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Developmental Changes in the Relations Between RAN, Phonological Awareness, and Reading in Spanish Children

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We examined the developmental relations of phonological awareness (PA) and rapid automatized naming (RAN) with reading in a cross-sectional study with 874 Spanish children from Grades 2 to 6. Our main prediction was that the RAN–reading relationship would decrease due to a gradual change in reading strategy, from serial decoding to sight word reading. Therefore, in contrast to most previous studies, we used discrete reading tasks. Serial RAN tasks for objects, colors, digits, and letters were included. First, we examined whether the RAN tasks loaded on the same constructs across time. An alphanumeric and a nonalphanumeric factor were identified, which were invariant over time. In subsequent multigroup structural equation models we found that the PA–reading relationship was low but slightly increased in the higher grades. As predicted, the RAN–reading relationship decreased for words, whereas the relationship remained stable for pseudowords.

INTRODUCTION

Reading is a complex task, and a large number of cognitive abilities are known to be involved in its development. Current evidence suggests that phonological awareness (PA) and rapid automatized naming (RAN) are two of the most important predictors of reading development (Albuquerque, 2012; Badian, 2001; Cardoso-Martins & Pennington, 2004; de Jong & van der Leij, 2003; Müller & Brady, 2001). Both abilities appear to be moderately related (Swanson, Trainin, Necoechea, & Hammill, 2003), and each ability has been found to make an independent contribution to the development of reading (e.g. de Jong & van der Leij, 1999; Lervåg, Bråten, & Hulme, 2009; Pennington, Cardoso-Martins, Green, & Lefly, 2001; Wimmer, Mayringer, & Landerl, 2000).

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However, the relative importance of PA and RAN for reading development is an issue that is not yet resolved as it seems to depend on a range of factors such as the characteristics of the orthography, the age of assessment, and the type of reading task.

In the current study we consider developmental changes in the relationships of PA and RAN with reading in a large sample of children learning to read in Spanish. Knowledge of such changes is relevant for the interpretation of studies on cross-orthographic differences. For example, if the relationship between PA and learning to read is developmentally limited (e.g., de Jong & van der Leij, 1999; Lervåg et al., 2009), but reading development proceeds more slowly in inconsistent orthographies, then the outcome of a comparison between orthographies differing in consistency would depend on the reading age at which a comparison is made. In itself, changes in the developmental relationships of PA and RAN with reading are also important, as they might reveal changes in the reading processes underlying reading as development proceeds. It has been argued that reading development can be characterized by a gradual shift from slow sublexical phonological processing to the lexical processing of words and sight word reading (e.g., Ehri, 2005; Share, 2008). Especially changes in the RAN–reading relationship have been associated with these developmental changes in word reading processes (Vaessen & Blomert, 2010; van den Bos, Zijlstra, & van den Broeck, 2003).

Currently there are relatively few studies in which the developmental changes in the relationships of PA and RAN with reading have been examined. In Spanish, for example, studies have focused only on the initial stages of reading acquisition (e.g., Aguilar et al., 2010; Suárez-Coalla, García de Castro, & Cuetos, 2013). In English, however, Kirby, Parrila, and Pfeiffer (2003) examined the effect of PA and RAN beyond the initial stage of reading acquisition. They assessed PA and RAN in kindergarten and analyzed their influence on reading accuracy from first through fifth grade. Kirby et al. found a strong effect of PA on reading accuracy in the first grades followed by a drop in the strength of this effect over the next years. Over this same period, an increase was found in the contribution of RAN to reading accuracy, although it emerged earlier for word than for pseudoword reading accuracy. Similar results were found for word reading accuracy in a longitudinal study by Torgesen, Wagner, Rashotte, Burgess, and Hecht (1997), who showed that the contribution of RAN to word reading increased slightly over time, whereas PA showed the opposite pattern. However, the effect of PA on nonword reading accuracy increased. With respect to reading speed, the magnitude of the relation between RAN, PA, and reading speed was stable, but the RAN–reading speed relationship was stronger than the PA–reading speed relationship.

The overall finding of a decrease in the relationship between PA and reading over time, observed in the studies with English children, is in line with results found in more transparent orthographies (Landerl & Wimmer, 2008; Vaessen & Blomert, 2010). Landerl and Wimmer (2008) reported, for children learning to read in German, that the relationship between PA and reading became weaker from Grade 1 to Grade 8. A similar result was reported by Vaessen and Blomert (2010) for a sample of Dutch children. In contrast, the results on the development of the relationship of RAN with reading tend to differ considerably across orthographies. Landerl and Wimmer found that the correlation between RAN and reading speed remained the same from Grade 1 to Grade 4. After Grade 4, a decrease was found in the strength of the relationship. This decrease could be due to the fact that Landerl and Wimmer used word and pseudoword list reading until fourth grade and then changed to text reading as a measure of reading fluency. Contrary to these results, in their cross-sectional study with varying age-groups, Vaessen and Blomert found that the relationship of RAN with reading fluency increased from first through sixth grade and argued that this increase indicated a gradual change in reading strategy from phonological decoding to automatic visual word recognition.

