Visual and Auditory Temporal Processing in Primary School Children*

Візуальна та слухова часова обробка у дітей молодшого шкільного віку**

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* This project was supported by the University of Antioquia, Colombia as part of the “Validation of a test of auditory and visual, linguistic and non-linguistic perceptual processes in primary school children in the city of Medellín” (Validación de una prueba de procesos perceptivos auditivos y visuales, lingüísticos y no lingüísticos en niños escuela primaria en la ciudad de Medellín) [CODI Acta-2017-16156] project in the Psycholinguistics and Prosody Research Group.

** Цей проект був підтриманий Університетом Антіокії, Колумбія, в рамках проекту “Валідація тесту слухових і зорових, мовних і немовних перцептивних процесів у дітей молодшого шкільного віку в місті Медельїн” (Validación de una prueba de procesos perceptivos auditivos y visuales, lingüísticos y no lingüísticos en niños escuela primaria en la ciudad de Medellín) [CODI Acta-2017-16156] у дослідницькій групі психолінгвістики та просодії.

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ABSTRACT

**Purpose.** Temporal processing shows an evolutionary character in accordance with age and schooling. The purpose of this study is to analyze the role of temporal processing in children in different grades in primary school.

**Methods.** 470 children (aged 5–13), in five school grades, were compared to a Temporal Order Judgment. Similar visual and auditory, linguistic, and nonlinguistic stimuli were presented to them. A three-factor repeated measure multivariate analysis of variance was used to examine the effects of Grade (1° vs. 2° vs. 3° vs. 4° vs. 5°) x Stimulus (Linguistic vs. Nonlinguistic) x Modality (Visual vs. Auditory).

**Results.** These three factors have significant interactions. Auditory-nonlinguistic tasks were easier than auditory-linguistic tasks in every grade. Visual-nonlinguistic tasks were easier than visual-linguistic tasks in higher grades, and 1st grade differed significantly from the other school grades in all cases. The higher the school grade, the better the performance of TOJ tasks. Visual-linguistic tasks were easier than auditory-linguistic tasks.

**Conclusions.** The present study provides evidence concerning the progressive nature of temporal processing among primary school children. This development trajectory is particularly noteworthy for students in lower primary school grades. Furthermore, the Temporal Order Judgment (TOJ) task exhibited robust experimental support, rendering it a valuable tool for assessing temporal processing within conventional school populations. This task offers the potential to assess TP across auditory and / or visual modalities, with diverse types of stimuli (linguistic vs. non-linguistic). Finally, the auditory modality, and especially the auditory linguistic modality, showed greater sensitivity depending on the school grade.

**Key words:** psycholinguistics, temporal process, perception, primary (elementary) school children, cognitive processes.
Introduction

A temporal process (TP) refers to the ability to perceive temporal information, such as duration, sequence, and rhythm in a short time (Farmer & Klein, 1995; Heath & Hogben, 2004a; Marcotti & Alvear, 2019; Mody et al., 1997; Muñetón et al., 2017; Ortiz et al., 2014; Ronen et al., 2018; Tallal, 1980; Wang et al., 2018). This information can differ by modality (visual, auditory) and type (linguistic or nonlinguistic).

On one hand, this ability holds significance in daily life due to the demand for rapid information processing such as conversation, music listening, and sound locating (Cañete, 2006; Ronen et al., 2018). On the other hand, the temporal process plays a fundamental role in perception, since all other perceptual processes depend on it (Marcotti & Alvear, 2019).

Equally important is the evidence of the gradual development of the TP. For instance, in the auditory domain, newborn babies have auditory abilities, however, some auditory aspects as intensity, frequency, and TP develop during the first six months of life. Babies need from 25 to 40 msec to detect silence. In contrast, adults need only three (3) msec. This suggests that babies have poor abilities when it comes to quickly detecting sound changes compared to adults’ ability to do the same (Werner, 2002; Werner et. al., 2001). Evidence to support this idea can also be seen in the case of Inter-Stimuli-Interval (ISI): babies in their 6th month need 20 msec to detect changes in duration of ISI in sequences of auditory stimuli, children younger than nine (9) years of age need longer ISI between two auditory stimuli than older children do. According to research (Farmer & Klein, 1995), children between five (5) to 12 years of age need 15 msec to do the same while adults need only 10 msec.

In the visual domain, human beings are born with certain processing skills, including movement perception and organization. However, some neural mechanisms and visual perceptual skills are not present at birth but instead develop in critical periods, thanks to maturation, contextual knowledge, and experience (Frostig, 2009; Parrish et al., 2005; Pires et al., 2014; Vihman, 2014).

During primary school, TP develops alongside perceptual and cognitive skills. Domínguez (2017) and Gallegos (2010) found that older
children in upper school grades had higher performance of and shorter execution times for perceptual tasks than younger children did. In this period, TP is related to phonological processes and reading acquisition. From this perspective, school children with low performance in TP tasks also present low performance in reading tasks. This suggests that a TP deficit contributes to phonological issues hindering reading skill acquisition (Benasich & Tallal, 2002; Cacace et al., 2000; Casini et al., 2018; Cestnick & Jerger’, 2000; Hautus et al., 2003; Johnson et al., 2007; Laasonen et al., 2002; Luque et al., 2008; Muñetón et al., 2017; Ortiz et al., 2014; Rey et al., 2002; Ronen et al., 2018; Vandermosten et al., 2011; Vásquez, 2013; Wang et al., 2018).

