within Mandarin sentences (indicated by punctuation marks). Moreover, Mandarin is a tone language (pitch distinguishes homophonic syllables: *shōu* "receive," *shóu* "ripe," *shǒu* "hand," *shòu* "sell") rather than a rhythmic language like English (e.g., alternation of stressed and unstressed syllables; perMIT vs. PERmit). Given the similarity (IPBs and punctuation marks) and difference (orthography and language types) between English and Mandarin, it is worthwhile to examine the role of sentence-level prosody (e.g., intonation) in Mandarin reading fluency and reading comprehension.

Additionally, children use fluctuations of intonation patterns to process spoken sentences even at age 4 and 5 years (Yang & Chen, 2018; Wells et al., 2004). Indeed, children read sentences aloud prosodically, according to the built-in intonation patterns they have acquired through ordinary conversation (Allington, 1983; Dowhower, 1987; Schreiber, 1980, 1987, 1991). Intonation fluctuations may help chunk spoken sentences into phrases (Kraljic & Brennan, 2005; Schafer et al., 2000; Snedeker & Trueswell, 2003) for syntactic processing. Later, these skills acquired in reading and prosody might transfer to an expressive inner voice in silent reading (i.e., "implicit prosody"), which guides syntactic processing for reading comprehension (Breen, 2014; Fodor, 1998; Webman-Shafran, 2018). However, children are not able to exploit variations in prosodic patterns to read aloud written sentences until they master automaticity (i.e., pronouncing words accurately; Chall, 1996; Kuhn & Stahl, 2003). In other words, children need to sound out individual words automatically before they can master using prosodic patterns for reading text out loud, as proposed by LaBerge and Samuels' (1974) automaticity theory.

Oral reading prosody refers to the individual variability in prosodic patterns when reading aloud. Oral reading prosody, reading rate, and reading accuracy are different dimensions of the construct "reading fluency" (Kuhn et al., 2010; Pikulski & Chard, 2005), which correlates with reading comprehension (Danne et al., 2005; Donahue et al., 1999; Pinnell et al., 1995). Scale rating is often used to quantify children's oral reading prosody (Wolters et al., 2020). However, this subjective judgment of oral reading prosody (i.e., coder's subjective evaluation) might bias the relationship between oral reading prosody and reading ability.

As an objective assessment, acoustic analyses have been conducted to examine children's oral reading prosody and the relation with reading abilities in rhythmic languages like English (Benjamin et al., 2013; Miller & Schwanenflugel, 2008; Schwanenflugel et al., 2004). Previous studies employing acoustic analyses have found that children with better word reading outperform their peers with lower word reading in the following ways: (a) fewer pause intrusions (Benjamin & Schwanenflugel, 2010; Miller & Schwanenflugel, 2008), (b) shorter intersentential pause duration (Miller & Schwanenflugel, 2006, 2008; Schwanenflugel et al., 2004), (c) shorter intra-sentential pause duration (Schwanenflugel et al., 2004; Miller & Schwanenflugel, 2008), (d) closer child–adult pitch match (Benjamin & Schwanenflugel, 2010; Miller & Schwanenflugel, 2008; Schwanenflugel et al., 2004), and (e) larger sentence-final pitch change in declarative sentences (Benjamin & Schwanenflugel, 2010; Miller & Schwanenflugel, 2006, 2008; Schwanenflugel et al., 2004). While these relations are established in English, it remains unknown whether the link between oral reading prosody and word reading persists in children speaking tone languages like Mandarin.

In addition to oral reading prosody varying as a function of word reading, different reading abilities could be predicted by separate acoustic features of oral reading prosody. First, reading fluency was explained by child–adult pitch match (Miller & Schwanenflugel, 2008) and sentence-final pitch change and pause ratio (i.e., the number of pause intrusions per passage divided by the number of intrasentential pauses per passage; Benjamin & Schwanenflugel, 2010). Second, reading comprehension was predicted by the number of pause intrusions (Miller & Schwanenflugel, 2008), child–adult pitch match (Schwanenflugel et al., 2004), and sentence-final pitch change (Benjamin & Schwanenflugel, 2010). However, it remains unclear whether separate acoustic features of oral reading prosody could account for individual variability in reading fluency and reading comprehension after controlling age, vocabulary and syntax knowledge, and word reading.