Theoretically, a decrease in the relationship of PA with reading fits well with the Dual Route Cascaded model of reading (DRC; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). Within the DRC model, a lexical and a nonlexical route toward letter string identification are distinguished. Both routes are simultaneously active, but familiar words are read mainly through the lexical route, whereas the nonlexical route dominates processing of unfamiliar words or nonwords. Through the faster lexical route, word identification is achieved in parallel by successive activation of a word's entry in the orthographic and phonological lexicon. Through the nonlexical route, in contrast, graphemes are serially decoded into phonemes according to grapheme–phoneme conversion rules. Beginning readers rely to a large extend on decoding or the nonlexical route to read words. Accordingly, PA can be expected to be an important predictor of reading performance. Throughout reading development, however, children store an increasing amount of word representations in their lexicon and activate these representations during reading (e.g., Ehri, 2005; Share, 2008). In this stage of sight word reading, the relation with PA can be expected to decrease.

The relation between RAN and reading development is more complex to understand. de Jong (2011) with Dutch children and Protopapas, Altani, and Georgiou (2013) with Greek children showed that the relationship of RAN with reading depends on the format of both the RAN and the reading task. In more advanced readers, relations were higher if both task formats were the same, that is both in serial or in discrete format (de Jong, 2011; Protopapas et al., 2013). De Jong (2011) argued that the advanced readers would read most of the high-frequency words included in the study by sight. Accordingly, the retrieval of the name of a written word was very similar to the retrieval of a pronunciation of a symbol and, therefore, for advanced readers the RAN and reading tasks of the same formats were similar. In contrast, in younger readers, assumed to use a serial decoding strategy, serial RAN would be related to both serial and discrete word reading. However, the relation of serial RAN with discrete word reading was predicted to decrease over time as children increasingly become able to read the words by sight. Accordingly, serial RAN and discrete reading would increasingly reflect different processes. Indeed this was what was found by de Jong (2011) and Protopapas et al. (2013).

In the current study, we examined the developmental relationships of RAN and PA with discrete measures of word and pseudoword reading in Spanish. Although reading lists of words involves multiple processes (e.g., sequential and articulatory processes) that exceed the word recognition process, a discrete reading measure, specifically discrete reading speed, represents a clear measure of the word identification process. Therefore, this measure allows interpreting the developmental changes between RAN and reading in terms of changes in reading strategies. Because of our discrete measure of reading, our predictions differ from previous studies in which serial reading tasks were administered. Contrary to these studies, we expect a decrease in the relationship between serial RAN and discrete word reading, reflecting the transition from serial decoding to automatic visual word recognition. This decrease, however, is not expected for the relation of RAN with pseudoword reading. Nonwords cannot be represented in the lexicon, and as a result always require involvement of the nonlexical route (Coltheart et al., 2001). A similar relation between serial RAN and pseudoword reading is therefore expected across reading development. In line with previous studies (Kirby et al., 2003; Landerl & Wimmer, 2008; Torgesen et al., 1997; Vaessen & Blomert, 2010), the relationship between PA and reading is expected to decrease.

Of interest, in the Spanish language, monosyllabic words are rare (there is less than 8%; Perea & Carreiras, 1998). The current study thus concerns reading of polysyllabic words and pseudowords. Little is known about how children read polysyllabic items, as both models (e.g., DRC model; Coltheart et al., 2001) and studies (e.g., de Jong, 2011) of reading processes have focused primarily on monosyllabic words.

Before examining the relationships between RAN, PA, and reading, we closely examined the RAN tasks. In most previous studies on developmental changes in the RAN–reading relationship, alphanumeric (letters and digits) and nonalphanumeric (colors and pictures) RAN composite scores have been distinguished, with alphanumeric RAN being the stronger correlate of reading (van den Bos et al., 2003). However, in computing a composite score, it is assumed that the structure of the RAN measures (digits, letters, colors and pictures) does not change over time (see van den Bos et al., 2003). Recent evidence, however, suggests otherwise. For example, Vaessen and Blomert (2010) showed that the relation between RAN-letters and RAN-digits increased from .36 in Grade 1 to .69 in Grade 6. Evidently, this results in differences in the reliability of the composite score over time, which in turn could affect the relationship of RAN with reading.

Taken together, two research questions were examined in the current study. First, we examined possible fluctuations in the reliability of RAN scores by testing the factor structure and measurement invariance of RAN measures across grades. Second, we examined the developmental relationships of RAN and PA with word and pseudoword reading in a large cross-sectional sample of children learning to read Spanish.