Several studies have demonstrated the connection between phonological processes and reading difficulties (Benasich & Tallal, 2002; Camargo, 2006; Cestnick, 2001; Cuetos, 2010; De los Reyes et al., 2008; E.-Jiménez et al., 2004; Escotto, 2014; Etchepareborda & Habib, 2001; Feld, 2015; Ferreres & Jacobovich, 2003; Klatte et al., 2018; Meneses et al., 2012; Mody et al., 1997; Rueda & Sanchez, 1996; Valdivieso, 2000). However, the causes of the phonological process difficulties remain unclear. Some studies suggest TP as a cause, others propose the problem lies in speech perception, rather than TP.

This debate regarding the relationship between TP and reading is the most studied aspect of TP. Furthermore, reading as a crucial skills for school learning (Cavallo et al., 2011; Cuetos, 2010; Jiménez et al., 1999; Kennedy et al., 2000; Klein, 2002). Therefore, it is important to understand the empirical results regarding this relationship. The evidence was researched and organized based on the stimulus type and perceptual modality.

(1) Five studies on auditory modality with linguistic stimuli were found (Luque et al., 2011; Ortiz et al., 2008; Ortiz, Estévez, & Muñetón, 2014; Rey et al., 2002; Snowling et al., 2018). The studies by Ortiz, Estévez, and Muñetón (2014) and Rey et al. (2002) analyzed school children with dyslexia as well as typical readers, but the first study was conducted in a transparent language (Spanish) while the second was carried out in an opaque language (French). Both studies used TOJ tasks with different ISIs. They found that school children with auditory TP deficits have reading problems. The research by Snowling et al. (2018) analyzed preschool children at family risk of dyslexia, among native speakers of English; and Luque et al. (2011);
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and Ortiz et al. (2008) studied Spanish school children between eight (8) and 12 years of age. These three studies found that difficulties in reading are related to a speech perception deficit. Luque et al. (2011) also analyzed TP but failed to identify a relationship between TP and reading problems.

(2). Eight studies focused on the auditory modality with no linguistic stimuli (Benasich & Tallal, 2002; Boets et al., 2006; Cestnick & Jerger', 2000; Fostick & Revah, 2018; Hautus et al., 2003; Heath & Hogben, 2004a, 2004b; Share et al., 2002). Results shared by (Fostick & Revah, 2018; Hautus et al., 2003; Benasich & Tallal, 2002; Cestnick & Jerger', 2000) suggest that TP is in the cause of phonological and reading difficulties. These studies are similar to one another because they used TP tasks, in general TOJ, with short and long ISIs, and they were divided into control and experimental groups. However, there are differences in the populations studied: Fostick and Revah (2018) evaluated university students who speak Hebrew and their experimental group was diagnosed with dyslexia. Hautus et al. (2003) evaluated English-speaking schoolchildren and university students with and without dyslexia, Benasich et al. Tallal (2002) evaluated 6- to 36-month-old infants with English as their native language, and Cestnick and Jerger (2000) evaluated schoolchildren in the critical stage of reading acquisition who spoke English as their native language. In contrast, Boets et al. (2006), Heath and Hogben (2004a), Heath and Hogben (2004b), and Share et al. (2002) found no correlations between a deficit in TP and reading. Also, in this case, all studies, except one in Dutch (Boets et al, 2006), were carried out in opaque languages, specifically in English. The studies by Heath and Hogben (2004a), and Boets et al. (2006) were conducted on preschoolers, those by Heath and Hogben (2004b), and Share et al. (2002) on schoolers. Finally, it should be noted that although these studies found no correlations between TP and reading, Boets et al. (2006) found that frequency and pitch discrimination tasks were significantly related to phonological awareness. In addition, Share et al. (2002) found that early temporal deficits (long ISI) predicted later difficulty in receptive vocabulary in 1st grade and poor reading comprehension in 2nd grade.

(3). Eight articles examine auditory modality with linguistic and no linguistic stimuli, (Gallegos, 2010; Johnson et al., 2007; Luque et al., 2008; Mody et al., 1997; Muñetón et al., 2017; Ronen et al., 2018;
Vandermosten et al., 2011; H.-L. Wang et al., 2016). All these studies, apart from that conducted by Mody et al. (2007), coincide in terms of the relationship between auditory TP and reading. This might suggest at the outset that, although auditory TP development is faster than visual, the parameterization of tasks with both stimuli may be more controlled and thus yield similar results. On the one hand, these studies were conducted in different opaque and transparent languages and mostly with preschool and school-aged populations. On the other hand, most of these studies used temporal discrimination and/or TOJ tasks. Those using TOJ tasks considered different ISIs, so that they were able to compare the effects of long vs. short ISIs. One aspect of the aforementioned studies that differs is that two of these investigations evaluated typically developing populations: Wang et al. (2016), children between four (4) and five (5) years of age, and Gallegos (2010), eight (8) to 11 years. Moreover, four of these studies (Johnson et al., 2007; Muñetón et al., 2017; Ronen et al., 2018; Wang et al., 2016) found that auditory TP was related to speech perception. This suggests that reading was related to the ability to temporally process auditory speech stimuli and not to other types of stimuli.

