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On the role of non-linguistic rhythm skills in the early stages of formal learning to read

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ABSTRACT

The study of the factors contributing to literacy acquisition is expanding, including prosodic factors. In addition, there is evidence that the rhythmic abilities of boys and girls participate in this acquisition process, but some results are inconsistent. The first objective of this work is to determine if non-linguistic rhythmic skills contribute to the prediction of reading once vocabulary, intelligence, and phonological awareness/stress awareness are controlled for. The second objective was to examine whether phonological or stress awareness mediates the relationship between nonlinguistic rhythm and reading, as can be expected from Goswami temporal sampling theory. This study's participants are Spanish children who had started formal learning to read (first grade) and who are asked to perform some phonological, rhythm, and reading tasks. In relation to the first objective, results suggest that the predictive ability of rhythm may depend on the type of non-linguistic rhythm, and that the slower rhythm (1.5 Hz) made a unique contribution predicting word reading (real and non-real) once phonological awareness was controlled for. In relation to the second objective, results show an indirect relationship between the quicker rhythm (2 Hz) and the reading of pseudowords mediated by phonological awareness. In addition, stress awareness mediates the relationship between the slower rhythm and pseudoword reading. These results highlight the role of rhythm in learning to read.

El papel de las habilidades de ritmo no-lingüístico en las primeras etapas del aprendizaje formal de la lectura

Palabras clave:
Lectura
Conciencia fonológica
Conciencia del acento
Habilidades rítmicas

RESUMEN

El estudio de los factores que contribuyen al aprendizaje de la lectoescritura incluye factores de tipo prosódico. La evidencia sugiere que las habilidades rítmicas de las niñas y niños participan en este proceso de adquisición, aunque algunos resultados son inconsistentes. El primer objetivo de este trabajo consiste en determinar si las habilidades rítmicas no-lingüísticas predicen la lectura una vez controlados el vocabulario, la inteligencia y la conciencia fonológica/conciencia del acento. El segundo objetivo consiste en comprobar si la conciencia fonológica o del acento media la relación entre ritmo no-lingüístico y lectura, tal y como cabe esperar según la teoría del muestreo temporal de Goswami. Los participantes de este estudio son niñas y niños españoles que se han iniciado el aprendizaje formal de la lectura (primer curso de Educación Primaria) y a los que se les pide que realicen diversas tareas fonológicas, rítmicas, y de lectura. En relación con el primer objetivo, los resultados sugieren que la capacidad predictiva del ritmo depende del tipo de ritmo no-lingüístico, y que el ritmo más lento (1,5 Hz) contribuye de forma independiente a la lectura de palabras (reales e inventadas) una vez se controla la conciencia fonológica. En relación con el segundo objetivo, los resultados muestran una relación indirecta entre el ritmo más

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rápido (2 Hz) y la lectura de pseudopalabras mediada por la conciencia fonológica. Además, la conciencia del acento media la relación entre el ritmo más lento y la lectura de pseudopalabras. Estos resultados ponen de manifiesto el papel del ritmo en el aprendizaje de la lectura.

Introduction

Learning to read and write is one of the most important milestones in the first years of schooling. Its acquisition is related to developing other academic skills and later academic and occupational achievement (National Early Literacy Panel, 2008). A significant body of work highlights the contribution of phonological skills to literacy development. The most important of these phonological skills is phonological awareness (PA), or the ability to identify and manipulate speech units (e.g., phrases, words, syllables, and phonemes). The achievement of phonemic awareness (awareness of individual sounds) in alphabetic systems receives a major boost from direct instruction, which, in interaction with PA, enables the acquisition of grapheme-phoneme correspondences (Melby-Lervåg et al., 2012). Furthermore, following the theory of temporal sampling (Goswami, 2011, 2018, 2019), the perception of rhythm ultimately facilitates the development of PA and, through it, literacy learning. The present study aims to investigate this relationship between rhythm, PA, and literacy in Spanish children who are beginning formal literacy learning.

The speech signal comprises different frequency bands that fluctuate in amplitude (intensity) over time (the amplitude envelope). The auditory system analyses the amplitude envelope at each of its frequencies. Endogenous oscillatory rates identified in the cortex correspond to frequency bands such as delta (1−3 Hz); theta (4−8 Hz); alpha (8−12 Hz); beta (15−30 Hz) and gamma - low gamma (30−50 Hz) and high gamma (60 Hz; Goswami, 2011, 2019). This work is mainly related to the slow frequency band delta. Cortex synchronization with this frequency is particularly relevant (Lallier et al., 2018), and relies heavily on the rapid changes detected in amplitude envelope (rise time; Goswami, 2011). Delta frequencies correspond to prosodic elements such as stress and syllables, which would serve as reference points for the synchronization with the rest of band frequencies of the acoustic signal (Goswami, 2011, 2018, 2019). In general, the temporal sampling framework suggests that rhythmic energy patterns identifiable in the amplitude envelope of speech act as prominent cues (e.g., stressed vs. unstressed syllables) during continuous speech processing. Attention to these cues facilitates the synchronization of neural oscillatory activity with the rhythmic periodicity of the auditory signal and, consequently, better processing of sound elements (Goswami, 2011, 2018; McAuley et al., 2006).

Recent studies support the basic assumptions associated with temporal sampling framework using behavioral and neurophysiological methodology in typically developing children (Pérez-Navarro et al., 2022); children with at-risk conditions related to reading and writing difficulties (Kalashnikova et al., 2021) as well as in children and adults with reading and writing difficulties (Zhang et al., 2021). A derivation of the temporal sampling framework is that the ability to establish synchrony with rhythmic frequencies is independent of the type of sounds, linguistic or non-linguistic. In both cases, a relationship with literacy learning is expected. Accordingly, this relationship has also been found even in non-linguistic rhythm tasks regardless of stimulus modality (Tierney et al., 2021). Thus, there is a general relationship between the ability to extract metrical structure from sound (linguistic or non-linguistic) and literacy learning.