METHOD

Participants

Participants were 874 Spanish children from Grade 2 to Grade 6 of primary school (Grade 2, $N = 172$ [95 boys]; Grade 3, $N = 175$ [72 boys]; Grade 4, $N = 172$ [96 boys]; Grade 5, $N = 188$ [119 boys]; Grade 6, $N = 167$, [105 boys]). The children came from intact classes of state and private schools in urban and suburban areas of Santa Cruz de Tenerife. Mean age per grade is presented in Table 1.

Measures

Measures for reading, phonological awareness, and rapid naming were selected. All these measures were included in the standard multimedia battery SICOLE-R (Jiménez et al., 2007). This tool is programmed in Java 2 Platform Standard Edition 1.4, de Sun, and HSQL Database Engine is used as the database. For the discrete reading measures, the time between the presentation of each stimulus and the onset of the vocal response was measured. The stimuli of all tasks appeared in the center of a 14-in. computer screen.

Phonological awareness. We administered the Prueba de Conciencia Fonémica (Test of Phonemic Awareness) that consisted of four different tasks. In the isolation task, the child listened

TABLE 1
Means and Standard Deviations by Grade on All the Measures

	Grade 2		*Grade 3*		*Grade 4*		*Grade 5*		*Grade 6*	
	M	SD	M	SD	M	SD	M	SD	M	SD
Age	7;6	0;4	8;5	0;5	9;5	0;5	10;6	0;5	11;5	0;6
PA	36.91	8.30	43.15	7.03	44.37	7.01	46.47	6.59	48.70	6.34
RAN-numbers	1.53	.28	1.76	.35	1.74	.37	1.91	.45	1.87	.52
RAN-letters	1.32	.32	1.58	.32	1.60	.30	1.76	.36	1.80	.41
RAN-colors	.91	.19	1.04	.20	1.07	.20	1.20	.21	1.26	.24
RAN-objects	.91	.17	1.03	.19	1.05	.18	1.18	.21	1.22	.23
Word speed	.67	.21	.83	.25	.85	.24	.95	.26	.99	.27
% accuracy	96	.07	98	.03	99	.02	99	.02	99	.02
Pseud speed	.60	.17	.67	.19	.66	.17	.75	.21	.76	.20
% accuracy	87	.07	91	.03	91	.02	93	.02	93	.03

Note. PA = phonological awareness; Words/s = number of words per second; Pseudowords/s = number of pseudowords per second.

to a word (e.g., *faro* [lighthouse]), and was asked to say its first sound (/f/). Then three pictures were presented on the computer screen (e.g., *falda* [skirt], *reloj* [watch], and *blusa* [blouse]), and the child had to select the picture of the word that began with that same sound (e.g., *falda* [skirt]). In the segmentation task, the child listened to a word (e.g., *casa* [house]) and was required to say its constituent sounds, phoneme by phoneme (e.g., /c/ /a/ /s/ /a/). Either pronouncing the sounds or saying the names of the letters constituted a correct response. In the deletion task, the child listened to a word (e.g., *fresa* [strawberry]) and was then asked to delete its first sound. Finally, in the blending task, the child listened to a sequence of phonemes (e.g., /f/ /o/ /c/ /a/) and was required to blend the sounds and say the whole word (e.g., *foca* [seal]). Each task was preceded by two practice items and contained 15 items. The total score was calculated by adding the correct responses in the four tasks (range = 0–60). Cronbach's alpha reliability coefficients were .90, .86, .87, .85, and .89 for Grades from 2 to 6, respectively.

Naming speed. The naming speed task was adapted from Denckla and Rudel's (1974) RAN task. The test consisted of four cards with a different stimulus set on each card: letters, one-digit numbers, common objects, and basic colors. Each stimulus set consisted of five symbols that were presented in five rows and 10 columns on the screen of the computer. The child was asked to name the stimuli as quickly as possible in a left-to-right, top-to-bottom order. All tests included 10 practice symbols presented in a chart of two rows and five columns. The score was the time needed to complete naming the 50 stimuli. To normalize the score distributions, the scores were converted to the number of symbols named per second.

Word and pseudoword reading tasks. These tasks required reading aloud of words or pseudowords that appeared one by one on a computer screen. The word reading task consisted of 32 high-frequency words with two, three, and four syllables. The items were selected on the basis of a normative study of subjective familiarity conducted by Guzmán and Jiménez (2001). In this study, words were selected from a sample of 2,968 words obtained from different texts of children's literature. The subjective word familiarity was measured by asking children to rate each word (of a different subset of words) on a scale from 1 (*least familiar*) to 5 (*most familiar*). The estimated familiarity was calculated for each word by averaging the ratings across 30 children. The stimuli of this task were selected from among those words that were rated between 3 and 5. Cronbach's alpha reliability coefficients for accuracy were .91, .90, .90, .81, and .86 for Grades 2 to 6, respectively. The pseudoword reading task consisted of 48 pseudowords with two and three syllables that were used by Vega, Carreiras, Gutiérrez, and Alonso-Quecuty (1990). Each task was preceded by two items for practice. Cronbach's alpha reliability coefficients for accuracy were .88, .96, .95, .88, and .89 for Grades 2 to 6, respectively. Split-half reliabilities from Grade 2 to Grade 6 were .81, .85, .89, .86, and .90 for pseudoword reading speed and .82, .84, .88, .84, and .84 for word reading speed, respectively.

