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*Evidencia de un deterioro general del juicio del orden temporal auditivo y visual en niños con problemas de lectura**

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ABSTRACT

Objectives: This study examined visual and auditory processing of children with reading disabilities (RD) to determine whether they show an impaired ability to judge a reading-related process such as temporal order of events and clarify whether or not this deficit is linked to rapid processing deficit. Method: The performance of 16 children with RD was compared with the performance of children in two control groups – one for chronological age (CA) and one for the same reading level –, doing visual and auditory temporal order tasks, both with linguistic and non-linguistic stimuli with inter-stimuli-intervals of 50, 150, or 300 ms. Results: The RD group performance was lower than the performance of the CA group in tasks requiring auditory temporal order processing for linguistic and non-linguistic stimuli. Regarding visual tasks, the RD group performed worse than both control groups in processing non-linguistic stimuli. In general, performance in every group decreased with decreasing inter-stimulus-interval (ISIs), suggesting that children with RD do not have impairments in the speed of perceptual processing. Conclusions: The perceptual problems of children with RD are better explained by temporal order processing problems than by difficulties in rapid processing. Inclusion of temporal order processing tasks in the evaluation of children with RD is recommended.

Keywords: temporal processing, visual perception, auditory perception, rapid processing, dyslexia, learning disabilities, reading.

RESUMEN

Objetivos: Este estudio examina el procesamiento visual y auditivo de niños con dificultades de aprendizaje (DA) para determinar si muestran problemas en la habilidad para juzgar procesos relacionados con la lectura como el orden temporal de eventos y clarificar si su déficit está unido al del procesamiento rápido. Método: Se comparó el rendimiento de 16 niños con DA con el de dos grupos control, uno por edad cronológica (EC) y otro del mismo nivel lector. Realizaron tareas visuales y auditivas de orden temporal, ambas con estímulos lingüísticos y no-lingüísticos con un intervalo interestímulo de 50, 150 y 300 ms. Resultados: El rendimiento del grupo con DA fue inferior al grupo EC en las tareas que requerían procesamiento de orden temporal auditivo en los estímulos lingüísticos como no-lingüísticos. En la tarea visual, el rendimiento del grupo con DA fue inferior al de ambos grupos control en el procesamiento de estímulos no-lingüísticos. En general, el rendimiento de los tres grupos decrecía con la disminución de los intervalos interestímulos (ISIs), sugiriendo que los niños con DA no tienen problemas con la velocidad del procesamiento perceptual. Conclusiones: Los problemas perceptuales de los niños con DA se explican mejor por problemas en el procesamiento de orden temporal que por dificultades en el procesamiento rápido. Se recomienda la inclusión de tareas de orden temporal en la evaluación de niños con DA.

Palabras clave: procesamiento temporal, percepción visual, percepción auditiva, procesamiento rápido, dislexia, problemas de aprendizaje, lectura.

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Introduction

The term "temporal order judgment" (TOJ) refers to the ability to discriminate different stimuli presented rapidly in one order ("1–2") from the same stimuli presented rapidly in a different order ("2–1") (Fostick & Revah, 2018; Ronen *et al.,* 2018; Wang *et al.,* 2018). Several researchers propose that the mechanism for temporal ordering is independent of the sensory stimulus modality (Kanabus *et al.,* 2002; Tallal *et al.,* 1998). When children learn to read, they need to process the order of the letters in the words before their pronunciation is retrieved. The processing order of sounds is also important in speech perception and phonological abilities; thus, an impaired ability to judge the temporal order of events could interfere in reading (Liu *et al.,* 2019).

Tallal and colleagues (Tallal, 1980) were the first to observe that dyslexic children were deficient in their ability to discriminate between and reproduce the order of non-linguistic auditory stimuli presented rapidly. This deficit would hamper the creation and access to phonological representations, which, in turn, would hinder learning to read.