Specific Aims of This Study

To this end, the current study examined oral reading prosody and the relation with reading abilities in Mandarin Chinese. Our specific aims were as follows. First, we aimed to examine whether children's oral reading prosody differs as a function of word reading. Based on previous studies (Benjamin & Schwanenflugel, 2010; Schwanenflugel et al., 2004), we hypothesized that children with better word reading would demonstrate better performance on oral reading prosody. Second, we aimed to determine how acoustic features signaling oral reading prosody contribute to reading fluency after controlling confounding variables. We expected reading fluency to be accounted for by child–adult pitch match (Miller & Schwanenflugel, 2008), sentence-final pitch change, and the number of pause intrusions (Benjamin & Schwanenflugel, 2010). Our third goal was to examine the acoustic contributions of prosody to reading comprehension after partialing out control variables. We anticipated that reading comprehension would be predicted by the number of pause intrusions (Miller & Schwanenflugel, 2008), child–adult pitch match (Schwanenflugel et al., 2004), and sentence-final pitch change (Benjamin & Schwanenflugel, 2010).

Method

Participants

Third-grade children (N = 109; 65 boys and 44 girls; age: M = 9.16 years, SD = 0.29) were recruited from several public elementary schools in Taipei. These children spoke Mandarin as a first language and received the compulsory Mandarin reading instruction from Grade 1. Third-grade children are the optimal participants for the current study examining the development of oral reading prosody because reading aloud (and with appropriate rates, rhythm, and melody) is an early requirement of the language arts curriculum guidelines for a 12-year basic education (Ministry of Education, 2018).

Additionally, 36 college students (18 males, 18 females) enrolled at the first author's institution were recruited to read the same passage as the third-grade children. The college students' recordings were used as an adult norm. This allowed us to examine the degree to which the pitch in children's productions correlated with those of adults' as one facet of oral reading prosody.

Procedure

The study's protocol was approved by the Human Research Ethics Committee at the National Cheng Kung University, Taiwan, before contacting public schools in Taipei for their cooperation. Consent/assent was obtained from children's parents via communication with their homeroom teachers. Once enrolled in the study, children received reading comprehension tasks in a group setting; the other tasks were given in an individual setting. In the individual setting, children assigned with an odd number received the tasks in the following order: vocabulary knowledge, oral reading prosody, syntactic knowledge, and word reading; their peers assigned with an even number received the same tasks in reverse order. Task order was counterbalanced to minimize disengagement over time. After completing the tasks, children received school supplies as a reward.

Materials

Oral Reading Prosody

Children read aloud one narrative prose selected from a standardized reading comprehension test designed for third graders (Meng et al., 2015a) followed by forced-choice questions. The narrative prose included seven declarative sentences. From the first to the last sentence, there were 22, 44, 46, 37, 27, 20, and 25 characters, respectively. Their production of the narrative prose was recorded with SONY digital voice recorders (ICD-UX570F and ICD-UX560) and analyzed through the software Praat (Boersma & Weenick, 2001). Several acoustic analyses were conducted to examine how children used acoustic features (e.g., duration and pitch variations) during reading.

Number of Pause Intrusions

Pause intrusions refer to temporal spaces between adjacent Chinese characters exceeding 100 ms in the spectrographic analyses (Benjamin & Schwanenflugel, 2010; Miller & Schwanenflugel, 2006, 2008). The number of pause intrusions was calculated only in the first three declarative sentences (Benjamin & Schwanenflugel, 2010).