According to the temporal sampling framework, the relationship between rhythm perception and literacy is established through PA. Research on typically developing children demonstrates this relationship. For example, Corriveau et al. (2010) found that sensitivity to rise time, an acoustic correlate of rhythmic energy patterns in the amplitude envelope (Goswami & Leong, 2013), was a predictor of rhyme awareness in children aged 3–6 years. Similarly, Woodruff Carr et al. (2014) found that phonological processing was better in children who show greater synchronization skills in a non-linguistic tapping task (e.g., tapping synchronously with beats).

Other research also highlights the relationship of rhythm with PA and learning to read. Moritz et al. (2013) found that rhythmic discrimination in preschoolers (5 years old) contributed to the prediction of PA and reading level. Ozernov-Palchik et al. (2018) found that rhythmic pattern discrimination in preschoolers (5–6 years) predicted the development of PA and skills for reading readiness (knowledge of letter-sound relationships) as well as the ability to access phonological information (RAN). Furthermore, Ozernov-Palchik et al. (2018), using structural equation modeling, established that PA mediates the relationship between rhythmic discrimination and reading readiness.

The relationship between rhythm and the development of literacy skills has also been studied at later learning stages. Moritz et al. (2013) and Dellatolas et al. (2009) found that rhythmic discrimination before formal learning predicted reading in second grade. In the same vein, Lundetrae and Thomson (2018) found that rhythmic ability before starting first grade contributed significantly to the prediction of writing at the end of first grade after controlling for risk conditions (e.g., family members with reading difficulties), PA, RAN and letter knowledge. This relationship between rhythm and literacy is expected as long as reading is a rhythmic activity that follows a pattern and periodicity that simulates the rhythm of speech. However, the results found in the literature are not entirely conclusive. Lê et al. (2020) studied third-graders' performance using structural equation modeling. These researchers found a direct effect of rhythmic skills on literacy, and significant relationships between phonological skills and literacy. However, the non-linguistic rhythm effect was not mediated by phonological skills. For these authors, the relationship between PA and rhythm is limited after the early stages of literacy acquisition. Similar conclusions are reached by Ríos-López et al. (2022) for whom rhythm sensitivity is an important contributor to the formation of phonological representations and relevant for reading decoding. The participants were bilinguals (Basque – a co-official language in Spain) in the early stages of reading instruction (first grade). Their data indicated that the degree of synchronisation between the delta-band (<1 Hz) EEG-derived neural signals and the speech signal at the end of grade 1 (time 2) was not related to word reading; however, it was related if the measure was taken before the start of formal learning (time 1). Ríos-López et al. (2022) suggested that as a result of literacy instruction, initial limitations in the synchronisation of both types of signals in those children with this less developed ability at time 1 could be compensated at time 2.

Contrary to the works above, the possibility that the relationship between rhythm and literacy through phonological skills extends beyond the early stages of literacy acquisition is suggested in the longitudinal research of David et al. (2007). Their results showed that this relationship was not independent of PA and that rhythmic skills identified in the first grade predicted the reading of real and non-real words in later grades (grades 2–5). The exception was found in 5th graders, a group in which rhythm predicted reading words independently of PA. This is consistent with the results of Lê et al. (2020) in third graders. For David et al. (2007), the results in fifth grade may indicate the importance of rhythmic skills in circumstances where literacy performance is complex.

One such complex condition may be, for example, the reading of multisyllabic words that require appropriate stress assignment. This is a requirement for the correct rhythmic alternation of stressed (i.e., strong) and unstressed (i.e., weak) syllables within the word (lexical stress) or through the sentence as a whole (metrical stress). Accordingly, Wood (2006) identified that sensitivity to metrical stress explained part of the variance in the development of phonological skills, as well as for word reading and spelling. Furthermore, Holliman et al. (2008) found that metrical stress sensitivity accounted for variance in reading once segmental PA, through morphological and/or lexical processes, was controlled for. In this line, Gutiérrez-Palma et al. (2019) found that sensitivity to lexical stress contributed to the prediction of reading once PA was controlled for in third graders. Other studies further identified this relationship between suprasegmental prosody and literacy in fifth-grade children (Calet et al., 2016; Defior et al., 2012) and in children from third to sixth grade (Gutiérrez-Palma et al., 2016). In the same vein, intervention on suprasegmental skills at previous academic levels produced greater development of reading (second graders; Gutiérrez-Fresneda et al., 2021), and better phonological skills in first grade (intervention on preschoolers; Rivera Ibaceta & Moreira Tricot, 2020).

In short, evidence shows a clear relationship between rhythm and literacy. However, it is unclear whether this relation extends beyond the early stages of reading acquisition and whether PA is the only mediator factor. In this sense, the first aim of the present work is to determine whether rhythmic skills are involved in the prediction of reading in first graders who have started the formal learning of reading. The second aim is to analyze the role of some potential mediator factors, such as phonological and stress awareness.

The relationship between rhythm and reading may depend on the type of rhythm. Slower rhythms may be related to elements of speech that also require longer temporal ranges, such as stress. Therefore, sensitivity to slower rhythms may facilitate the perception of stress and then the processing of multisyllabic words. Formal reading instruction can play an important role in this process by allowing the child to pick up the stress pattern of words by reading polysyllabic words. Thus, McAuley et al. (2006) suggest that through learning, children can synchronize their activities with events at rhythms that differ from the preferred tempo defined by maturational processes; that is, learning modulates children's sensitivity to different time scales.