Numerous studies have examined the link between TOJ and reading impairment; however, empirical evidence concerning temporal order processing deficit is unclear. In the auditory modality, it has been found that dyslexic readers are impaired in speech temporal order processing (Muñetón *et al.,* 2017; Ortiz *et al.,* 2014; Rey *et al.,* 2002) and in the temporal order processing of tones (Laasonen *et al.,* 2001; Laasonen *et al.,* 2002; Lorusso *et al.,* 2014; Richardson *et al.,* 2004). In contrast, in the Breier et al. (2002) study, temporal deficits were found for syllables but not pure tone complexes in dyslexic children.

In the visual domain, Liddle *et al.* (2009) found that adults with dyslexia were significantly less sensitive to the temporal order of the non-linguistic visual stimuli than control participants. Jaśkowski and Rusiak (2008) also found performance on the non-linguistic visual TOJ tasks differed between dyslexic and typical-reading control subjects. Furthermore, Hairston *et al.* (2005) showed that dyslexic subjects required over 33% more time to perform at the same level of accuracy on the TOJ tasks. Other studies into the visual domain have not produced corroborative data (Laasonen *et al.,* 2001).

The notion of a TOJ requires evidence of the existence of deficits across modalities and stimuli. However, relatively few studies have used comparable methods to assess temporal order processing ability for both visual and auditory modalities in the same group of readers. In a longitudinal study, Steinbrink *et al.* (2014) investigated whether temporal order processing affects reading development regardless of modality. They measured both auditory and visual temporal order processing at the beginning of Grade 1 and the end of Grade 2 and found that auditory TOJ accounted for small but significant amounts of variance in reading, whereas visual TOJ made no independent contribution to the prediction of reading. Interestingly, other longitudinal studies showed developmental changes in the specific TOJ measures that predicted unique variance in reading. For example, Hood and Conlon (2004) found that the auditory TOJ tasks at both Preschool and Grade 1 are predictors of reading in Grade 1. In contrast, visual TOJ abilities measured at Preschool were not related to reading development, but, later, visual TOJ abilities measured at Grade 1 were; in the studies that examined this issue in individuals with reading impairments or dyslexia, the results are also mixed. Some studies have observed that temporal order deficits in

dyslexics are more pronounced in the auditory domain (Laasonen *et al.,* 2001), while others have not still obtained evidence of a modality effect (Cacace *et al.,* 2000; Chung *et al.,* 2008; King *et al.,* 2008; Laasonen *et al.,* 2002; Ortiz *et al.,* 2014). Consequently, it is necessary to clarify if children with reading disabilities present a problem with auditory and visual temporal order processing because it is related to the reading process.

The effect of the type of stimuli may be a possible explanation for the conflicting results. Some studies on auditory TOJ in reading disabilities have used both linguistic and non-linguistic stimuli. These found that children with RD performed more poorly on tasks using linguistic stimuli than children without RD, but the two groups performed similarly on tasks using non-linguistic stimuli (e.g., Breier *et al.,* 2002). Other studies on visual TOJ have also used both stimuli and found that poor readers required more time to make accurate TOJs regardless of stimulus type (Brannan & Williams, 1988). Some researchers have argued that the perceptual substrate processing of non-linguistic stimuli is not the same as speech processing (Ellis Weismer, 2005) and argue that the connection between deficits in processing skills of non-linguistic sounds and difficulties with speech sounds has not been demonstrated (Rosen, 2003). Despite that, in TOJ studies with both visual and auditory modalities, only non-linguistic stimuli were used (e.g., Chung *et al.,* 2008; King *et al.,* 2008; Laasonen *et al.,* 2001). Therefore, more studies evaluating the visual and auditory order processing of linguistic and non-linguistic stimuli in the same sample of people with reading disabilities are needed.