Intersentential Pause Duration

Intersentential pause duration (in milliseconds) was measured when participants temporarily stopped their reading aloud for in-text periods marking the end of sentences. Using spectrographic analyses, we measured intersentential pauses as the span after the end of a sentence-final word and before the onset of the following sentence. In the study, three intersentential pause durations were examined based on the first three declarative sentences (Benjamin & Schwanenflugel, 2010) and were calculated as the mean (Schwanenflugel et al., 2004).

Phrase-Final Comma Pause Duration

Phrase-final comma pause duration (in milliseconds) was measured when participants temporarily stopped their reading aloud for in-text commas breaking sentences into phrases. Again using spectrographic analyses, we measured phrase-final comma pauses as the span between the end of a phrase-final word and before the onset of a following phrase. In this study, seven phrase-final comma pause durations were examined based on the first three declarative sentences (Benjamin & Schwanenflugel, 2010) and were calculated as the mean (Schwanenflugel et al., 2004).

Child–Adult Pitch Match

We assessed the correspondence between children's and adults' pitch values via correlations. In Mandarin, each character (corresponds to one syllable) has its own pitch variations. Modeling Benjamin and Schwanenflugel (2010), we analyzed each participant's production of 112 characters in the first three sentences as follows. First, a mean pitch value of each character was extracted using the software Praat (Version 6.1.05), resulting in 112 mean pitch values per participant. Second, a grand mean pitch value of each character was calculated for adults and then males and females, resulting in 112 pitch values for each, respectively. Third, each boy's individual 112 mean pitch values were correlated with the aggregate males' 112 grand mean pitch values; the same analyses were conducted for girls and females. Each sex was analyzed separately since they differ in frequency ranges (Howie, 1974; Tseng, 1990). Finally, a correlation coefficient was computed for each child to quantify the child–adult pitch match.

Sentence-Final Pitch Change

Sentence-final pitch change was measured by computing the differences between maximum and minimum fundamental frequency in hertz around sentence-final words. In the spectrogram, the last falling pattern from high to low fundamental frequency was identified around sentence-final words and its difference between the highest and lowest fundamental frequency were computed. The average differences between maximum and minimum fundamental frequency in the first five declarative sentences were calculated (Schwanenflugel et al., 2004).

Vocabulary Knowledge

Children's receptive vocabulary in Mandarin was assessed through the Peabody Picture Vocabulary Test–Revised in Mandarin version (PPVT-R; Lu & Liu, 1998). The PPVT-R in Mandarin version is composed of 125 test items. In each test item, children were auditorily presented one spoken word and were then required to select its corresponding item from four pictures. In the current study, third-grade children started from the age 8 or 9 level. A baseline was obtained with the first eight consecutive correct items. The test was completed once six errors were found in eight consecutive items or when all items were finished. As reported in the instruction manual, the task's internal consistency is > .90.

Syntactic Knowledge

Children's syntactic knowledge was measured through the Syntactic Comprehension subtest of The Test of Language Comprehension (Lin & Chi, 2002). As a standardized test diagnosing children with language disorders in Taiwan, the test was designed to evaluate children's comprehension of Mandarin syntactic structures including word order, passive construction, question types, temporal adverbs, pronouns, adjective order, conjunction, and complex sentences (Lin & Chi, 2000). Two practice questions preceded 24 test questions. In each question, children heard a sentence (e.g., The monkey that was bumped into by a cat was chasing an elephant) and then answered a question (e.g., Who was chasing the elephant?). The internal consistency of the task ranges from .75 to .95. The test–retest reliability coefficients range from .74 to .96.

Word Reading

Children's word reading in Mandarin was assessed through The Graded Chinese Character Recognition Test (Huang, 2004). There are 200 Chinese characters (10 characters × 10 rows × 2 pages) arranged from high to low frequency. Each Chinese character was pronounced in Mandarin until 20 consecutive errors were made. The task's internal consistency is .99, and test–retest reliabilities range from .81 to .95.