In opposition to the hypothesis of auditory TP deficit, Mody et al. (1997) showed no correlation between auditory TP and reading difficulties, although they observed a correlation with speech perception. Therefore, according to the authors, some relationship seems to exist between rapid nonverbal TOJ performance, pitch, and phonological decoding in reading ability. However, the relationship is statistical, but its functional basis remains uncertain.

(4). Two examined visual modality with no linguistic stimuli (Ison & Korzeniowski, 2016; Skottun & Skoyles, 2010). Analyzing these studies suggests that the visual perception is related to reading ability, both in typically developing school children and adults with and without dyslexia, in Spanish and in English. Despite this, and the fact that the number of subjects is significant in both studies, it must be recognized that there are many methodological differences in the studies. This has two sides: it could indicate that visual perception does indeed affect reading in different populations and for different tasks, or, that in addition to visual perception there are other aspects that intervene in both the assessment and visual perception results. In contrast, regarding the hypothesis of a causal relationship between visual TP and reading,
Skottun and Skoyles (2010), found no correlations supporting a causal link between visual TP and reading, suggesting that reading difficulties are due to non-temporal visual characteristics.

(5). Three articles focused on visual modality with linguistic and no stimuli (Coalla & Vega, 2012; Lachmann et al., 2012; Wu et al., 2015). The results of Lachmann et al. (2012) and Wu et al. (2015) concur in attributing importance to the development of visual perception in reading in typically developing individuals. The former in adults and the latter in preschool children. Both studies were conducted in iconographic languages, Mandarin and Hindi, respectively, and used figure and grapheme identification tasks. In contrast, the study by Coalla and Vega (2012) argues against the relationship between a deficit in visual perception and reading difficulties. Notable, this study, conducted in a transparent language, did not find correlations between general visual perception and reading, but did identify them when the stimuli were linguistic. One possible explanation could be that phonological processing failures are related to difficulties in visual perception of linguistic stimuli. If this were the case, it would imply a greater complexity in the processing of linguistic visual stimuli compared to non-linguistic ones, and a probable causal relationship between linguistic visual perception and phonological processing.

(6). Six studies addressed auditory and visual modality with linguistic stimuli or no linguistic stimuli. One of them, which uses only linguistic stimuli found a relationship between speech perception and reading (Erdener & Burnham, 2013). The others used non-linguistic stimuli and all agreed on the relationship between speech perception and reading (Cacace et al., 2000; Hood & Conlon, 2004; Laasonen et al., 2002; Steinbrink et al., 2014; Wang et al., 2018). Erdener and Burnham (2013) found correlations between speech perception and reading skills in a typically developing English speaking population of school children and university students. It is worth noting that this study had 154 participants; moreover, it allows us to observe the relationship between speech and reading, the complexity of speech perception in its auditory and visual modalities, and the developmental nature of speech perception and reading. Apropos of auditory and visual modalities with non-linguistic stimuli, the results of Wang et al. (2018), Steinbrink et al. (2014), Hood and Conlon, (2004), Cacace et al. (2000) and Laasonen et al. (2002) agree that TP correlated with reading. The study by Wang et al. (2018) was conducted in an iconographic language,
and the others in opaque alphabetic languages. Most assessed primary school children, apart from Laasonen et al. (2002), who assessed young adults. All used TOJ tasks, except for Cacace et al. (2000) who used discrimination tasks with different ISIs.

(7). Five articles explored both auditory and visual modality using linguistic and nonlinguistic stimuli (Au & Lovegrove, 2001a, 2001b; Casini et al., 2018; Ortiz, Estévez, Muñetón, et al., 2014; Vásquez, 2013). All these studies agree on the relevance of TP for reading acquisition. One aspect that is evident and could explain this convergence of results is that these studies share several methodological features: (1) they analyzed both modalities and stimulus types; (2) they used computerized TOJ tasks with short and long ISIs, and as a control task, they used ID tasks; (3) they controlled stimulus complexity, taking into account differences in transduction and stimulus type; (4) although not presented in this exposition, all these studies used diagnostic tasks of IQ, phonological awareness, and word and pseudoword reading. They also presented differences (a) in the developmental stage of the participants: the first three were carried out with preschool and school populations; (b) in the language in which they were conducted, the studies by Ortiz et al. in Spanish (2014); that conducted by Vásquez (2013); Au and Lovegrove (2001a, b) in English; and Casini et al. (2018) in French. These differences in population and language characteristics show that temporal processing can be involved in reading at different developmental stages, in both transparent and opaque languages.

In addition, it should be noted that studies by Casini et al. (2018) and Vásquez (2013) found a relation between specific temporal deficits in speech. Both studies also indicate that differences were found between auditory and visual temporal processing, and between linguistic and non-linguistic stimulus type. One possible explanation could be that suggested Farmer and Klein (1995), who indicate that these types of studies could indicate that TP difficulties are the result of linguistic difficulties because children with these difficulties have less experience with language and, therefore, less practice in integrating information quickly in the auditory modality.