Moreover, the task difficulty can also be influenced by the duration of the inter-stimulus-interval (ISI) between the two successive stimuli, which refers to the time elapsed between the termination of one stimulus and the onset of a second one (later). On the one hand, Kanabus *et al.* (2002) demonstrated that distinct events require a temporal separation longer than 40 milliseconds to be perceived as successive, regardless of the sensory modality. However, the studies that examined temporal order processing ability of individuals with dyslexia on visual and auditory modalities also used ISIs lower than 40 ms (e.g., Chung *et al.,* 2008; King *et al.,* 2008; Laasonen *et al.,* 2001). On the other hand, it is possible that if the difficulty of the task is more pronounced when the presentation is more rapid, then underachievement in TOJ tasks might be due to a limited speed to process perceptual events across brief time intervals. Although Tallal (1980) found that children with dyslexia had difficulty in determining the order of two non-linguistic stimuli presented at short ISIs but not at long ISIs, several studies have not found any significant interaction between ISI and Group for the TOJ tasks (Breier *et al.,* 2002; Bretherton & Holmes, 2003; Chung *et al.,* 2008). Therefore, it is necessary to clarify whether the problems of TOJs are or are not linked to rapid processing. In an attempt to clarify this issue in the present study, TOJ tasks with short, medium, and long ISIs were presented.

To demonstrate the existence of a deficit of temporal order processing in children with reading difficulties, we employ an experimental design to compare the reading disabilities group with two control groups, one matched to chronological age (CA) and one matched to reading age (RL). The inclusion of a reading age control group is to account for the possibility that any differences found between groups are due to their reading expertise (for the importance of that comparison, see Goswami, 2003). Some studies with this design only examined the auditory temporal order processing of non-linguistic stimuli (e.g., Richardson *et al.,* 2004). Other studies explored the visual and auditory temporal order processing, but they did not use linguistic stimuli (e.g., Chung

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et al., 2008; King *et al.,* 2008). In both studies, the dyslexic group performed significantly worse than the CA but similar to the RL group. None of the studies with this design examined temporal order processing of linguistic stimuli despite the impact that a deficit of this type could have on the phonological representations involved in reading.

Intending to determine whether children with reading disabilities show an impaired ability to judge the temporal order of events, we compared the performance of children with RD with two control groups, one for CA and one for RL, in visual and auditory tasks with linguistic and non-linguistic stimuli. Thus, the presence of group-specific differences may reflect true TOJ difficulties with certain stimuli and/or modality characteristics.

This study goes beyond the existing knowledge for two reasons. First, the inclusion of linguistic and non-linguistic stimuli across modalities helps establish the generality vs. specificity of TOJs difficulties. Second, the presentation of TOJ tasks at short, average and long ISIs helps to clarify whether or not the deficits of TOJ are linked to rapid processing deficit. Taking the above into account, the predictions of this study are (1) if children with reading disabilities present a general problem with temporal order processing, their performance will be lower than the control groups in TOJ tasks across modalities and stimuli; and (2) if the problems of TOJs are linked to rapid processing deficiencies, we expect an interaction of ISI and group.

Method

Participants

Forty-eight children (27 male, 21 female) who were native Spanish speakers with an age range of 7 to 10 years (M = 108.08; SD = 14.24) participated in the study. These children attended second and fourth grades of primary schools. They were recruited from 10 schools located in urban areas with average socioeconomic backgrounds. In order to select children with RD for this study, first, teachers were asked to nominate children with RD; forty-eight children were nominated. Second, these children were tested on the word and pseudoword reading tasks of the PROLEC-R standardized reading skills test (Cuetos *et al.,* 2009), on a phonological awareness test (Jiménez, 1995), and a measure of nonverbal IQ (Cattell & Cattell, 2001). To ensure that they had a specific problem in reading ability, only those who fulfilled the following criteria were included in the study: a) reading efficiency score (accuracy/time of reading x 100) at least 1.5 standard deviations below the expected reading score for their age on at least one of the two reading tasks (word or pseudoword reading); b) a score at least 1.5 standard deviations below the expected score for their age on the phonological awareness test; c) IQ score was above 85; d) no reported history of language impairment; e) regular school attendance; f) have received supplementary reading support; g) absence of sensory deficits or neurological deficits. Thirty-two children did not reach all-inclusive criteria and were therefore excluded from the study: 6 children did not reach criterion a; 16 did not reach criterion b; 10 children had history of language impairments; and 10 had not received supplementary reading support. Accordingly, the RD group was composed of 16 children (see Table 1).