Reading Fluency

Children's reading fluency was measured through reading aloud one narrative prose selected from a standardized reading comprehension test (Meng et al., 2015a) designed for third graders. Their production of the narrative prose was analyzed for reading rate and reading accuracy. Given that oral reading prosody, reading rate, and reading accuracy are different dimensions of the construct "reading fluency" (Pikulski & Chard, 2005; Kuhn et al., 2010), children's production of the same narrative prose was analyzed for the three variables. Reading rate was calculated based on the number of characters read in a minute minus the number of errors; reading accuracy was calculated as the percentage of errors of total characters read per minute (Valencia et al., 2010).

Following Valencia et al.'s (2010) study, children were instructed to read aloud one passage in the following ways: (a) read aloud as usual, (b) try to sound out unfamiliar words or skip them, (c) keep reading aloud after a short pause, (d) not receive any feedback or additional information, and (e) need to answer questions after reading aloud a passage.

Reading Comprehension

Children's reading comprehension was assessed through two tasks: The Elementary School Reading Comprehension Diagnostic Assessment–Grades 1–3 (Meng et al., 2015a) and The Elementary School Reading Comprehension Diagnostic Assessment–Grades 4–6 (Meng et al., 2015b). That is, the third-grade children received a Grade 3 reading comprehension task and then a Grade 4 reading comprehension task 1 year later. Both tasks have four parallel forms and contain five types of questions: literal comprehension, syntactic analyses, content comprehension, inference, and summarization. It is worth noting that oral reading prosody was measured via a narrative prose selected from Form A and Grade 3 reading comprehension was assessed via Form B. Children were instructed how to take the task in 5 min and then answered forced-choice questions (i.e., 25 questions in Grade 3; 35 questions in Grade 4) in 15 min. The tasks have parallel-form reliabilities ranging from .53 to .76, and internal consistencies of > .82.

Results

Descriptive statistics based on children's word reading quartiles are displayed in Table 1. Before comparing children's oral reading prosody across word reading quartiles, we screened potential influential data points through dot plots. Based on extreme low performance on oral reading prosody, three out of 109 children were removed for the following analyses of variance (ANOVAs). Several one-way ANOVAs were conducted when word reading quartiles were entered as the independent variable and oral reading prosody (acoustic measures) as the dependent variable. ANOVA assumptions (e.g., homogeneity of variance) were confirmed via Levene's test. Children with different word reading skill differed in the number of pause intrusions, $F(3, 102) = 5.07$, $p = .003$, $\eta^2 = .13$. Follow-up Tukey's tests indicated that children with high word reading outperformed their peers with low word reading on the number of pause intrusions (lower intrusion rate). Other prosodic measures did not differ between readings groups. Analyses were not corrected for multiple comparisons.

Pearson correlations between oral reading prosody and reading abilities are shown in Table 2. Intersentential pause duration and phrase-final comma pause duration were intercorrelated with each other. More critically, reading rate was negatively related with the number of pause intrusions, intersentential pause duration, phrase-final comma pause duration, and sentence-final pitch change. Reading accuracy was related to the number of pause intrusions, phrase-final comma pause duration, and child–adult pitch match. Also of note, reading comprehension in Grades 3 and 4 were negatively correlated with the number of pause intrusions, intersentential pause duration, and phrase-final comma pause duration. Lastly, reading comprehension in Grade 3 was positively related with child–adult pitch match.

Table 1. Descriptive statistics for all variables.