In both reading tasks, the children were asked to read the words and pseudowords aloud as quickly as possible but without making errors. After the presentation of a stimulus, a voice key registered the latency time from the presentation of the stimulus to the onset of the response, and the examiner scored whether the word/pseudoword was read correctly. The sequencing in the administration of the stimuli was as follows: blank screen on the computer (200 ms), fixation point in the center of the screen (400 ms), and stimulus word/pseudoword. In total, the time between items was 2,000 ms.

Two measures, accuracy and speed, were assessed for both types of stimuli. The score was calculated based on the latency time of the stimuli read correctly. To normalize the score distributions, the latency times were inverted and multiplied by 1,000 (Tabachnick & Fidell, 2007).

Procedure

The tasks were individually administered in a quiet room. All tests were administered by trained university and master students of the Developmental Psychology Department of the University of La Laguna. Testing started 1 month after the summer holidays and continued until February.

Statistical Analysis

First, we examined the structure of the four measures of RAN. Using multigroup (grade) confirmatory factor analysis, we tested whether the tasks in each grade reflected one RAN factor or whether two RAN factors (alphanumeric and nonalphanumeric) should be distinguished. Furthermore, measurement invariance was examined through equality constraints on factor loadings, residual variances, factor variances, and factor correlations. Constraining parameters to be equal across grades results in changes in model fit. If the decrease in model fit is not significant, parameters are equal across grades, whereas significant changes in model fit indicate unequal parameters across grades. Next, the development in the relationships of PA and RAN with reading was examined through multigroup structural equation modeling. A composite score of RAN was calculated for these analyses, based on the outcomes of the analyses of the structure of RAN, because only single scores were available for PA and reading.

Comparing relationships between variables across grades, specifically correlations, raises an important methodological issue. In structural equation modeling, hypotheses are tested through comparisons of covariance matrices across groups. Covariances, however, are a function of both

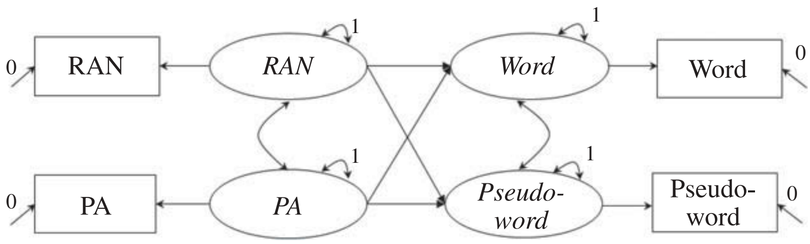

FIGURE 1 Example of a phantom-factor model used in testing the relations of rapid automatized naming (RAN) and phonological awareness (PA) with word and pseudoword reading.

the variance of each variable and the correlations between variables (Marsh & Hocevar, 1985). Therefore, differences in correlations across time can only be tested reliably in a structural equation model when the differences in variances are controlled for. Variances and correlations can be tested apart with the use of phantom factors, which are latent variables of which the variance is constrained (see de Jong, 1999; Macho & Ledermann, 2011). Therefore, when correlations were examined, a second-order factor model was specified, with the first-order scores as single indicators (see Figure 1 for an example). The variances of these second-order factors were fixed to 1, and the residual variances of the first-order indicators were fixed to 0. Accordingly, the factor loadings on the second-order factors reflect the standard deviations of the first-order constructs. The second-order factors all have equal variances (constrained to 1). Therefore, factor covariances become factor correlations, no longer influenced by possible differences in factor variances. To test possible changes in the relationships of RAN and PA with reading across grades, an initial saturated model was specified. Again, equality constraints were used to examine whether relationships were the same or different across grades.

We also examined the unique relations of RAN and PA with reading. We specified a regression model with simultaneous direct effects of both variables on reading of words, and pseudowords. Because in a regression model, the variance of the dependent variables cannot be fixed but should be estimated, the factor loadings of the reading variables on their respective latent factors were fixed to the standard deviations. As a result, the residual variances of word and pseudoword reading could be estimated under the condition that the total variance of each factor representing a dependent variable equals 1 (see also van den Boer, van Bergen, & de Jong, 2014).

All models were specified using Mplus version 5.21 (Muthén & Muthén, 2009). Parameter estimates were obtained through full information maximum likelihood estimation. Several fit indices were used to examine model fit. First and most important, the chi-square test statistic of overall goodness of fit should be larger than .05 to indicate exact fit (Hayduk, 1996). The chi-square test was also used to test differences in model fit between nested models (Kline, 2011). In addition, a comparative fit index larger than .95 in combination with a standardized root mean square residual below .08 indicated good approximate fit (Hu & Bentler, 1999). Values of the root mean square error of approximation below .05 indicate close fit, and below .08 a satisfactory fit, whereas values over .10 indicate poor fit (Browne & Cudeck, 1993).