However, in addition to learning, rhythmic ability is also age-dependent. The most basic rhythmic skill is perceiving and reproducing pulses (beat) with good levels of performance between the ages of 3 and 5 years. In addition, the ability to synchronise motor activity (clapping, tapping, walking) with rhythm improves with age. Slightly older children (e.g. 7–11 years), progressively reduce the variability in synchronous tapping to a beat, although only older children are able to maintain synchronisation with the beat when the tempo of the sequence is altered. As for rhythmic patterns, first and second graders are able to reproduce simple rhythmic patterns, although the reproduction of more complex rhythmic patterns, usually from the age of seven, requires prior instruction (Reifinger, 2006).

The hypothesis put forward in this paper is that literacy instruction fosters the acquisition of different skills relevant to the reading process by emphasising the acquisition of basic decoding skills, but also by directing attention to patterns of stress, that is, to relevant events that occur over longer time intervals such as those associated with syllabic stress patterns in words (Arvaniti, 2009). These patterns are especially important in a language such as Spanish, which has the characteristic of contrastive stress. As previously exposed, research in Spanish has shown that stress awareness (SA) is related to the correct assignment of stress when reading aloud in Spanish. Therefore, the ability to perceive rhythms close to stress (e.g., 1.5 Hz) should be linked to a direct effect on reading both words and pseudowords.

The second objective is to examine through mediational models whether PA and/or SA mediate the relationships between rhythm and reading. According to the temporal sampling theory, the ability to perceive the language in low frequencies facilitates the development of PA. The stress and sequences of syllables' rhythm correspond to the range of delta frequencies (1–3 Hz). Therefore, an indirect effect between rhythm and reading within this frequency band is expected.

Method

Participants

The sample comprised 56 primary school children from three public middle-class schools in Spain (26 boys, 41 girls) aged between 6–7 years (M = 6.93, SD = 0.33) and attending the first year of Primary Education. Data from 11 children were excluded because their mother tongue was not Spanish, they were diagnosed with learning difficulties or had some kind of disability. All the children had previously attended pre-school, a stage in which they had begun to learn to read and write. Participants received reading instruction through either a phonic or a mixed phonic-global method. These participants were assessed at the end of the second trimester of the school year.

Instruments

Non-verbal intelligence (I). The *Raven's Progressive Matrix*, CPM subtest (Raven et al., 1996; Spanish adaptation by Seisdedos Cubero, 1996) was used. The maximum possible score is 36 points. In this study, Cronbach's alpha was .86, Guttman's split-half coefficient was .71 (Omega index could not be calculated), Composite Reliability (CR) was .87, and Average Variance Extracted (AVE) was .19.

Vocabulary (V). Vocabulary level was assessed with the vocabulary subtest of the *Dyslexia Screening Test for Children* (*DST-J*) (Fawcett & Nicolson, 2004; Spanish adaptation by Fernández-Pinto et al., 2010). In this study, item means were nearly at maximum possible in many items, then critically reducing the items variability. Therefore, reliability and validity indexes were very low. Cronbach's alpha was .15, Guttman's split-half coefficient was .14 (Omega index could not be calculated), CR was .1, and AVE was .18. However, according to the confirmatory factorial analysis (necessary for computing CR and AVE), there were four items with positive and above .1 factorial loads. If these items are just considered, then Cronbach's alpha was .34, McDonald's omega was .31, CR was .76 and AVE was .51. As indicated in the result section, we further checked if the analyses were different when just the reduced four items scores were used.

Phonological awareness (PA1). The oddity task was an abbreviated version of the Defior et al. (2006). The child listened to three words (disyllabic and trisyllabic; e.g., /pipa/ [*pipe*], /pato/ [*duck*], and /botella/ [*bottle*]) while looking at pictures of those words on the child's answer sheet. He/she had to identify the picture beginning with a different sound (e.g., /botella/) on the answer sheet by marking the selected picture with a cross. The words were presented once through loudspeakers and other time, if necessary, within a time limit of 20 seconds. *PA1* consists of 15 items, and the maximum achievable score was 15 points. Before presenting the assessment items, three triplets of words were practised to check the comprehension of the task and the recording system. In this study, Cronbach's alpha was .80, McDonald's omega was .77, CR was .84, and AVEwas .29.

Phonological awareness (PA2). This blending task consisted of listening slowly (approximately one sound per second) to the sounds (i.e., phonemes) that made up monosyllabic, disyllabic, and trisyllabic words with various syllabic structures (V, CV, VC, CVC) (e.g., /l/, /u/, /z/). These words were selected from the phonemic awareness task included in the EPALE test (Mata & Serrano, 2019). The sequence of sounds was presented once over loudspeakers and other time, if necessary, within a time limit of 20 seconds. Then, children had to select the picture (among three) representing the word on a response sheet. The set of test items was 11, with a maximum score of 11 points. Two practice trials were included. Cronbach's alpha for this study was .56, McDonald's omega was .47, CR was .71, and AVE was .20.

Stress awareness (SA). This task consisted of identifying the position of the stressed syllable in words. The stressed syllable (CV or CVC) was placed in the last, penultimate, or antepenultimate position (e.g., pantaLÓN [trouser], fanTASma [ghost], MÚSculo [muscle], stressed syllables are in capitals). This study used a modified Jiménez-Fernández et al. (2015) task. Due to a technical problem, a word had to be eliminated, and only 17 items were considered. In the present study, a picture of three mountains was used in each column, where the higher mountain represented the position of the stressed syllable. The child's task was to cross out on the answer sheet the column representing the position of the stressed syllable. The items were presented through loudspeakers and listened to by the children once and other time, if necessary, within a time limit of 20 seconds. The maximum achievable score was 17. Previously, two trials were practiced. In this study, Cronbach's alpha was .66, and Guttman's split-half coefficient was .61 (Omega index could not be calculated for this measure), CR was .74, and AVE was .19.