Variables	Low word reading		Low-middle word reading		High-middle word reading		High word reading	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
No. of participants	27		24		29		29	
Word reading ability								
Range	9–56		57–71		72–94		95–147	
Scores	45.74	10.63	63.50	4.55	82.93	7.58	109.31	13.43
Age in years	9.12	.32	9.18	.28	9.19	.28	9.13	.28
Vocabulary knowledge	89.59	9.72	94.75	7.91	96.55	8.62	99.21	11.71
Syntactic knowledge	19.22	2.60	20.63	1.92	20.69	2.14	20.34	3.10
Reading rate	108.52	31.41	135.04	23.19	143.90	22.17	155.21	30.42
Reading accuracy	.06	.06	.02	.01	.02	.01	.03	.03
Grade 3 reading comprehension	17.33	4.96	21.08	2.66	21.28	2.17	21.21	3.59
Grade 4 reading comprehension	19.67	6.17	25.67	4.70	27.75	4.31	28.36	6.78
Oral reading prosody								
No. of pause intrusions	21.81	16.94	13.04	9.21	11.64	6.64	8.45	8.31
Intersentential pause duration	866.02	526.12	704.31	396.78	706.71	221.81	592.61	199.42
Phrase-final comma pause duration	734.01	386.01	598.23	265.38	556.48	156.98	555.16	207.72
Child–adult pitch match[a]	.32	.24	.39	.20	.34	.21	.31	.21
Sentence-final pitch change	57.90	33.21	66.37	42.60	58.70	35.35	53.76	43.95

[a]Correlations between children's and adults' pitch values of characters.

Table 2. Correlations between variables.

Variable	1.	2.	3.	4.	5.	6.	7.	8	9.	10.	11.
1. No. of pause intrusions	—										
2. Intersentential pause duration	.30**	—									
3. Phrase-final comma pause duration	.60***	.45***	—								
4. Child–adult pitch match[a]	–.17	–.15	–.14	—							
5. Sentence-final pitch change	.12	.08	.22*	–.05	—						
6. Vocabulary knowledge	–.16	–.01	–.01	.13	.03	—					
7. Syntactic knowledge	–.13	–.01	–.13	.08	.02	.41***	—				
8. Chinese character recognition	–.45***	–.26**	–.29**	–.05	.01	.38***	.22*	—			
9. Reading rate	–.78***	–.43***	–.62***	.15	–.24**	.21*	.26**	.55***	—		
10. Reading accuracy	.47***	.05	.22*	–.28**	–.09	–.31**	–.11	–.25**	–.40***	—	
11. Grade 3 reading comprehension	–.39***	–.20*	–.45***	.19*	.01	.37***	.53***	.40***	.54***	–.41***	—
12. Grade 4 reading comprehension	–.48***	–.23*	–.43***	.04	–.02	.40***	.45***	.55***	.60***	–.32**	.71***

[a]Correlation between children's and adults' pitch values of characters; significant values (p < .05) are marked in boldface.
*$p \leq .05$. **$p < .01$. ***$p \leq .001$.

Given that oral reading prosody, reading rate, and reading accuracy are different dimensions of the construct "reading fluency" (Kuhn et al., 2010; Pikulski & Chard, 2005), which correlates with reading comprehension (Danne et al., 2005; Donahue et al., 1999; Pinnell et al., 1995), we aimed to further examine (a) the role of oral reading prosody (a novel dimension of the construct "reading fluency") in reading rate and accuracy (two established dimensions of the construct "reading fluency") and (b) the contributions of oral reading prosody to Grade 3 and Grade 4 reading comprehension. In the hierarchical regressions, age, vocabulary and syntactic knowledge, word reading, and oral reading prosody were entered as the independent variables and reading rate, reading accuracy, Grade 3 reading comprehension, and Grade 4 reading comprehension as the dependent variables. To test the assumptions of regressions, the five independent variables with four separate dependent variables were entered in the regression equations simultaneously. Preliminary diagnostics confirmed low multicollinearity in the data (all variance inflation factors < 2) and no influential data points. Assumptions of independence, normality, and homoscedasticity were also met.