RESULTS

The results are presented in three sections. In the first section the descriptive statistics of the scores on the PA, RAN, and reading measures are given. Next, we present analyses on the structure of the RAN tasks. Then, in the final section, we report the results on the developmental changes in the relationships among PA, RAN, and reading.

Descriptive Statistics

In Table 1, the means and standard deviations of all measures are shown. As expected, on all tasks there is an increase in mean performance across grades. The accuracy on both word and pseudoword reading was high across grades (87% or higher). In each grade, the mean word reading fluency was higher than the mean pseudoword reading fluency. Furthermore, digit and letter naming speed were higher than the speed of naming colors and objects.

For each grade, the correlations of PA and RAN with the various reading tasks are presented in Table 2. The correlation patterns of the various measures of RAN with the word and pseudoword reading task were quite similar. From Grades 2 to 4, the correlations tended to increase, whereas after Grade 4 the correlations tended to decrease. The decline seemed more pronounced for words. The correlations between PA and all reading measures were mostly significant but showed slight fluctuations across reading measures and grades.

TABLE 2
Correlation of Reading Tasks and RAN-subtests and PA

	Words/s				
	Grade 2	*Grade 3*	*Grade 4*	*Grade 5*	*Grade 6*
PA	.259**	.407**	.232**	.302**	.342**
RAN-numbers	.253**	.295**	.292**	.104	.096
RAN-letters	.385**	.357**	.404**	.275**	.167*
RAN-colors	.186*	.298**	.461**	.199**	.188**
RAN-objects	.224**	.433**	.410**	.395**	.178*
	Pseudowords/s				
	Grade 2	*Grade 3*	*Grade 4*	*Grade 5*	*Grade 6*
PA	.138	.180*	.134	.252**	.213**
RAN-numbers	.244**	.307**	.335**	.204**	.212**
RAN-letters	.292**	.314**	.422**	.323**	.293**
RAN-colors	.199**	.229**	.425**	.238**	.184**
RAN-objects	.149*	.277**	.396**	.360**	.260**

Note. PA = Phonological Awareness; Words/s = Number of words per second; Pseudowords/s = Number of pseudowords per second.

*$p < .05$; **$p < .01$.

Structure of RAN

There were four measures of RAN pertaining to alphanumeric (letters and digits) and nonalphanumeric symbols (colors and pictures). First, we examined the factor structure of these four measures of RAN. The fit statistics of the models that were tested are presented in Table 3. We tested a one-factor model in which the four tasks loaded on one factor and a model with two RAN factors, one alphanumeric (letters and digits), and one nonalphanumeric (objects and colors). The model with one RAN factor fitted the data poorly. Instead, a model with two RAN factors provided a good fit to the data.

The two-factor model could be constrained further. A model with the factor loadings constrained to be equal across grades provided a good fit to the data and did not differ significantly from the previous model, $\Delta\chi^2(8) = 14.941$, $p = .060$. This model was used as the baseline model in testing additional constraints. Model fit was poor when the factor loadings of the nonalphanumeric RAN tasks objects and colors were constrained to be equal. Color naming loaded more strongly on nonalphanumeric RAN than object naming. However, good model fit was obtained when the factor loadings of the alphanumeric RAN tasks letters and digits were constrained to be equal, $\Delta\chi^2(1) = 0.365$, $p = .546$.

Invariance of residual variances was not found. A model in which residuals were constrained to be equal across grades fitted the data poorly. Modification indices showed that this invariance could not be ascribed to one specific indicator. Constraining factor variances to be equal across grades also resulted in poor model fit. Both at the indicator and at the factor level, variances increased across grades. Finally, the model including an equality constraint on the relationship between alphanumeric and nonalphanumeric RAN provided a good fit to the data, $\Delta\chi^2(4) = 0.524$, $p = .971$. The correlation between the factors was .816.

Because only one score was available for PA, word and pseudoword reading, a composite score was computed for RAN. The structure of the RAN tasks suggested that an alphanumeric and a nonalphanumeric composite score could be computed. The reliability (Cronbach's alpha) of these composites depends on the correlations between the two variables contributing to the composite score. To test whether the reliability of the composite remained stable over time, we tested whether the relation between the two indicators of each factor changed across grades. Two models were tested, one for the alphanumeric RAN tasks letters and digits, and a similar model for the nonalphanumeric RAN tasks objects and colors. A model with equal relationships between letter and digit RAN across grades provided a good fit to the data. Similarly, a model with an equality constraint on the relationships between object and color RAN across grades fitted the data. The correlation between RAN letters and digits was .734, and the correlation between RAN objects and colors was .682.