Overall, the presented evidence shows a general agreement among studies that TP and reading are related. Even in cases where there’s no direct correlation between overall TP and reading, a relationship is found between certain temporal tasks and phonological processing.
The differences in findings are attributed to methodological variations: (1) Studies use different modalities (visual or auditory). Therefore, it is difficult to generalize the result from one modality to all TP modalities. Even if both modalities need a similar time of presentation permanence exposure to be processed, the processing of each input is different: auditory input is faster than visual (Burr et al., 2009; Recanzone, 2009). (2) Studies use different stimuli (linguistic or nonlinguistic). It is not possible to compare the results for this particular aspect. In the case of linguistic auditory stimuli, the fundamental frequency (F0) and speed of language perception allow the decoding of the stimulus in the perceptual process and lead to the creation of mental representations. In the case of linguistic visual stimuli, aspects of the grapheme such as size, continuity, and spacing are different from other shapes or images in the context while nonlinguistic auditory and nonlinguistic visual stimuli do not present this level of specificity. (3) Different tasks. The researchers used different temporary tasks, including Temporal Order Judgment (TOJ), ID, Gap detection, AXB-type tasks. Specifically, the TOJ tasks used short, medium, and long ISIs, but the duration of these intervals was different. The use of SOA* was also observed as a temporary control measure in some cases, but the studies that used it had different parameters. Finally, the duration of the stimuli varied considerably from one study to another. (4) There is no typification of temporal processing. Auditory and visual TP typification measures have not been established for linguistic and nonlinguistic stimuli in the school population with typical reading development for either transparent or opaque languages. Consequently, there is no point of comparison to establish when TP (auditory and visual, linguistic and nonlinguistic) indicates adequate development and when this development is related to the acquisition of reading and when it is not.

Consequently, for evaluating temporal processes in typical primary school children, Temporal Order Judgment (TOJ) tasks were used in visual and auditory modalities, with linguistic and nonlinguistic stimuli, and all stimuli were controlled. Based on the evidence from previous studies we hypothesized that temporal processing development is influenced by grade, modality, and stimuli type. A statistical interaction between grade, modality and stimuli would indicate that those processes

* Stimulus Onset Asynchrony.
are associated with the temporal process, while independent statistical effects would be related to differentiated cognitive processes. Our prediction on the temporal processing was based on the evidence describe in the literature. First, we compared the linguistic and non-linguistic stimuli in the visual and auditory modality task in each grade. We hypothesized that the performance of linguistic stimuli would be lower than non-linguistic stimuli for both modalities in each grade. Second, we compared the grades for each stimulus and modality. We hypothesized that the performance of the students in lower grades would be worse than that of students in higher grade independent of the modality or stimuli. Third, we compared the performance of visual and auditory modality for each stimulus in each grade. We hypothesized that performance for auditory modality would be lower than the visual modality.

**Method**

**Participants**

The number of participants was 470 children (173 girls, 297 boys), between five (5) to 13 years of age. These students were spread across five different school grades (1\textsuperscript{st}, 2\textsuperscript{nd}, 3\textsuperscript{rd}, 4\textsuperscript{th}, 5\textsuperscript{th}). Table 1 shows means and standard deviation for age, IQ, attention, and memory by grade.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Mean and Standard Deviation for Age, IQ, Attention, and Memory by Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1\textsuperscript{o}</td>
</tr>
<tr>
<td></td>
<td>M</td>
</tr>
<tr>
<td>Age</td>
<td>5.97</td>
</tr>
<tr>
<td>IQ</td>
<td>103.92</td>
</tr>
<tr>
<td>Attention</td>
<td>0.28</td>
</tr>
<tr>
<td>Memory</td>
<td>9.28</td>
</tr>
</tbody>
</table>

**Materials and Stimuli**

**Temporal Processing Tasks**

The experimental test was the Perceptual Process Test (PRAVI, as per the acronym in Spanish*) created by Estévez et al. (2011). This is

* The original name in Spanish is *Prueba de procesos perceptivos* (PRAVI).
a computer test that resembles a game. It has a simple interface and has been specially designed to evaluate children. The test uses Judgment Time Order Tasks (TOJ). In this task the same stimuli are presented in pairs and the participants must differentiate the order of presentation of the two stimuli, indicating which of them was presented first. The task is presented in two modalities, one auditory and the other visual. Also, the stimuli are of two types: linguistic and non-linguistic. Therefore, there are four tasks: auditory linguistic, auditory non-linguistic, visual linguistic, and visual non-linguistic. ISI of 50, 150, or 300 msec was used between the two stimuli.

Each task was divided in three stages. The first one is related to the association between the stimuli identification and the proper response key. Participants must correctly respond to a minimum of 75% of 20 items to advance to the next stage. In this stage participants had to respond a block of ten examples with a similar structure of the evaluation stage but with a different ISI (600 ms). They must respond correctly to a minimum of 70% of the examples to advance to the final stage (the evaluation stage). There were three ISIs (50, 150, and 300 ms) here, each with eight trials. Thus, each task was made up of 24 trials, meaning that the whole evaluation task was made up of 96 trials (Ortiz, Estévez, Muñetón, et al., 2014, p. 2675).

**Visual Temporal Order Judgement**

There were two types of stimuli used: (1) Linguistic: Stimuli were two of visual stimuli (A/a) that appeared serially on the screen. There were four pairs presented (A-a, a-A, a- a, A-A) in a random order. (2) Nonlinguistic: there were two stimuli without linguistic content, which differed only in the presence or absence of one visual feature.