Results for reading rate are shown in the left of Table 3. The whole model reached significance when the independent variables at Step 2 were the number of pause intrusions, $F(5, 103) = 43.81$, $p < .001$; intersentential pause duration, $F(5, 103) = 15.13$, $p < .001$; phrase-final comma pause duration, $F(5, 103) = 25.95$, $p < .001$; child–adult pitch match, $F(5, 103) = 11.79$, $p < .001$; and sentence-final pitch change, $F(5, 103) = 13.49$, $p < .001$. After controlling age, vocabulary and syntactic knowledge, and word reading, unique variance in reading rate was explained by the number of pause intrusions (35%), intersentential pause duration (9.3%), phrase-final comma pause duration (22.7%), child–adult pitch match (3.4%), and sentence-final pitch change (6.5%). The number of pause intrusions accounted for the greatest amount of unique variance in reading rate.

Results for reading accuracy are shown in the right of Table 3. The whole model reached significance when the independent variables at Step 2 were the number of pause intrusions, $F(5, 103) = 8.38$, $p < .001$; intersentential pause duration, $F(5, 103 = 2.89$, $p = .017$; phrase-final comma pause duration, $F(5, 103) = 3.94$, $p = .003$; child–adult pitch match, $F(5, 103) = 4.88$, $p < .001$; and sentence-final pitch change, $F(5, 103) = 3.09$, $p = .012$. After partialing out control variables entered at Step 1, unique variance in reading accuracy was accounted for by the number of pause intrusions (16%), phrase-final comma

Table 3. Hierarchical regressions showing the variance in reading rate and accuracy accounted for by different dimensions of oral reading prosody after partialing out control variables.

	Reading rate		Reading accuracy	
Step	β	R^2 change	β	R^2 change
1. Age	.021	.331***	–.002	.123**
Vocabulary knowledge	–.070		–.268*	
Syntactic knowledge	.179*		.035	
Word reading	.538***		–.164	
2. No. of pause intrusions	–.673***	.350***	.464***	.166***
3. Intersentential pause duration	–.319***	.093***	.006	.000
4. Phrase-final comma pause duration	–.506***	.227***	.206*	.037*
5. Child–adult pitch match[a]	.187*	.034*	–.267**	.068**
6. Sentence-final pitch change	–.256**	.065**	–.087	.008

[a]Correlations between children's and adults' pitch values of characters.

*$p \leq .05$. **$p < .01$. ***$p < .001$.

Table 4. Hierarchical regressions showing the variance in reading comprehension (RC) in Grades 3 and 4 accounted for by different dimensions of oral reading prosody after partialing out control variables.

	RC in Grade 3		RC in Grade 4	
Step	β	R^2 change	β	R^2 change
1. Age	–.009	.374***	–.035	.427***
Vocabulary knowledge	.091		.096	
Syntactic knowledge	.434***		.314***	
Word reading	.270**		.443***	
3. No. of pause intrusions	–.263**	.053**	–.302***	.071***
4. Intersentential pause duration	–.144	.019	–.136	.017
5. Phrase-final comma pause duration	–.354***	.111***	–.288	.074***
6. Child–adult pitch match[a]	.164*	.026*	.015	.000
7. Sentence-final pitch change	–.011	000	–.043	.002

[a]Correlations between children's and adults' pitch values of characters.

*$p \leq .05$. **$p < .01$. ***$p < .001$.

pause duration (3.7%), and child–adult pitch match (6.8%). The number of pause intrusions predicted the vast amount of unique variance in reading accuracy.

Results for Grade 3 reading comprehension are shown in the left of Table 4. The whole model reached significance when the independent variables at Step 2 were the number of pause intrusions, $F(5, 103) = 15.34$, $p < .001$; intersentential pause duration, $F(5, 103) = 13.31$, $p < .001$; phrase-final comma pause duration, $F(5, 103) = 19.39$, $p < .001$; child–adult pitch match, $F(5, 103) = 13.70$, $p < .001$; and sentence-final pitch change, $F(5, 103) = 12.29$, $p < .001$. After partialing out control variables, unique variance in Grade 3 reading comprehension was predicted by the number of pause intrusions (5.3%), phrase-final comma pause duration (11.1%), and child–adult pitch match (2.6%). Phrase-final comma pause duration explained the greatest amount of unique variance in reading comprehension in Grade 3.