Taken together, these results indicated that the four RAN measures constituted two factors. These factors, as well as the relationships between the four tasks, were stable across grades. Furthermore, letter and digit naming loaded equally strongly on the alphanumeric factor. We therefore computed the average naming speed of letters and digits and used this RAN score in subsequent analyses, because alphanumeric RAN has been shown to be a better predictor of reading abilities than nonalphanumeric RAN (e.g., van den Bos et al., 2003).

TABLE 3
Fit Statistics of the Models Used to Examine the Structure of RAN and the Relationships Between RAN, PA, and Reading

Model		χ^2	df	p	*RMSEA*	*CFI*	*SRMR*
Structure of RAN							
1	Four RAN tasks load on one RAN factor in all grades	137.654	10	.000	.250 [.214, .288]	.933	.044
2	Four RAN tasks load on two RAN factors in all grades	2.933	5	.710	.000 [.000, .072]	1.00	.005
2.1	Equal factor loadings of RAN tasks on RAN factors across grades	17.874	13	.162	.043 [.000, .087]	.977	.063
2.2	Equal factor loadings of colors and objects on non-alphanumeric RAN	27.639	14	.016	.069 [.029, .107]	.993	.082
2.3	Equal factor loadings of letters and digits on alphanumeric RAN	18.239	14	.196	.038 [.000, .082]	.998	.064
2.4	Equal residual variances of the RAN tasks across grades	77.859	29	.000	.091 [.067, .115]	.974	.160
2.5	Equal variances of RAN factors across grades	58.189	21	.000	.093 [.065, .122]	.980	.266
2.6	Equal correlations between RAN factors across grades	18.398	17	.364	.020 [.000, .068]	.999	.065
3	Equal correlations between RAN letters and digits across grades	4.750	4	.314	.030 [.000, .114]	.999	.075
4	Equal correlations between RAN colors and objects across grades	3.929	4	.416	.000 [.000, .105]	1.00	.075
Relations among PA, RAN, and reading							
1	Correlations word and nonword reading are equal across grades	8.469	4	.076	.074 [.000, .143]	.995	.053
2	Correlations RAN and PA are equal across grades	9.561	4	.049	.082 [.006, .151]	.994	.041
3	Correlations RAN with word reading are equal across grades	11.974	4	.018	.098 [.037, .165]	.992	.052
3.1	Correlations RAN with word reading changes between Grades 4 and 5	0.729	3	.867	.000 [.000, .061]	1.00	.011
4	Correlations RAN with pseudoword reading are equal across grades	4.255	4	.373	.018 [.000, .108]	1.00	.028
4.1	Correlations RAN with pseudoword reading changes between Grades 4 and 5	2.311	3	.510	.000 [.000, .106]	1.00	.020
5	Correlations PA with word reading are equal across grades	4.910	4	.297	.033 [.000, .115]	.999	.032
6	Correlations PA with pseudoword reading are equal across grades	3.159	4	.532	.000 [.000, .095]	1.00	.025

Note. RAN = rapid automatized naming; PA = phonological awareness; RMSEA = root mean square error of approximation; CFI = comparative fit index; SRMR = standardized root mean square residual.

Relations Among PA, RAN, and Reading

The main aim of this study was to examine whether the relations of PA and RAN with word and pseudoword reading changed across grades. The fit statistics of the models used to examine this question are presented in Table 3. Table 4 includes the parameter estimates of the saturated baseline model. The relationship between word and nonword reading did not change across grades. However, the relationship between RAN and PA did differ across grades. From Grade 2 to Grade 5, the relationship seems to decrease. However, an increase in the relationship is found in Grade 6.

Next, we examined the relationships of RAN and PA with the reading tasks. We found that the relation of RAN with word reading changed significantly across grades. Parameter estimates seemed to indicate that the largest difference appeared between Grades 4 and 5. Indeed, a model in which two parameters were estimated, one for the relationship in Grades 2–4 and one for the relationship in Grades 5–6, provided a better fit to the data, $\Delta\chi^2(1) = 11.245$, $p = .001$. The relationship dropped from .354 in Grades 2–4 to .154 in Grades 5–6. In contrast, the relationship of RAN with pseudoword reading did not change significantly across grades. The estimated correlation was .318. Furthermore, a model in which the effect of RAN on pseudoword reading also changed after Grade 4 fitted the data but including this additional parameter did not result in an increase in model fit, $\Delta\chi^2(1) = 1.944$, $p = .163$. For PA, we found that its relationship with word reading did not change significantly across grades, nor did the relationships between PA and pseudoword reading. Taken together these findings indicated that changes in the relationship with RAN are different for word and pseudoword reading. The relationship of RAN with word reading decreased after Grade 4, whereas its relationship with pseudoword reading remained stable across grades. For PA, the relationships with word and pseudoword reading were also stable across grades.