**Auditory Temporal Order Judgement**

Two types of stimuli were used: (1) Linguistic: Stimuli were two syllables with vowel consonant structure (CV), that contained the same articulatory features (bilabial and stops), while differing only in the vibration of the vocal cords: one was voiceless (/ pa /) and the other voiced (/ ba /). Each pair of stimuli was presented serially and randomly. (2) Nonlinguistic: Two-200ms-long tones readily recognizable as a mouse squeak (470 Hz) and a duck quack (260 Hz) were presented in pairs. The auditory linguistic stimuli were studio recordings of a female voice presented via earphones in accordance with the procedure presentation (pa-ba, ba-pa, ba-ba, pa-pa).
Figure 1
Temporal Process Tasks

Note: 1 = Linguistic auditory stimuli: / pa / / ba /. 2 = Non-linguistic auditory stimuli: the squawk of a duck and the squeak of a mouse. 3 = Visual linguistic stimuli: letters A / a. 4 = Non-linguistic visual stimuli: amorphous images, Pototo with hair, Pototo without hair.

Control Variables

Intelligence

The G Factor (Cattell & Cattell, 2001) was used to measure IQ. This test made it possible to assess general intellectual ability through non-verbal tasks. Scale 1, children between four (4) to eight (8) years of age. The subtests applied were substitution, identification, labyrinths, and similarities. Scale 2 (form A) for schoolchildren from eight (8) to 14 years of age. The subtests applied for this scale were series, classification, matrices, and conditions.

Attention

Magallanes Scale of Visual Attention (Magaz et al., 2011) was used to measure attention. EMAV-1: from five (5) to eight (8) years of age.; EMAV-2: nine (9) years old and above.

Memory

Wechsler Intelligence Scale for Children Digits Subtest WISC-IV (Wechsler, 2005). The objective of this test was to measure short-term
auditory memory and working memory, to rule out problems of this type. In this task, the girl or boy repeated a series of numbers that the evaluator presented verbally. The test started with two digits and increased by one digit until there were two consecutive failures. The series was first repeated in the same order of presentation and later in reverse order.

Procedure

Three primary schools (two private, one public) were contacted, the three of them had the same social conditions. The parents signed the informed consent approved by the Bioethics Committee of the Faculty of Medicine of the University of Antioquia in order to start the research process. Firstly, the cognitive tests (intelligence, attention, memory) were applied in a general session. Secondly, the PRAVI test was applied in four individual sessions, lasting 20 to 30 minutes each, taking place in a quiet, comfortable environment: without noise, with good lighting and ventilation, and in a private space. A clinical psychologist and ten psychology practitioners carried out all tests. The data was analyzed using the IBM SPSS v22.0 software program.

Results

The first step of analysis tested the assumption that the groups did not differ regarding the mean of the control variables. In short, there were significant differences in IQ ($F(4; 464) = 5.94, p = .001; \eta^2 = .04$), in attention ($F(4; 464) = 38.22, p = .001; \eta^2 = .25$), and in memory ($F(4; 464) = 48.79, p = .001; \eta^2 = .29$). Given that the use of a covariance analysis requires the covariate to be correlated with the dependent variable, correlation analysis was carried out. Table 2 presents Pearson bivariate correlations between the measurements.

Thus, in this study, multivariate variance analysis was used to examine the effects of Grade (1 vs. 2 vs. 3 vs. 4 vs. 5) x Stimuli (Linguistic vs. Nonlinguistic) x Modality (Visual vs. Auditory) for ratio performance (response time/accuracy) with memory and attention as covariates. Table 3 shows the mean and standard deviation of the five groups in each stimulus and each modality.
Table 2
Correlations Between Performance on the TOJ Task and Measurements of Memory and Attention

<table>
<thead>
<tr>
<th>Test</th>
<th>Visual Linguistic</th>
<th>Visual Nonlinguistic</th>
<th>Auditory Linguistic</th>
<th>Auditory Nonlinguistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>CI</td>
<td>-0.061</td>
<td>-0.091</td>
<td>-0.022</td>
<td>-0.081</td>
</tr>
<tr>
<td>Attention</td>
<td>-0.228**</td>
<td>-0.265**</td>
<td>-0.173**</td>
<td>-0.210**</td>
</tr>
<tr>
<td>Memory</td>
<td>-0.361**</td>
<td>-0.381**</td>
<td>-0.280**</td>
<td>-0.352**</td>
</tr>
</tbody>
</table>

The analysis showed a significant effect of Grade (F (4; 461) = 33.06. p = .001; ηp2 = .37), Stimulus (F (1; 463) = 46.94. p = .001 ηp2 = .09), and Modality (F (4; 463) = 12.59. p= .001; ηp2 = .03). The interactions Grade x Modality (F (4; 463) = 3.58. p= .007; ηp2 = .03) and Stimulus x Modality (F (4; 463) = 49.94. p = .001; ηp2 = .10) were significant. Also, higher order interaction of the three variables Grade x Stimulus x Modality (F (4; 463) = 3.98. p = .003; ηp2 = .03) were significant. In order to explain the higher order interaction, data were organized into two figures based on modality. Figure 2 shows the results in the linguistic and nonlinguistic stimuli by grade i for the visual modality, whereas Figure 3 shows the results in the linguistic and nonlinguistic stimuli by grade for the auditory modality.

The comparison of Figures 2 and 3 indicates that there is a different pattern between the students’ grades and stimuli when it comes to visual and auditory modality.