Results for Grade 4 reading comprehension are shown in the right of Table 4. The whole model reached significance when the independent variables at Step 2 were the number of pause intrusions, $F(5, 97) = 19.21$, $p < .001$; intersentential pause duration, $F(5, 97) = 15.46,6$ $p < .001$; phrase-final comma pause duration, $F(5, 97) = 19.45$, $p < .001$; child–adult pitch match, $F(5, 97) = 14.45$, $p < .001$; and sentence-final pitch change, $F(5, 97) = 14.55$, $p < .001$. After partialing out control variables, unique variance in Grade 4 reading comprehension was explained by the number of pause intrusions (7.1%) and phrase-final comma pause duration (7.4%). Phrase-final comma pause duration explained the greatest amount of unique variance in Grade 4 reading comprehension.

Discussion

The past decade has witnessed growing interest in the relationship between prosody and reading. Several studies have revealed that prosody at the word level (e.g., lexical stress or lexical tone) is important to word reading across rhythmic and tone languages. Beyond the word level, prosody at the sentence level (i.e., oral reading prosody) was found to contribute to reading fluency and reading comprehension in rhythmic languages like English. To extend results found in English monolingual children, we aimed to examine oral reading prosody through acoustic analyses and the relation with reading fluency and reading comprehension in Taiwanese children speaking tone languages like Mandarin.

The first aim was to examine whether children's oral reading prosody would differ as a function of word reading. In line with a previous study (Benjamin & Schwanenflugel, 2010), our results show that children with better word reading outperformed their peers with poorer word reading in the form of fewer pause intrusions. However, the different reading groups of our Taiwanese sample did not differ in other acoustic features signaling oral reading prosody found in English monolingual children, that is, intersentential pause duration, phrase-final comma pause duration, child–adult pitch match, and sentence-final pitch change (Benjamin & Schwanenflugel, 2010; Schwanenflugel et al., 2004). These cross-language differences might be attributable to the text children are required to read aloud in their respective language systems. In the case of the former, children can see Chinese characters and their corresponding phonetic symbols (i.e., consonants, vowels, and tones), which might aid character pronunciation. The coupled information of having grapheme and phonetic symbols might speed up children's decoding and thus decrease the time needed to read passages aloud. This would, in turn, decrease individual variability in the acoustic prosody features that are produced during oral reading.

The second research question we aimed to address was to determine the contributions of acoustic prosody features to reading fluency after controlling for known confounding variables (i.e., age, vocabulary and syntactic knowledge, word reading). Our findings show that reading rate is strongly linked to all acoustic features of oral reading prosody, whereas reading accuracy is explained by the number of pause intrusions, phrase-final comma pause duration, and child–adult pitch match. In accordance with previous research (Benjamin & Schwanenflugel, 2010; Miller & Schwanenflugel, 2008), pause intrusions and child–adult pitch match are two important predictors of reading fluency across English and Mandarin. These data imply that children who insert fewer pause intrusions during online reading and show similar rising and falling pitch fluctuations as adults have better reading fluency.

We further found that phrase-final comma pause duration was also related to reading fluency. This might reflect how sentences are represented in Mandarin. Contrary to English where spaces are used to separate adjoining words, Mandarin children cannot identify words via spaces but instead require an extra word-chunking process. That is, children need to decode Chinese characters, map those sounds onto spoken words in their mental lexicon, and then group adjacent Chinese characters to words through statistical cues of character combinations (Yen et al., 2012; Zang et al., 2016). For example, the four Chinese characters, *yuè dú yán jiū*, could be grouped into two words: *yuèdú* "reading" and *yánjiū* "research." In other words, children who read aloud passages with shorter phrase-final comma pause duration would decrease the time they need to decode characters, map sounds onto spoken words in their long-term memory, group characters into words, and then read aloud Chinese characters as many/accurately as possible. It is worth noting that sentence-final pitch change did not explain significant variance in reading accuracy. This might be due to the fact that Mandarin speakers are inclined to interpret sentences using syntactic cues (i.e., word order), but not prosodic cues (Chen et al., 2019).