Reading real and non-real words ($WR_{R,}$ $WR_{NR,}$ respectively). The Reading Processes Evaluation Battery-Revised (PROLEC-R) by Cuetos et al. (2012) was used (*word* and *pseudoword* subtests). Correct responses were scored for a maximum possible of 40 points in each subtest. Syllabic reading was not considered a mistake. In this sample, Cronbach's alpha was .86, McDonald's omega was .83, CR was .88, and AVE was .18 for words. In the case of pseudowords, Cronbach's alpha was .82, Guttman's split-half coefficient was .83 (Omega index could not be calculated), CR was .85, and AVE was .15.

Rhythmic tapping ability (R). On *Track Rhythm Test* (Lundetrae, 2015) was applied (short version). In this test, a tablet device was used which reproduced a rhythmic sequence of beeps. Child's task consisted on tapping on the tablet's screen on the image of a drum following the beeps rhythm at the same time the beets were reproduced. The sequences were presented at a frequency of 2 Hz (R1) and 1.5 Hz (R2), corresponding to one beat every 500 or 667 milliseconds. As practice, the child listened to and played both sequences, first 2 Hz and then 1.5 Hz, for approximately 27 seconds. In the evaluation phase, the sequences were played again in the same order. The application calculated the time intervals every two consecutive beats for 15 beats (14 inter-beats intervals). To check the synchronization of the rhythmic sequences, the deviation between the average time intervals and the intended average, every 500 or every 667 milliseconds, was calculated in absolute values. The smaller the deviation, the greater the synchronization with the target rate. In this study, for the asynchrony related to *R1* (500 ms), Cronbach's alpha was .79, McDonald's omega was .88, CR was .88, and AVE was .37. For asynchrony related to *R2* (667 ms), Cronbach's alpha was .84, McDonald's omega was .83, CR was .89 and AVE was .38.

Regarding the instruments used in this study, the result for CR is satisfactory in all cases (above .7), although the AVE value is below .5. However, the AVE index is a particularly conservative convergent validity index and some authors suggest that CR values above .7 are sufficient. For example, Malhotra et al. (2017) stay that "... *AVE is a more conservative measure than CR. On the basis of CR alone, the researcher may conclude that the convergent validity of the construct is adequate, even though more than* 50% *of the variance is due to error*" (p. 808).

Procedure

Favourable consent was obtained from the Ethics Committee from the University of Jaén and, subsequently, from the school principals and the parents or legal tutors. During the procedure, the protocol approved by the Ethics Committee was maintained. Contact with the schools was made through the guidance counsellors and/or interviews with the school management, who also signed an authorisation to carry out the study on their facilities. As stated in the informed consent, parents or legal tutors were informed of the confidentiality of the data and the voluntary nature of participation, as well as the right of withdrawal and data processing. The verbal consent of the children participating in the study was also taken into account.

The administration of the tests was carried out by staff hired under the project through which this research was funded. The tests were administered collectively (groups of 3–6 children) with the exception of the word reading and rhythm tasks which were administered individually. The test administration space reserved by the school was quiet, suitable for the assessment process and close to the classroom. For the administration of the tests, a booklet was created for each child consisting of answer sheets. The number of weekly sessions was one or two, depending on the agreements reached with the teachers and lasted, on average, 30 minute. The total duration of this evaluation was about one month carried out between April and May 2021.

Data analysis

The analyses were carried out with SPSS software (version 27). The reliability and validity of the measurement instruments were determined by means of Cronbach's alpha and McDonald's omega or Guttman's split-half coefficient (if the omega index could not be computed), CR and AVE. To calculate CR and AVE, a single-factor Confirmatory Factor Analysis was performed, according to the principal component's method, obtaining the factor loading values of each of the test items necessary for the calculation of both indices.

To answer objective 1, hierarchical regression analyses were conducted to identify possible predictors of *reading* outcomes. Previously, the assumptions were examined by visual representation identifying the presence of linearity, homoscedasticity through the White test, and independence of errors with the Durbin-Watson test. Non-compliance was identified about normality when PA and R1 were included in the model for WR_R and WR_{NR} or when SA and R1 were included in the model for the prediction of WR_R. For this reason and to determine the possible generalizability to other populations, a simulation analysis using bootstrapping (3000 samples) was used.

With reference to objective 2, the relationship between *rhythm* and *literacy*, considering the mediating role of PA or SA, was examined using Process model 4 (Hayes, 2022), where the antecedent variable is R1 or R2; the outcome variable is WR_R or WR_{NR} and the

Table 1
Descriptive statistics for reading real words, non-real words, intelligence, vocabulary, phonological awareness, stress awareness, rhythmic asynchrony in rhythmic sequence 500 ms, rhythmic asynchrony in 667 ms and correlation with reading real and non-real words

	N	*M*	*SD*	Skewness	*SE*	Kurtosis	*SE*	*r* WR_R	*r* WR_{NR}
WR_R	56	29.840	7.370	−1.234	.319	1.424	.628		
WR_{NR}	56	24.460	6.540	−.890	.319	.869	.628	.820***	
I	56	22.161	5.780	.169	.319	−.053	.628	.133	.134
V	55	13.000	1.478	−.428	.322	.770	.634	.263*	.388**
PA	54	−.014	1.686	−.539	.325	−.837	.639	.335**	.440***
SA	50	9.100	3.260	.563	.337	−.023	.662	.231	.290**
R1	54	44.162	63.802	2.131	.325	4.446	.639	−.204	−.210
R2	53	76.304	95.939	1.433	.327	1.111	.644	−.427***	−.406***

Note. N = participants; *M* = Mean; *SD* = Standard deviation; *SE* = Standard error; *r* = Bivariate Pearson correlation; WR_R = Reading real words; WR_{NR} = Reading non-real words; *I* = Non-verbal intelligence; *V* = Vocabulary; *PA* = Phonological awareness; *SA* = Stress awareness; *R1* = Asynchrony in the rhythmic sequence of 500 ms; *R2* = Asynchrony in the rhythmic sequence of 667 ms..
*p < .1. **p < .05. ***p < .001.