In addition to this group, two control groups were recruited from the same classrooms as the RD group. To begin this procedure, Grade 2 and 4 teachers from the same schools as the RD group nominated children who did not experience reading difficulties. These children were tested with the same tests of reading skills and intelligence. Finally, two control groups were selected: (1) a control group of 16 typical readers matched in age with RD group (CA),

with a reading efficiency score above or equal to the expected scores for their age on word and pseudoword reading tasks; and (2) a control group of 16 younger children with reading efficiency scores corresponding to their age on both tasks (RL; see Table 1). According to school records, all children had typical hearing.

Measures

Measure for selection of the groups

Reading. The word and pseudoword reading subtests of the PROLEC-R test (Cuetos *et al.,* 2009) were administered. We registered time and number of successes in the reading of 40 words and 40 pseudowords. Word and pseudoword reading efficiency was computed for each child (accuracy/ time of reading x 100).

Intelligence. (Cattell & Cattell, 2001). We used two scales depending on the age. We administered Scale 1 (Form A) to the RL group (age 7), and Scale 2 (Form A) was administered to the RD and CA groups (ages 9-10).

Phonemic Awareness. In order to assess the phonemic awareness of the children with reading difficulties, the Phonemic Awareness Test (Jiménez, 1995) was administered; this consists of four tasks: phonemic synthesis, phonemic isolation, phonemic segmentation of words, and omission of phonemes in words. There were ten words presented in each task.

Descriptive measures

Attention. We used the Magallanes Scale of Visual Attention (EMAV-1; García & Magaz, 2008) to measure attention in RL group and D2 Test (Brickenkamp, 1997) to measure attention in RD and CA groups. Age ranges of participants forced two different tests to be used. The D2 Test of Attention only can be applied from 8 years old (as RD and CA groups), but the EMAV-1 is intended for evaluation of children between the ages of 5 and 8 years old (as RL group). Both are timed tests of visual attention. The child must distinguish and mark all elements that match the model that they are able to do in a certain amount of time.

Memory. The Digit Test subtest of the WISC-IV (Wechsler, 2005) was applied. In this task, the child repeats a series of numbers (in the same order of presentation and then in reverse order) that the evaluator presents verbally.

Discrimination of sounds of the environment. One subtest of the EDAF test (Brancal *et al.,* 1998) was administered. In this subtest, the children listened to a sound from the computer and had to match the sound heard with one of four different pictures. There were 15 sounds presented.

Experimental tasks: perceptual processing stimuli and tasks

TOJ tasks (TOJ). In these tasks, subjects distinguished the order of presentation of two stimuli. The children's task was to indicate which stimulus was presented first. Inter-Stimuli-Interval (ISI) used in each pair varied from 50, 150, or 300 ms. Participants indicated their response by pressing a key on the keyboard where a picture related to the stimulus was (for example, duck or mouse in auditory non-linguistic TOJ). There were four TOJ tasks: auditory non-linguistic (ANL), auditory linguistic (AL), visual non-linguistic (VNL), and visual linguistic (VL). Each TOJ task consisted of three phases. At the beginning of each one, subjects were trained to respond to each separate stimulus (a tone, a syllable, a letter, or a non-linguistic visual stimulus) by pressing the proper response key. A block of 20 trials with feedback was presented.