TABLE 4
Standardized Parameter Estimates of the Relations Among PA, RAN, and Reading From the Multigroup Factor and Regression Models

	Grade				
Model/Relations	*2*	*3*	*4*	*5*	*6*
Factor model (correlations)					
Word ⟷ Pseudoword	.768**	.659**	.722**	.743**	.653**
RAN ⟷ PA	.410**	.269**	.228**	.148*	.335**
RAN ⟷ Word	.355**	.347**	.359**	.193*	.112
RAN ⟷ Pseudoword	.299**	.326**	.419**	.281**	.256**
PA ⟷ Word	.263**	.393**	.216**	.283**	.354**
PA ⟷ Pseudoword	.136	.171*	.159*	.237**	.284**
Regression model (betas)					
RAN → Word	.297**	.260**	.326**	.154*	−.007
RAN → Pseudoword	.293**	.302**	.402**	.252**	.181*
PA → Word	.141	.323**	.142*	.260**	.357**
PA → Pseudoword	.016	.090	.068	.201**	.223**

Note. PA = phonological awareness; RAN = rapid automatized naming.
$^*p < .05$. $^{**}p < .01$.

Finally, we examined the unique relations of RAN and PA with reading. The parameter estimates of this model are presented in Table 4. The unique relationship of RAN with reading showed a pattern similar to the overall correlations. RAN was a predictor of word and pseudoword reading in Grades 2 to 4. In Grade 5, the relationships decreased, and in Grade 6 the unique relationship of RAN with word reading was no longer significant. The relationship between RAN and pseudoword reading also decreased but not as strongly. The unique relationships of PA with reading showed a more mixed pattern. PA showed a nonsignificant or small unique relationship with word and pseudoword reading in Grades 2 to 4 that was smaller than the unique relationship with RAN, with the exception of the relationship between PA and word reading in Grade 3. In contrast, in Grade 5, and even more so in Grade 6, the unique relationship between PA and word and pseudoword reading increased and became stronger than the relationships between RAN and reading. When the equality of the specific relationships across grades was tested, most results were the same as for the overall correlations. The unique relationship of RAN, controlling for PA, with word reading decreased significantly after Grade 4, whereas its unique contribution to pseudoword reading remained stable across grades. For PA, controlling for RAN, its unique contribution to word reading remained stable across grades. However, unlike the results of the analyses on the overall relationships between PA and pseudoword reading, which remained stable, in the regression analyses the unique relation of PA and pseudoword reading was found to increase significantly between Grades 4 and 5.

DISCUSSION

In the current study we analyzed developmental changes in the relationships of both serial RAN and PA with reading in a large sample of Spanish children from second to sixth grade. Although many studies have focused on the effects of these variables on reading at different points in reading development, relatively few studies have directly studied developmental changes in the relations throughout development. Contrary to most previous studies we used discrete reading tasks instead of list reading. Performance on discrete reading tasks can more easily be interpreted in terms of underlying reading processes, thus enabling the interpretation of the changes in the relations of PA and RAN with reading also in terms of reading processes.

Our first research question, however, concerned the structure and measurement invariance of four regularly used measures of RAN. Fluctuations in the relations among the RAN measures, and therefore in the reliability of RAN scores, across grades could affect the relationship of RAN with reading. The results were straightforward. Confirmatory factors analyses revealed that the four RAN measures were most accurately described by an alphanumeric (letters and digits) and a nonalphanumeric (colors and objects) factor. This pattern was equal across grades. The relations between the two indicators of each factor also remained stable across grades. However, whereas digit and letter naming were equally strong indicators of alphanumeric naming, color naming was a stronger indicator of nonalphanumeric naming than picture naming.

The existence of stable alphanumeric and nonalphanumeric RAN factors since second grade differs from the findings of van den Bos and colleagues (van den Bos, Zijlstra, & Spelberg, 2002; van den Bos et al., 2003), to our knowledge the only studies in which the stability of the structure of RAN over time has been examined. In Dutch children from about the age of 10 they found that, as in the current study, an alphanumeric and a nonalphanumeric factor could be distinguished. At an earlier age, however, separate alphanumeric factors for digits and letters were found. Indeed, from the ages 8 to 11 the correlation between digit and letter naming increased from .53 to .72. Van den Bos et al. (2003) suggested that the dissociation of letter and digit naming in the early years of reading acquisition was due to the fact that in Dutch schools the learning of letter names is preceded by the learning of letter sounds. Therefore, although Dutch children are acquainted with the letter names, these are possibly not sufficiently familiar to enable automatic retrieval, as with digits. Spanish children are probably more familiar with letter names as they are acquired from the start of reading instruction alongside the acquisition of letter-sound knowledge. As a consequence, the relation between letter and digit naming is stable from an early age (here, second grade), and both naming tasks are related to the same underlying factor.

Next, we focused on the relationship of alphanumeric RAN and reading from second to sixth grade. As expected there was a decrease in the relation of RAN with word reading. Specifically, the relationship was stable until Grade 4 but decreased in Grades 5 and 6. In contrast, the relation of RAN with pseudoword reading remained stable across grades. This developmental pattern of relationships between RAN and reading remained the same after controlling for the effects of PA. With the exception of sixth grade, RAN had an independent effect on reading.