Table 2
Indices in the hierarchical regression analyzes in reading real and non-real words involving intelligence, vocabulary, phonological awareness and asynchrony with the rhythmic sequence R1 or R2

	Unsampled linear regression				Sampled linear regression	
	WR_R		WR_{NR}		WR_R	WR_{NR}
Steps	*Beta Std*	*Change* R^2	*Beta Std*	*Change* R^2	*Beta (LLCI; ULCI)*	*Beta (LLCI; ULCI)*
1. *I*	−.108	.014	−.205	.010	−.137 (−.470; .286)	−.230 (−.460; .069)
2. *V*	.107	.052	.220	.128**	.533 (−1.097; 2.747)	.972 (−.366; 2.824)
3. *PA*	.334*	.076**	.429**	.121**	1.492* (.093; 2.815)	1.691** (.419; 2.910)
4. *R1*	−.096	.008	−.063	.004	−.011 (−.055; .023)	−.006 (−.039; .019)
1. *I.*	−.118	.012	−.212	.006	−.150 (−.473; .189)	−.233* (−.458; .025)
2. *V*	.148	.054	.243*	.117**	.755 (−.788; 2.906)	1.074 (−.309; 2.908)
3. *PA*	.249	.067*	.332**	.101**	1.167* (.019; 2.157)	1.341** (.237; 2.246)
4. *R2*	−.365**	.127**	−.320**	.098**	−.029* (−.054; .002)	−.022* (−.042; .002)

Note. WR_R = Reading real words; WR_{NR} = Reading non-real words; *Beta Std* = Beta standardized; *LLCI* = Lower limit confidence interval; *ULCI* = Upper limit confidence interval; *I* = Non-verbal intelligence; *V* = Vocabulary; *PA* = Phonological awareness; *R1* = Asynchrony in the rhythmic sequence of 500 ms; *R2* = Asynchrony in the rhythmic sequence of 667 ms.
*p < .1. **p < .05. ***p < .001.

mediating variable is SA or PA. Ten thousand samples were used in the bootstrap procedure.

Results

Descriptive statistics for the variables are presented in Table 1. Initial correlational analyses indicated that there was a relatively high significant relationship between the two PA tasks (r = .428, p < .001). Moreover, in both cases the phoneme was the unit of processing, and both tasks present a similar level of difficulty (Defior, 1996). Therefore, the typical score of these two variables (PA1, PA2) was summed, generating the variable *PA*, which will be used in this paper when referring to *phonological awareness*. Pearson's correlation index was used to examine the relationship between WR_R, WR_{NR}, *R1*, *R2*, *I*, *V*, *PA* and *SA*. This relationship was significant between WR_R with *PA* and *R2* and marginally significant with *V*. In the case of WR_{NR}, the relationships with *V*, *PA*, *SA*, and *R2* were significant.

Hierarchical regression analyses

Hierarchical regression analyses were conducted to identify possible predictors of *reading* outcomes. The predictor variables included were I (first step), V (second step), PA/SA (third step), and R1/ R2 (fourth step). Non-compliance was identified about normality. For this reason and to determine the possible generalizability to other populations, a simulation analysis using bootstrapping (3000 samples) was used. Table 2 (when the predictor is PA) and Table 3 (when the predictor is SA) present the results with and without the simulation process.

Unsampled results suggest that R2 predicts WR_R and WR_{NR} once I, V, and PA were controlled for. In these conditions, R1 does not predict the reading of real or non-real words. Rhythm (either R1 or R2) was not related to *reading* when *SA* (vs. PA) was included in the model (see Table 3). Moreover, if the sampling process is considered, the significant contributions of R2 (controlling for PA) become marginal. These analyses were repeated using the four items measure of V and results were similar.

Mediational analysis

The relationship between rhythm and literacy, considering the mediating role of PA or SA, was examined using Process model 4 (Hayes, 2022), where the antecedent variable is R1 or R2; the outcome variable is WR_R (see Table 4) or WR_{NR} (see Table 5) and the mediating variable is SA or PA. Ten thousand samples were used in the bootstrap procedure. When PA was the mediating variable, the direct relationship between R1 and WR_R (B = −.013, *SE* = .016, p = .432, 95% CI [−.0448, .0195]) or the indirect relationship (B = −.001, *SE* = .007, 95% *CI* [−.0271, .0007]) did not reach the level of statistical significance (see Figure 1). However, *R1* was related to WR_{NR} through PA (B = −.012, *SE* = .007, 95% CI [−.0278, −.0009]) but not directly (B = −.010, *SE* = .014, p = .484, 95% CI [−.0368, .0177]) (see Figure 1). As shown in Figure 1, the relationship between R1 and PA was negative (lower asynchrony higher *PA*), while between PA and WR_{NR} the relationship was positive.