Figure 2 shows that means performance of children with visual linguistic and visual nonlinguistic stimuli is very similar. Thus, the contrast between both stimuli did not reach significance for any grade: 1º (F (1; 465) = .08. p = .784; ηp2 = .00); 2º (F (1; 465) = 1.06. p = .303; ηp2 = .00); 3º (F (1; 465) = .10. p = .755; ηp2 = .00); 4º (F (1; 465) = .16. p = .689; ηp2 = .00); and 5º (F (1; 465) = .55. p = .459; ηp2 = .00).

In contrast, Figure 3 shows means performance of children with auditory linguistic and auditory nonlinguistic stimuli were different and, additionally, auditory linguistic stimulus is the most difficult: 1º (F (1; 465) = .08. p = .001; ηp2 = .08); 2º (F (1; 465) = 1.06. p = .001; ηp2 = .06); 3º (F (1; 465) = .10. p = .001; ηp2 = .02); 4º (F (1; 465) = .16. p = .01; ηp2 = .01); and 5º (F (1; 465) = .55. p = .034; ηp2 = .01).
Figure 2
Mean Rate of Performance of Children with Linguistic and Nonlinguistic Stimuli in the Visual Modality

Figure 3
Mean Rate of Performance of Children with Linguistic and Nonlinguistic Stimuli in the Auditory Modality.

Note: VL = Visual linguistic. NNL = Visual nonlinguistic. AL = Auditory linguistic. ANL = Auditory nonlinguistic.

Table 3
Mean Rate and Standard Deviation of Grade (1 Vs. 2 Vs. 3 Vs. 4 Vs. 5) X Stimulus (Linguistic Vs. Nonlinguistic) in Each Modality (Visual Vs. Auditory)

<table>
<thead>
<tr>
<th>Grade</th>
<th>Visual Linguistic</th>
<th>Visual Nonlinguistic</th>
<th>General Visual</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>1°</td>
<td>1.92</td>
<td>.89</td>
<td>1.94</td>
</tr>
<tr>
<td>2°</td>
<td>1.40</td>
<td>.57</td>
<td>1.48</td>
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<tr>
<td>3°</td>
<td>1.29</td>
<td>.65</td>
<td>1.27</td>
</tr>
<tr>
<td>4°</td>
<td>1.00</td>
<td>.35</td>
<td>.97</td>
</tr>
<tr>
<td>5°</td>
<td>.93</td>
<td>.38</td>
<td>.89</td>
</tr>
<tr>
<td>Total</td>
<td>1.29</td>
<td>.69</td>
<td>1.29</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Grade</th>
<th>Auditory Linguistic</th>
<th>Auditory Nonlinguistic</th>
<th>General Auditory</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>1°</td>
<td>1.90</td>
<td>1.09</td>
<td>1.40</td>
</tr>
<tr>
<td>2°</td>
<td>1.62</td>
<td>.99</td>
<td>1.16</td>
</tr>
<tr>
<td>3°</td>
<td>1.31</td>
<td>.59</td>
<td>1.04</td>
</tr>
<tr>
<td>4°</td>
<td>1.10</td>
<td>.49</td>
<td>.91</td>
</tr>
<tr>
<td>5°</td>
<td>.93</td>
<td>.33</td>
<td>.77</td>
</tr>
<tr>
<td>Total</td>
<td>1.35</td>
<td>.82</td>
<td>1.04</td>
</tr>
</tbody>
</table>
As can be observed in table 4, contrasts between the groups in each stimulus by each modality show that 1st grade students had a significant difference when compared to students of higher grades in every case. In addition, there was a significant difference between 2nd and 4th-grade students in visual linguistic stimuli. In both group of results, the performance of lower grades was worse than that of the higher grades.

Moreover, children in second grade performed better in visual linguistic stimuli than in auditory linguistic stimuli (F (1; 465) = 5.81. p = .016; ηp2 = .01); but in non-linguistic stimuli, the pattern is contrary, children in first, second, and third grades performed better in the auditory than visual modality (F (1; 465) = 55.27. p = .001; ηp2 = .10; F (1; 465) = 17.35. p = .001; ηp2 = .03; F (1; 465) = 9.76. p = .002; ηp2 = .01, respectively).

Table 4
Effect of Grade

<table>
<thead>
<tr>
<th>Grades compared</th>
<th>Visual Linguistic</th>
<th>Visual Nonlinguistic</th>
<th>Auditory Linguistic</th>
<th>Auditory Nonlinguistic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>p</td>
<td>µp²</td>
<td>F</td>
</tr>
<tr>
<td>1° vs. 2°</td>
<td>26.20</td>
<td>.001</td>
<td>.05</td>
<td>12.07</td>
</tr>
<tr>
<td>1° vs. 3°</td>
<td>34.39</td>
<td>.001</td>
<td>.07</td>
<td>24.62</td>
</tr>
<tr>
<td>1° vs. 4°</td>
<td>69.14</td>
<td>.001</td>
<td>.13</td>
<td>50.76</td>
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<tr>
<td>1° vs. 5°</td>
<td>75.96</td>
<td>.001</td>
<td>.14</td>
<td>57.89</td>
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<tr>
<td>2° vs. 3°</td>
<td>0.08</td>
<td>.771</td>
<td>.01</td>
<td>1.16</td>
</tr>
<tr>
<td>2° vs. 4°</td>
<td>3.96</td>
<td>.047</td>
<td>.01</td>
<td>1.00</td>
</tr>
<tr>
<td>2° vs. 5°</td>
<td>1.75</td>
<td>.187</td>
<td>.01</td>
<td>0.05</td>
</tr>
<tr>
<td>3° vs. 4°</td>
<td>2.06</td>
<td>.152</td>
<td>.01</td>
<td>1.01</td>
</tr>
<tr>
<td>3° vs. 5°</td>
<td>.02</td>
<td>.892</td>
<td>.01</td>
<td>.09</td>
</tr>
<tr>
<td>4° vs. 5°</td>
<td>1.10</td>
<td>.233</td>
<td>.01</td>
<td>1.01</td>
</tr>
</tbody>
</table>
Discussion