Of importance, discrete measures of word and pseudoword reading were used in the current study, unlike most previous studies, which have generally considered list reading speed. The findings of in these previous studies were equivocal, some finding an increase (e.g., Kirby et al., 2003; Vaessen & Blomert, 2010), whereas others have reported a decrease (e.g., Georgiou, Papadopoulos, Fella, & Parrila, 2012; van den Bos et al., 2003) in the relationship between RAN and reading. In contrast, the results of the few studies that used discrete reading tasks are more consistent (e.g., de Jong, 2011; Protopapas et al., 2013) in showing a decrease in the RAN–word reading relationship. The results of the present study were in line with these findings. We predicted that if the development of reading is (partly) due to a gradual change in reading strategy from a serial decoding strategy to the parallel processing of words, then the relationship between serial RAN and discrete reading should decrease. This is exactly what was found in both the current and previous studies (de Jong, 2011; Protopapas et al., 2013). A novel aspect of this study was the inclusion of a discrete pseudoword reading task. We did not expect a drop in the RAN–pseudoword reading relationship, because pseudowords are assumed to involve serial decoding (e.g., Coltheart et al., 2001). Indeed, the RAN–pseudoword reading relationship appeared to remain stable over the entire period from second to sixth grade.

These findings are in accordance with developmental theories of reading that suggests a progressive change from phonological recoding strategies to more automatic recognition of words (e.g., Share, 2008). Of interest, the findings also fit well with the DRC model of reading (Coltheart et al., 2001). This model of reading processes specifically concerns reading of monosyllabic words. Little is known about how polysyllabic words and pseudowords are processed. However, the current results suggest that predictions derived from a computational model about monosyllabic word and pseudoword reading seem to apply to the reading of polysyllabic items as well. The findings, together with the findings of Protopapas et al. (2013), suggest that, like monosyllabic words, polysyllabic words can be processed in parallel. Polysyllabic pseudowords, in contrast, seem to be processed serially.

It should be noted, however, that Protopapas et al. (2013) had a slightly different explanation for the decrease in the serial RAN–discrete word reading relationship. They proposed that serial tasks are increasingly approached with a cascaded processing strategy. This strategy becomes more efficient over time and allows for multi-element processing. Under this hypothesis a decrease in the RAN–discrete word reading relationship is also expected. Beginning readers would solve a serial-RAN task mainly by processing the symbols one by one, that is, as isolated symbols, similar to discrete word reading. As reading skill improves the amount of multi-element processing in serial RAN increases although the task remains serial. However, due to an increase in multi-element processing, the serial RAN task becomes increasingly dissimilar to the discrete word reading task as there is a limit to multi-element processing in the latter task. Thus, Protopapas et al. argued that it is the multi-item processing ability, more than the acquisition of orthographic knowledge, that underlies the relation of RAN with reading. However, if there is a general increase in multi-element processing, then a similar drop in the RAN–discrete pseudoword reading relationship might be expected. This was not found.

We also examined the developmental changes in the relationship of PA with reading. Studies in languages with a regular orthography have reported a decrease in this relation over time (e.g., Vaessen & Blomert, 2010). In contrast, we found that PA had, controlling for RAN, an independent effect on reading especially in the higher grades. We have no ready explanation for this finding, although it has been reported previously, especially for pseudoword reading (e.g., Kirby et al., 2003). It might be due to the lower effect of RAN on reading in the higher grades. In addition, familiar words were used in the PA tasks, which might have allowed the children to use their orthographic knowledge of the words to perform the task. The influence of orthographic knowledge on phonemic awareness tasks has been shown in several studies (Castles, Holmes, Neath, & Kinoshita, 2003; Castles, Wilson, & Colheart, 2011; Ehri & Wilce, 1980). As reading acquisition proceeds, the children might have become increasingly able to use orthographic knowledge resulting in a somewhat higher correlation between PA and reading. It should be noted that the relation between PA and reading was rather low in the early grades. Similar results have been found in other Spanish studies in which reading fluency was studied (Aguilar et al., 2010; Suárez-Coalla et al., 2013). When reading accuracy measures are used, the influence of PA on reading tends to be higher and significant (Defior, Serrano, & Martín-Cano, 2008).

To summarize, the contribution of the current study was twofold. First, we showed that stable alphanumeric and nonalphanumeric RAN factors can be distinguished from second to sixth grade, which differs from previous studies where this factor structure was only observed from Grade 4 onward (van den Bos et al., 2002). Second, we found, as hypothesized, that the relationship of RAN with discrete word reading decreased over time, whereas its relationship with pseudoword reading did not change. This developmental change in the RAN–reading relationship, which occurred around fourth grade, is taken to reflect a change in reading strategy of polysyllabic words from serial decoding to parallel processing.

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