With reference to R2, a direct relationship was found with WR_R (B = −.028, *SE* = .010, p < .05 95% CI [−.0487, −.0077]) but not indirectly mediated by PA (B = −.004, *SE* = .004, 95% CI [−.0134, .0019]). Similar results were obtained for WR_{NR} with direct relationship to

Table 3
Indices in the hierarchical regression analyzes in reading real and non-real words involving intelligence, vocabulary, stress awareness and asynchrony with the rhythmic sequence R1 or R2

	Unsampled linear regression				Sampled linear regression	
	WR_R		WR_{NR}		WR_R	WR_{NR}
Steps	*Beta Std*	*Change R^2*	*Beta Std*	*Change R^2*	*Beta (LLCI; ULCI)*	*Beta (LLCI; ULCI)*
1. *I*	−.107	.000	−.164	.000	−.118 (−.453; .281)	−.157 (−.385; .111)
2. *V*	.247	.063*	.407**	.159**	1.090 (−.372; 3.362)	1.156**(.414; 3.482)
3. *SA*	.227	.049	.288**	.080**	.455 (−.043; .939)	.504** (.080; 912)
4. *R1*	−.097	.009	−.082	.006	−.010 (−.056; .020)	−.008 (−.041; .018)
1. *I.*	−.097	.000	−.151	.000	−.108 (−.416;.235)	−.145 (−.381; .101)
2. *V*	.262*	.065*	.398**	.146**	1.192 (−.253;3.409)	1.549 (.484; 3.347)
3. *SA*	.188	.052	.269*	.088**	.381 (−.170; .918)	.468** (.033; .925)
4. *R2*	−.156	.022	−.107	.011	−.012 (−.040; .020)	−.007 (−.028; .017)

Note. WR_R = Reading real words; WR_{NR} = Reading non-real words; *Beta Std* = Beta standardized; *LLCI* = Lower limit confidence interval; *ULCI* = Upper limit confidence interval; *I* = Non-verbal intelligence; *V* = Vocabulary; *SA* = Stress awareness; *R1* = Asynchrony in the rhythmic sequence of 500 ms; *R2* = Asynchrony in the rhythmic sequence of 667 ms.
$^{*}p < .1$. $^{**}p < .05$. $^{***}p < .001$.

Table 4
Indices related to the total, direct and indirect effect in the simple mediation analyzes for R1 or R2 as antecedent; phonological awareness or stress awareness as mediator; and real word reading as output

			Effect	*SE*	*t*	*LLCI*	*ULCI*
PA	*R1*	Total	−.023	.016	1.404	−.0549	.0097
		Direct	−.013	.016	.793	−.0448	.0195
		Indirect	−.010	.007		−.0271	.0007
	R2	Total	−.033	.010	3.201**	−.0531	−.0121
		Direct	−.028	.010	2.766**	−.0487	−.0077
		Indirect	−.004	.004		−.0134	.0019
SA	*R1*	Total	−.014	.016	.901	−.0455	.0173
		Direct	−.015	.015	.965	−.0458	.0161
		Indirect	.001	.003		−.0046	.0080
	R2	Total	−.017	.011	1.489	−.0397	.0059
		Direct	−.013	.012	1.103	−.0365	.0107
		Indirect	−.004	.004		−.0121	.0017

Note. *SE* = Standard error; *LLCI* = Lower limit confidence interval; *ULCI* = Upper limit confidence interval; *PA* = Phonological awareness; *SA* = Stress awareness; *R1* = Asynchrony in the rhythmic sequence of 500 ms; *R2* = Asynchrony in the rhythmic sequence of 667 ms.
$^{**}p < .05$.

Table 5
Indices related to the total, direct and indirect effect in the simple mediation analyzes for R1 or R2 as antecedent; phonological awareness or stress awareness as mediator; and non-real word reading as output

			Effect	*SE*	*t*	*LLCI*	*ULCI*
PA	*R1*	Total	−.021	.014	1.481	−.0496	.0075
		Direct	−.010	.014	.705	−.0368	.0177
		Indirect	−.012	.007		−.0278	−.0009
	R2	Total	−.027	.010	2.965**	−.0444	−.0085
		Direct	−.021	.009	2.461**	−.0388	−.0039
		Indirect	−.005	.004		−.0136	.0021
SA	*R1*	Total	−.014	.014	.992	−.0408	.0139
		Direct	−.014	.013	1.090	−.0408	.0121
		Indirect	.001	.003		−.0052	.0082
	R2	Total	−.013	.010	1.323	−.0325	.0067
		Direct	−.008	.010	.812	−.0279	.0119
		Indirect	−.005	.003		−.0123	−.0002

Note. *SE* = Standard error; *LLCI* = Lower limit confidence interval; *ULCI* = Upper limit confidence interval; *PA* = Phonological awareness; *SA* = Stress awareness; *R1* = Asynchrony in the rhythmic sequence of 500 ms; *R2* = Asynchrony in the rhythmic sequence of 667 ms.
$^{**}p < .05$.

R2 (B = −.021, *SE* = .009, *p* < .05, 95% CI [−.0388, −.0039]), but not indirect through PA (B = −.005, *SE* = .004, 95% CI [−.0136, .0021]) (see Figure 1). These results indicated a negative relation of R2 with both WR_R and WR_{NR} when PA was controlled for. This pattern corresponded with the results of linear regression analyses when R2 independently predicted WR_R and WR_{NR} in spite PA was included in the model.