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If the participants reached 75% correct responses, the program ran the next phase, where they practiced with the examples of the task. Participants were given a block of 10 examples (with 600-ms ISI). If they achieved 70% correct responses, the program ran the evaluation phase where eight trials for each of the three ISIs were (50, 150, and 300 ms). If they did not satisfy this criterion, the computer continued the presentation of examples in blocks up to four blocks; and if the participant did not pass the example blocks, the program ended. In this study, all participants exceeded the criteria, and no children were excluded from the study for this reason. Each TOJ evaluation task consisted of 24 trials.

Auditory stimuli. All auditory stimuli were matched in intensity, and the fixed reference duration was 200 ms. We used two types of stimuli: (1) ANL: Two 200-ms-long tones readily recognizable as a mouse squeak (470 Hz) and a duck quack (260 Hz) were presented in pairs separated by varying ISIs. (2) AL: Stimuli were two spoken CV syllables that differed in voicing (/pa/ and /ba/). Those stimuli were studio recordings of a female voice and presented via earphones, according to the procedure presentation (/pa/-/ba/, /ba/-/pa/, /ba/-/ba/, /pa/-/pa/). Cronbach's alpha reliability coefficient in our sample was .73 for the non-linguistic task and .72 for the linguistic task.

Visual stimuli. There were two types of stimuli. (1) VNL: Two visual stimuli without linguistic content, which differed only in the presence or absence of one visual feature, were presented (). There were four pairs presented in random order. (2) VL: A pair of letters (A / a) appeared serially on the screen. There were four pairs presented (A-a, a-A, a-a, A-A) in random order. In all visual tasks, the second stimulus of the pair was presented in the center of the screen, the same location as the first stimulus. Cronbach's alpha reliability coefficient in our sample was .73 for the non-linguistic task and .81 for the linguistic task.

Procedure

All children were tested individually by three psychologists in a quiet room in their school in three sessions, each one lasting approximately 30–35 minutes. The order of tests was: intelligence test, phonemic awareness test (only RD group), PROLEC-R test, three TOJ presented randomly, memory test, three TOJ, discrimination of sounds of environment test, attention test, and two TOJ.

Table 1. Means and standard deviation for age (in months), IQ, memory, attention, discrimination of sounds of the environment, phonemic awareness and word and pseudoword reading efficiency by groups

	Groups							
	RD group (n = 16)		RL group (n = 16)		CA group (n = 16)		F- Value	Post-hoc
	Mean	SD	Mean	SD	Mean	SD	F(2, 45)	Tukey HSD
Age in months	119.31	6.62	89.31	3.47	115.62	3.03	197.32***	RD = CA RD > RL RL < CA
IQ	96.81	9.37	106.75	11.36	112.68	13.05	7.97***	RD < CA RD = RL RL = CA
Memory	5.06	1.28	5.37	1.14	6.43	1.31	5.29*	RD < CA RD = RL RL = CA

	Groups							
	RD group (n = 16)		RL group (n = 16)		CA group (n = 16)		F- Value	Post-hoc
	Mean	SD	Mean	SD	Mean	SD	F(2, 45)	Tukey HSD
Attention	40.12	29.50	55.62	21.04	76.31	18.45	9.56***	RD < CA RD = RL RL < CA
Discrimination of sounds of the environment	13.56	0.72	13.00	1.71	14.00	1.06	1.80	RD = CA RD = RL CA = RL
Word Reading Efficiency	60.70	20.81	61.33	20.33	125.72	19.98	53.77***	RD < CA RD = RL RL < CA
Pseudoword Reading Efficiency	32.75	9.57	40.41	9.90	64.48	12.11	39.11***	RD < CA RD = RL RL < CA
Phonemic Awareness	10.48	0.64	89.31					

Note. RD = reading disabilities; CA = chronological-age matched; RL= reading-level matched.

*p <.05. ***p <.001.