In order to analyze the role of temporal processing in children in primary school, a PRAVI computer perceptual test was used. There was a general hypothesis indicating that the development of temporal processing is mediated by the students’ grade, the modality, and type of stimuli. According to the study’s rationale, the statistical interaction supported the hypothesis. Also, the results enabled the three questions asked in the introduction to be answered: (1) the performance of linguistic stimuli is lower than that seen for non-linguistic stimuli in both modalities in each grade; (2) the performance of the 1st-grade students is worse than that of students in higher grades independent of the modality or stimuli; (3) the performance of auditory modality is lower than that seen for the visual modality.

In order to address the first question, the performance of the students in each grade for linguistic and nonlinguistic stimuli was examined for each modality. This hypothesis was completely confirmed in auditory TP: the results show that auditory nonlinguistic tasks were easier than auditory linguistic tasks for students in every grade. These results are similar to those found by (Casini et al., 2018; Johnson et al., 2007; Luque et al., 2008; Mody et al., 1997; Muñetón et al., 2017; Ronen et al., 2018; Vásquez, 2013). It is worth emphasizing that, except for the study by Ronen et al., 2018, all studies evaluate school population with and without reading difficulties, between seven (7) and 12 years of age. This could indicate that auditory TP is of vital importance at the school stage both for populations with typical development and those with reading-learning difficulties. This result was expected considering that auditory TP is an ability that enables the differentiation of phonemes from absolute syllable duration, relative syllable duration index, and voice onset time (Marcotti & Alvear, 2019) related to the ability to decode speech. Contrary to this view, Ortiz, Estévez, Muñetón et al. (2014) found differences in the TP of children with or without dyslexia, as mentioned above, but this...
processing was not related to either modality or stimulus type. Similarly, Vandermosten et al. (2011) found no differences according to the type of stimulus and suggest that nonlinguistic sounds are as complex as linguistic ones, but they only analyzed auditory stimuli. Not only was the study conducted with preschool children but also the experimental task only examined discrimination, not TOJ. It is likely that these differences explain the divergent results.

Regarding the visual modality, this hypothesis was partially confirmed: visual nonlinguistic tasks were easier than visual linguistic tasks in 3rd, 4th, and 5th; however, visual linguistic tasks were easier than visual nonlinguistic tasks in 1st, 2nd grade. This result is similar to that found by Domínguez (2017) in Spanish children between five (5) to seven (7) years of age. In this regard, the results of Coalla and Vega (2012) show that there is no correlation between visual perception in children with difficulties. However, they do find differences in processing when the visual stimulus is linguistic; an aspect that leads them to conclude that the visual difficulties of dyslexics are associated with the complexity of the linguistic stimulus and not with the VP itself. Although this study is clearly different from the present one because it sets out to show that visual perception is not related to reading deficits, it could be a factor indicating that visual perception is (1) relatively simple for children with typical reading development, independent of the type of stimulus, and (2) indeed, as these researchers point out, in the case of children with difficulties it would be necessary to assess whether or not they have a difficulty at the level of visual perception or a linguistic difficulty, which in some cases affects the visual perception of linguistic stimuli. Contrary to the hypothesis put forward and the results, Lachmann et al. (2012) indicate that the visual perception of letters is special as they have a functional relationship with phonemic representation. Their practice and familiarity makes them be processed more efficiently than nonlinguistic stimuli with similar characteristics. This difference in perspective can be explained by differences in language and population characteristics: Lachman’s study was conducted in Hindi, with bilingual vs. illiterate university adults.

Finally, in the comparison of peers across different school grades, it was identified that 1st grade differed significantly from the other school grades, in all cases, in each modality with each stimulus (visual linguistic, visual nonlinguistic, auditory linguistic, auditory
nonlinguistic). Also, 2nd grade was significantly different from 4th with regards to the performance of visual linguistic tasks. In this sense, Gallegos (2010) maintains that the significant differences in his study were observed between the 8-year-old group and the others. He argues that these differences are due to a maturation of the biological and behavioral auditory perception, which occurs in children of these ages. In addition, he indicates that the maturation of executive functions at these ages favors efficiency in task performance.

The answer to the second question was confirmed. Results show significant differences between grades in TOJ task performance: as the grade increases, the performance of TOJ tasks improves. These results suggest that visual and auditory temporal processes are evolutionary developments in primary school. These results are similar to other studies:

(1) In the development of auditory temporal processing (Gallegos, 2010) coincides with the results presented, finding that children had higher scores in TOJ tasks as age increased. On the linguistic auditory temporal processing of school children, Domínguez (2017) identified evolutionary development in schooled children from five (5) to seven (7) years of age. He points out that this finding shows a differential pattern in speech perception.

(2) In the evolution of non-linguistic auditory temporal processing in preschoolers (Benasich & Tallal, 2002; Hood & Conlon, 2004; Steinbrink et al., 2014) also identified a developmental pattern. Finally, Hautus et al. (2003) found evolutionary development in auditory perception, comparing children and adults with and without dyslexia.