The above analyses were repeated with SA as the mediating variable (see Figure 2). In this case, the direct (B = −.013, *SE* = .012, *p* = .276, 95% CI [−.0365, .0107] or indirect (B = −.004, *SE* = .004, 95% *CI* [−.0121, .0017]) relationship between R2 and WR_R did not reach

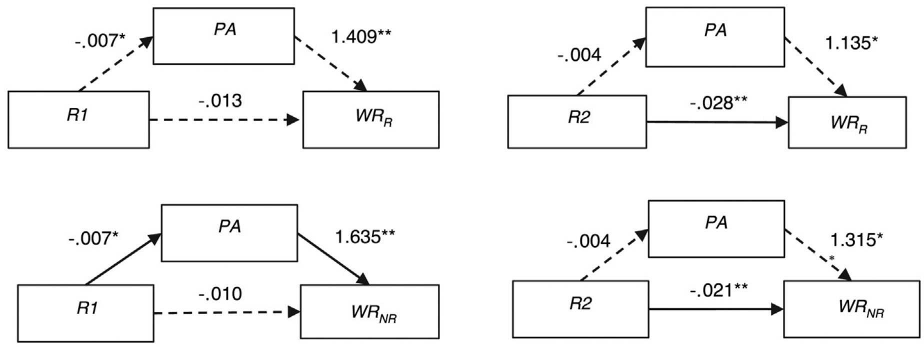

Figure 1. Results of the mediation analysis with phonological awareness (PA) as a mediator between the reading of real (WR_R) or non-real (WR_{NR}) words and rhythmic asynchrony in the 500 ms sequence (R1) or rhythmic asynchrony in the 667 ms sequence (R2). The figure shows non-standardized regression coefficients. The solid lines represent significant direct/indirect effects.
$^{*}p < .1$. $^{**}p < .05$.

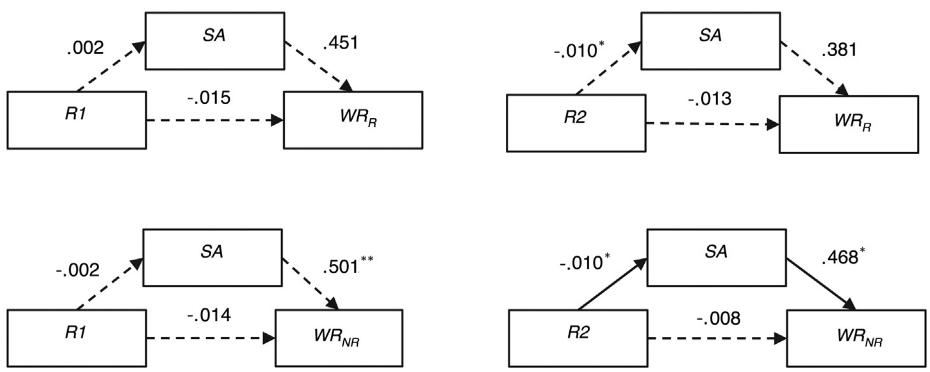

Figure 2. Results of the mediation analysis with stress awareness (SA) as a mediator between the reading of real (WR_R) or non-real (WR_{NR}) words and rhythmic asynchrony in the 500 ms sequence (R1) or rhythmic asynchrony in the 667 ms sequence (R2). The figure shows non-standardized regression coefficients. The solid lines represent significant direct/indirect effects.
$^{*}p < .1$. $^{**}p < .05$.

significance; nor did the direct (B = −.015, *SE* = .015, *p* = .339, 95% CI [−.0458, .0161]) or indirect (B = .001, *SE* = .003, 95% CI [−.0046, .0080]) between *R1* and WR_R; or direct (*B* = −.014, *SE* = .013, *p* = .281, 95% CI [−.0408, .0121] or indirect (B = .001, *SE* = .003, 95% CI [−.0052, −.0082]) between R1 and WR_{NR}. However, there was a significant indirect effect (B = −.005, *SE* = .003, 95% CI [−.0123, −.0002] when SA was the mediator between R2 and WR_{NR} but no direct effect (B = −.008, *SE* = .010, *p* = .421, 95% CI [−.0279, .0119]), suggesting that R2 was related to WR_{NR} through SA. The relationship between R2 y SA was negative (lower asynchrony higher *SA*), while that between SA and WR_{NR} was positive. No direct effects were found when SA was controlled for.

Discussion

The general aims of this work were twofold. First, to determine whether sensitivity to rhythm, either faster (2 Hz, R1) or slower (1.5 Hz, R2), independently contributes to the prediction of reading performance in Spanish first graders. Second, to test whether PA and/or SA mediate the relationship between rhythm and reading skills. Results indicated that R1 did not independently accounted for reading (WR_R, WR_{NR}), but R2 did it after I, V, and PA (marginally when bootstrapping is used) were controlled for. However, if SA was included in the model instead of PA, R2 did not predict reading, suggesting that SA is a mediator factor between R2 and Reading. This involvement of rhythm (via R2 in this study) in the prediction of WR_R and WR_{NR} is consistent with empirical evidence, either in transparent (e.g., Kertész & Honbolygó, 2021; Lundetrae & Thomson, 2018) or in opaque (e.g., Lé et al., 2020; Ozernov-Palchik et al., 2018) orthographies. In the present work, rhythm contributed to the prediction of reading as investigated by Kertész and Honbolygó (2021), in which rhythm was significantly involved in the prediction of reading at the end of first grade in typical children whose mother tongue was Hungarian, a language with a transparent orthographic system.

It is difficult to conclude about the relationship between rhythm and reading when children have started to learn to read formally. This research suggests the involvement of R2 in predicting the reading of real and non-real words when PA was included in the model but not when SA was included, and may indicate commonality between R2 and SA. The factor common to R2 and SA may be the 667 milliseconds temporal window needed to estimate the stressed syllable; that is, R2 and SA may relate to word reading primarily through the processes of lexical stress assignment. In this process, formal literacy may be one of the triggers for children's ability to synchronize their performance at a slower rate (McAuley et al., 2006). Additionally, Holliman et al. (2017) highlight that SA is involved in reading polysyllabic words, which present changes in the stress pattern.