Source: authors

Ethics statement: This study was performed following the recommendations of the Ethics Committee of the University of la Laguna, Spain, and the declaration of Helsinki. Written consent was obtained from the parents of all children.

Conflict of interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Results

Two types of analysis were executed. The first one compares the performance of literacy and cognitive skills across the three groups. And the second one compares each task on the function of the modality and type of stimuli.

Literacy and cognitive skills

To compare the groups in literacy and cognitive skills an ANOVA was performed (see Table 1). Group differences were found in Age $F(2, 45) = 197.32$, $p < .001$; Intelligence $F(2, 45) = 7.97$, $p < .001$; Memory $F(2, 45) = 5.29$, $p = .009$; Attention $F(2, 45) = 9.56$, $p < .001$; Word Reading Efficiency $F(2, 45) = 53.77$, $p < .001$; and in Pseudoword Reading Efficiency $F(2, 45) = 39.11$, $p < .001$; but not for Discrimination of sounds of the environment $F(2, 37) = 1.80$, $p = .179$]. *Post hoc* tests showed that RD group had significantly lower scores than chronological-age matched group in IQ ($p < .001$), Attention ($p < .001$), Memory ($p = .009$) and reading measures ($p < .001$). There were no differences between the RD group and reading-level matched group in IQ, Attention, Memory ($p = .045$; $p = .160$; $p = .761$, respectively) and reading measures.

Comparison of the reading disabilities group and the control groups on TOJ

Four separate analyses of variance were performed for each task considering the modality (auditory, visual) and type of stimuli (linguistic, non-linguistic).

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Temporal order tasks

A repeated-measures analysis of variance (ANOVA) with between subject factor Group (RD vs CA vs RL) and within subject factor ISI (50, 150 and 300) was carried out on temporal tasks accuracy.

Due to unexpected inequivalence of IQ, Memory, and Attention of the three groups prior to the analysis, the assumptions for ANCOVA were examined. Results showed that IQ were not significantly associated with AL $F(1,41) = 2.92$, $p = .095$, $\eta^2 = .067$; ANL $F(1,42) = 0.091$, $p = .765$, $\eta^2 = .002$; VL $F(1,42) = 0.932$, $p = .340$, $\eta^2 = .022$ and VNL $F(1,42) = 1.206$, $p = .278$, $\eta^2 = .028$. The same pattern was found in Memory in AL $F(1,42) = 0.466$, $p = .499$, $\eta^2 = .011$; ANL $F(1,42) = 0.570$, $p = .454$, $\eta^2 = .013$; VL $F(1,42) = 0.379$, $p = .541$, $\eta^2 = .009$ and VNL $F(1,42) = 0.265$, $p = .609$, $\eta^2 = .006$. And the same pattern was found for Attention in AL $F(1,42) = 0.18$, $p = .894$, $\eta^2 = .001$; ANL $F(1,42) = 0.277$, $p = .601$, $\eta^2 = .007$; VL $F(1,42) = 2.049$, $p = .160$, $\eta^2 = .047$ and VNL $F(1,42) = 0.231$, $p = .633$, $\eta^2 = .005$. Results showed that it was unnecessary to use those measures as covariates. So, analyses of variance (group by ISI) were carried out for TOJ tasks (see Table 2).

Table 2. Means and Standard Deviations of the RD group, RL control group, and the CA control group by ISI (ms) in each task and the F values for group differences on TOJ Accuracy