The last research question we aimed to answer was the degree to which acoustic prosody features predict reading comprehension in early readers (Grades 3–4). Similar to previous research (Benjamin & Schwanenflugel, 2010; Miller & Schwanenflugel, 2008), the number of pause intrusions and child–adult pitch match predicted reading comprehension in Grade 3 after controlling confounding variables. As an extension, the number of pause intrusions also predicted variance in reading comprehension in Grade 4 (1 year later). These findings suggest that children better comprehend texts when mastering oral reading prosody as evidenced by fewer pause intrusions and similar pitch fluctuations as adults during verbal reading. This might be due to the fact that children who read sentences prosodically (Allington, 1983; Dowhower, 1987; Schreiber, 1980, 1987, 1991) would develop implicit prosody in silent reading (an expressive inner voice), which guides syntactic processing for reading comprehension (Breen, 2014; Fodor, 1998; Webman-Shafran, 2018).

It is interesting to mention the following key findings: (a) Phrase-final comma pause duration is an important predictor of reading comprehension in Grades 3 and 4, and (b) sentence-final pitch change did not explain significant variance in reading comprehension in Grades 3 and 4. These findings might also reflect language differences between Mandarin and English. First, phrase-final comma pause duration might be a unique predictor of Mandarin reading comprehension. Shorter phrase-final comma pause duration would tend to provide less time to decode characters, associate sounds onto spoken vocabulary in long-term memory, and group characters into words via statistical cues of character combinations (Yen et al., 2012; Zang et al., 2016). Faster processing efficiency would then spare more cognitive resources to parse sentences for text comprehension. Second, sentence-final pitch change is not an important predictor of reading comprehension in Grades 3 and 4 because Mandarin speakers seldom use pitch change, but different syntactic structures to process language (Chen et al., 2019).

Last, all acoustic features of oral reading prosody contributed to reading rate, whereas only the number of pause intrusions, phrase-final comma pause duration, and child–adult pitch match predicted reading accuracy and Grade 3 reading comprehension. Given that the construct "reading fluency" (including oral reading prosody, reading rate, and reading accuracy) correlates with reading comprehension (Danne et al., 2005; Donahue et al., 1999; Pinnell et al., 1995), the number of pause intrusions, phrase-final comma pause duration, and child–adult pitch match might be more sensitive to the development of reading fluency and reading comprehension than the other dimensions of oral reading prosody. Contrary to the number of pause intrusions and phrase-final comma pause duration, child–adult pitch match did not explain significant variance in Grade 4 reading comprehension. This suggests that relative to the number of pause intrusions and phrase-final comma pause duration, reading aloud with pitch fluctuations as adults might be less sensitive to the degree to which children chunk sentences into phrases for syntactic processing, which, in turn, reduced its predictive power of Grade 4 reading comprehension. Developmentally, children who adapt at oral reading prosody (as evidence by fewer pause intrusions and shorter phrase-final comma pause duration) may develop good implicit prosody in silent reading (an expressive inner voice), which guides syntactic processing for reading comprehension from Grade 3 to 4 (cf. Breen, 2014; Fodor, 1998; Webman-Shafran, 2018).

To sum up, this study, built on a recent meta-analysis study (Wolters et al., 2020), might be a first study examining the role of prosody at the sentence level in reading abilities in tone languages like Mandarin. This study reveals that Taiwanese children with better reading fluency and reading comprehension also produce better (i.e., more accuracy and dynamic) oral reading prosody. Findings of the current study might further lead educators and clinicians to consider screening children's reading aloud in the number of pause intrusions, phrase-final comma pause duration, and child–adult pitch match when considering instruction or intervention.

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