The second objective of this paper was to assess whether the relationship between rhythm and reading in children who begin formal reading instruction was mediated by PA and/or SA. The results obtained through mediation analyses showed an indirect relationship between R1 and WR_{NR} through the PA acting as mediator variable, and between R2 and WR_{NR} if SA was the mediating variable. The mediational role of PA adds to the empirical evidence obtained by Kalashnikova et al. (2021) before the start of literacy instruction (i.e., reading readiness). This research further extends the results of Kalashnikova et al. (2021) on the mediation of PA in reading in typical children who have already started literacy learning and highlights that PA mediates the relationship between reading and rhythm. Moreover, the present results align with the temporal sampling theory of Goswami (2011, 2018, 2019), where rhythm underlies PA development.

Therefore, R1 seems related to reading through PA and R2 through SA. However, this relationship may depend on the stage of reading acquisition. During reading acquisition, the first phase would be marked by the development of phonological skills with the involvement of other skills, such as stress awareness, later in the process. David et al. (2007) found that phonological skills predicted reading, although rhythm contributed independently when the skills required were more complex (e.g., advanced stages of learning). In the same line, Kertész and Honbolygó (2023) and Lê et al. (2020) suggested that short after systematic literacy learning has begun, phonological skills become less important in favor of other skills (e.g., lexical). Similarly, studies in Spanish suggested that in advanced formative stages (grades 3–6), awareness of lexical stress was related to stress assignment in reading aloud in Spanish (Gutiérrez-Palma et al., 2016).

However, the relationship between reading and the ability to establish prosodic contrasts can already be identified in earlier stages. Thus, Gutiérrez-Palma and Palma-Reyes (2007) concluded that 1st and 2nd-grade students who discriminated better between prosodic contrasts also read pseudowords with greater precision and with fewer stress errors. Accordingly, children's ability to attend to stimuli that are presented at a lower rate (longer periods), such as those associated with R2 (667 ms), may facilitate the child's grasp of more complex rhythmic events (e.g., three syllables instead of two) allowing them to be sensitive to the stress patterns that are necessary for reading multisyllabic words. This involvement of SA and R2 at later stages of literacy learning is in line with McAuley et al. (2006) that formal learning of reading may be one of the factors contributing to the extension of the entrainment region at certain developmental periods.

Limitations and conclusions

The results obtained in this work suggest that once formal reading instruction has begun, children's rhythmic skills are involved in the prediction of reading, although the body of research needs to be expanded. The role of rhythm may depend on the phase of literacy acquisition and the type of rhythm. Sensitivity to slower rhythm (R2) is independently involved in predicting reading words once the involvement of PA is controlled for. Similar results were obtained by Lundetrae and Thomson (2018) when predicting the reading of children with low academic performance. Likewise, the absence of an independent contribution of R2 when controlling for SA in the prediction model suggests that SA also contributes to the development of reading, especially when reading multisyllabic words that require stress assignment. These suggestions are more accurately outlined with mediational models. In these models, R1 was related to WR_{NR} through PA, while R2 was related to WR_{NR} through stress awareness. This result goes in the direction of the previous proposal that the inclusion of R2 as an independent predictor in linear regression models suggests the contribution of SA once basic decoding skills have been achieved.

A limitation of this study is the low reliability of the blending task. This may be because this task is tapping some PA (phoneme) skills that are probably later acquired at the end of the first grade, that is, later in the PA acquisition process. However, the significant correlation with the other PA measure suggests that this task is tapping the same factor. Then, it can be used within a composite measure of both PA tasks. Moreover, results pattern differently for PA and SA, suggesting that our PA measure is relevant for the purposes of this study. In the same vein, reliability on the SA task was moderate, although similar reliability values have been reported in other work, especially when young children participate (e.g., Calet et al., 2015; Goswami et al., 2013; Holliman et al., 2014). Moreover, perhaps the low reliability coefficients would have been better if a larger sample of participants had been available, which is another limitation of the study. Another limitation is the low reliability of measure V. Many of the items in this test had a very high mean score, close to the maximum possible, reducing the variability and, therefore, the reliability and validity measures. This same argument has been used to explain the low reliability of some of the subtests of a widely used test in literacy assessment, such as the PROLEC-R (Cuetos et al., 2012). Like some of the PROLEC-R subtests, the test used to assess vocabulary corresponds to a screening-type measure, with few items, and also designed to detect students at risk of dyslexia. However, in this study, students with difficulties were precisely eliminated, further limiting the variability of scores. Even so, the results using an abbreviated version of the test with only four items do not change.

The results of this work have been obtained following a correlational design, thus limiting the establishment of cause-effect relationships. Conclusions about the relationships between rhythm (R1, R2), PA, SA, and literacy require longitudinal studies that evaluate the evolution of children in different educational periods; the development of intervention studies, as well as an increase in the number of participants to increase the generalisability of the results. These relationships may be complex and influenced by factors such as the learning phase and the characteristics of the rhythmic sequence under consideration, at least in orthographic systems similar to Spanish.

In any case, the results obtained in this study have implications for educational practice. On the one hand, they suggest that introducing activities that work on rhythmic skills may facilitate the development of literacy. On the other hand, results of this study suggest that low rhythmic ability could be considered an indicator of reading difficulties, and then it could be used for the early detection of the risk of suffering dyslexia. Educational policies aimed at promoting the intervention and assessment of rhythmic skills as part of the school curriculum could improve the reading efficiency achieved by schoolchildren, an aspect of interest for the school system once children have reached full schooling.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author statement

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