	Groups					
	RD M (SD)	RL M (SD)	CA M (SD)	F	η^2	Tukey post hoc p<.05
Auditory Linguistic TOJ				4.086*	.157	RD < CA
50	0.79(0.22)	0.94(0.10)	0.92(0.08)			
150	0.82(0.12)	0.90(0.09)	0.93(0.12)			
300	0.88(0.20)	0.93(0.09)	0.94(0.07)			
Auditory Non-linguistic TOJ				6.02**	.211	RD < CA
50	0.82(0.16)	0.88(0.14)	0.93(0.11)			
150	0.80(0.18)	0.87(0.12)	0.97(0.05)			
300	0.89(0.11)	0.92(0.10)	0.97(0.05)			
Visual Linguistic TOJ				7.00**	.237	RD < CA
50	0.73(0.17)	0.85(0.13)	0.93(0.06)			
150	0.82(0.19)	0.85(0.17)	0.97(0.06)			
300	0.81(0.19)	0.89(0.15)	0.96(0.07)			
Visual Non-linguistic TOJ				5.08**	.184	RD < RL RD < CA
50	0.76(0.18)	0.90(0.12)	0.89(0.13)			
150	0.83(0.14)	0.93(0.07)	0.93(0.11)			
300	0.88(0.20)	0.94(0.07)	0.94(0.07)			

Note. RD = reading disabilities; RL= reading-level matched; CA = chronological-age matched. Standard Deviations appear in parentheses below means.
***p< .001. **p< .01.

Source: authors

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Auditory linguistic TOJ task

For AL TOJ tasks, there was a significant effect of group $F(2,45) = 4.08$, $p = .024$, $\eta^2 = .157$. Tukey post-hoc analysis indicate that the RD group performed significantly worse than CA ($p = .033$).

Auditory non-linguistic TOJ task

For AL TOJ tasks, there was a significant effect of group $F(2,45) = 6.02$, $p = .005$, $\eta^2 = .211$ and a significant effect of ISI $F(2,90) = 5.22$, $p = .007$, $\eta^2 = .104$. With respect to group post hoc analysis showed that RD group performed significantly worse than CA group ($p = .003$). With respect to ISI, paired test comparison showed that children performed better in 300 ms than in 50 ms ($p = .008$) and 150 ms ($p = .009$) ISIs.

Visual linguistic TOJ task

For VL TOJ tasks, there was a significant effect of group $F(2,45) = 7.00$, $p = .002$, $\eta^2 = .237$ and a significant effect of ISI $F(2,90) = 4.34$, $p = .016$, $\eta^2 = .088$. With respect to the significant effect for group, post hoc analysis showed that RD group performed significantly worse than CA group ($p = .001$). With respect to ISI, paired test comparison showed that children performed better in 300 ms ($p = .022$) and 150 ms ($p = .010$) ISIs than in 50 ms ISI.

Visual non-linguistic TOJ task

For VNL TOJ tasks, there was a significant effect of group $F(2,45) = 5.08$, $p = .010$, $\eta^2 = .184$ and a significant effect of ISI $F(2,90) = 5.24$, $p = .007$, $\eta^2 = .104$. With respect to group, post, hoc analysis showed that the RD group performed significantly worse than CA ($p = .010$) and RL ($p = .007$) groups. With respect to ISI, analysis showed that children performed better in 300 ms ($p = .032$) and 150 ms ($p = .007$) ISIs than in 50 ms ISI.

Discussion

The present study has been designed to determine whether children with reading disabilities show an impaired ability to judge the temporal order of events. The results revealed that visual and auditory TOJs (with linguistic and non-linguistic stimuli) are problematic for children with RD and that the difficulty is not related to the ISI.

The performance of children with RD showed that the processing deficits are not specific to linguistic stimuli. The impairments in auditory non-linguistic TOJ are consistent with the results found in several studies that showed problems in the temporal order processing of tones in children with reading difficulties (i.e., Chung *et al.,* 2008; King *et al.,* 2008; Lorusso *et al.,* 2014; Richardson *et al.,* 2004) and adults with dyslexia (i.e., Laasonen *et al.,* 2001; 2002). The RD group showed the same pattern of response to ISI as the control groups. The performance of RD children was lower than age-matched controls in auditory linguistic TOJ with independence of ISI. This result is consistent with the findings of studies that show impairment in linguistic stimuli temporal order processing in children with dyslexia (e.g., Ortiz *et al.,* 2014; Rey *et al.,* 2002). However, the children with RD did not differ in auditory TOJ performance from their reading level controls. Similar findings have been shown in previous studies (e.g., Chung *et al.,* 2008; King *et al.,* 2008).

Concerning visual temporal order processing, the current study shows the RD group performed worse than both control groups in processing non-linguistic stimuli. The results agree with those found in children with RD (Brannan & Williams,

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1988; Chung *et al.,* 2008; Kibby *et al.,* 2015; King *et al.,* 2008), young with dyslexia (Jaśkowski & Rusiak, 2008), and adults with dyslexia (Hairston *et al.,* 2005; Laasonen *et al.,* 2001; 2002; Liddle *et al.,* 2009). In the present study, the children with RD also performed worse than the age control group in tasks requiring visual TOJs of linguistic stimuli. Thus, the results suggest the generality of the problems of visual temporal order processing in individuals with reading disabilities. These findings are convergent with the results found in the study of Brannan and Williams (1988), whose poor readers required more time to make accurate TOJs regardless of stimulus type.

The problem with TOJ was shown in auditory and visual modalities. This finding is in accordance with the study of Cacace et al. (2000) that showed that children of 9 to 11 years old with reading impairments had deficits in temporal-order discrimination, but these effects were not modality-specific. Similar results can also be seen in other studies with children (Chung *et al.,* 2008; King *et al.,* 2008) and adults with dyslexia (Francisco, Jesse, Groen & McQueen, 2017; Laasonen *et al.,* 2002). Therefore, concerning the debate as to whether there is one central mechanism or different mechanisms for the judgment of temporal order, our results support that the mechanism for temporal ordering is independent of the sensory modality.

In three of the four TOJ tasks, the analysis showed that the RD group performed significantly worse than the CA group, but no differences were found between RD and RL groups. Performance on TOJ could improve with age; thus, it is likely that when compared to a younger group of reading matched controls, the deficit of older children with RD may not be apparent.

The analysis of the interstimulus interval revealed that children with RD presented impairments in linguistic auditory temporal order tasks regardless of ISIs used between each of the two stimuli in the pair. This result does not support the predictions of Tallal (1980) that shorter ISIs would better differentiate between the low achieving and typical readers. For the other visual and auditory temporal order tasks, we found that for all groups, performance generally decreased with decreasing ISI. Results of our study are consistent with previous research (Breier et al, 2002; Bretherton & Holmes, 2003; Chung *et al.,* 2008) that did not find any significant interaction between ISI and group for the temporal order discrimination tasks. Thus, the poor performance of children with RD in the TOJ task is not due to a deficit in the speed of perceptual processing of stimuli presented with short intervals between them. These findings do not support the argument that children with RD require significantly more time between stimuli when judging their temporal order, as compared with typical readers suggesting that children with RD do not have a deficit in the rapid processing of information. In summary, the results of this study show that the poor performance of children with RD on TOJ tasks cannot be explained by a problem of timing.

The present study has certain methodological limitations. The sample size was relatively small. To test the generalization of findings, future studies should increase the sample size. Another limitation is that the included ISIs (50, 150, and 300 ms) represent large intervals between them. An adaptive procedure or smaller sequentially fast stimuli would provide more detailed information about individual differences.

Regarding the practical implications of this study, there appears to be enough evidence to recommend the inclusion of temporal order processing tasks to evaluate children with reading difficulties.

Conclusion

We have demonstrated in this study that children with reading disabilities present TOJs difficulties in visual and auditory domains with linguistic and non-linguistic stimuli. The interstimulus interval does have an effect on TOJs performance, but this effect is similar in the groups. The findings may be interpreted in terms of the idea that children with RD show processing deficits across modalities and stimuli which are "temporal order" in their nature. The temporal order difficulties could interfere with the sequential processes involved in word reading.

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