As for the third question, both modalities were analyzed looking at all types of stimuli (Visual linguistic, Visual nonlinguistic, Auditory linguistic and, Auditory nonlinguistic). This hypothesis was partially confirmed. General results for visual and auditory tasks show that visual temporal processing was more difficult in comparison with auditory tasks, except in 4th grade. This goes against the hypothesis. However, when each modality was observed with different stimulus, visual linguistic tasks were easier than auditory linguistic tasks for students in the 2nd, 3rd, 4th, and 5th grades. This result suggests that auditory linguistic TP plays an important role in primary school.

It should be noted that this is a flashpoint in the analysis of a TP deficit because other studies found differences between auditory TP and visual TP. Wang et al. (2018) found a significant relationship between
the auditory modality with typically developing children in reading and the visual modality with children with dyslexia. Casini et al. (2018) identified differences between modalities and the prevalence of an auditory TP deficit in children with difficulties. Steinbrink et al. (2014), and Hood and Conlon (2004) also found differences and suggest that auditory TP is predictive of eventual reading difficulties. In typically developing college adults, Au and Lovegrove (2001) found that auditory TP and visual TP developed differently according to the participants' reading abilities. Note that there are three differential aspects between the cited studies and the present one: (1) The earlier studies are in the field of learning disabilities. (2) Some of the studies only use nonlinguistic stimuli to assess auditory and visual TP, and (3) Au & Lovegrove’s (2001)we compared the rapid visual and auditory temporal processing ability of above average and average readers. One hundred five undergraduates participated in various visual and auditory temporal tasks. The above average readers exhibited lower auditory and visual temporal resolution thresholds than did the average readers, but only the differences in the auditory tasks were statistically significant, especially when nonverbal IQ was controlled for. Furthermore, both the correlation and stepwise multiple regression analyses revealed a relationship between the auditory measures and the wide range achievement test (WRAT study focused on expert readers with several years of linguistic experience. This suggests that different cognitive profiles may lead to different temporal perception profiles.

Conclusions

In summary, the present study provides evidence concerning the progressive nature of temporal processing among primary school children. This development trajectory is particularly noteworthy for students in lower primary school grades. Furthermore, the Temporal Order Judgment (TOJ) task exhibited robust experimental support, rendering it a valuable tool for assessing temporal processing within conventional school populations. This task offers the potential to assess TP across auditory and / or visual modalities, with diverse types of stimuli (linguistic vs. non-linguistic). Finally, the auditory modality, and especially the auditory linguistic modality, showed greater sensitivity depending on the school grade.
Acknowledgments. We want to thank the Faculty of Communication, and the Psycholinguistics and Prosody Research Group of University of Antioquia, Colombia, the Cognition, Language and Education Research Group of University of La Laguna, Tenerife, Spain, and psychology practitioners of Faculty of Psychology of University of Antioquia. We would also like to thank the participants for taking part in this study.

ADHERENCE TO ETHICAL STANDARDS

Ethics declarations. The ethical examination of the conducted empirical research was carried out and it was approved by the Bioethics Committee of the Faculty of Medicine of the University of Antioquia in order to start the research process. Approval record from the Bioethics Committee of the Faculty of Medicine at the University of Antioquia, number 022. The study was conducted according to the guidelines of the Declaration of Helsinki (1964).

Funding. This project was supported by the University of Antioquia, Colombia as part of the “Validation of a test of auditory and visual, linguistic and non-linguistic perceptual processes in elementary school children in the city of Medellín” (Validación de una prueba de procesos perceptivos auditivos y visuales, lingüísticos y no lingüísticos en niños escuela primaria en la ciudad de Medellín) [CODI Acta-2017-16156] project in the Psycholinguistics and Prosody Research Group.

Author contributions. Claudia Vásquez.: modeling of the theoretical concept and general design of the research, formulation of goals and objectives of the research, general organization of empirical research, writing abstracts to the article, reviewing and editing the article, preparation of the final version of the manuscript, submission of data to the international repository, preparation of tables and figures in their original form. Mercedes Muñetón: preparation of the development of software, data collection and analysis, interpretation of data of the research, reviewing tables and figures.

Two authors commented on previous versions of the manuscript. Two authors have read and approved the final version of the manuscript.

Consent for Publication. The authors jointly consent for the manuscript to be published by the journal.

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References


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АНОТАЦІЯ
Темпоральна обробка демонструє еволюційний характер відповідно до віку та навчання.

Мета. Метою цього дослідження є аналіз ролі часової обробки у дітей в різних класах початкової школи.

Методи. 470 дітей (у віці 5–13 років) з п’яти шкільних класів порівнювали з судження про темпоральний порядок. Їм пропонували однакові зорові й слухові, мовленнєві й немовленнєві стимули. Трифакторний багатовимірний дисперсійний аналіз з повторним вимірюванням був використаний для вивчення впливу класу (1° проти 2° проти 3° проти 4° проти 5°) х стимул (мовний проти немовного) х модальність (зорова проти слухової).

Результати. Ці три фактори мають значну взаємодію. Слухові немовленнєві завдання були легшими за слухові мовленнєві завдання в кожному класі. Візуально-нелінгвістичні завдання були легшими за візуально-лінгвістичні у старших класах, а 1-й клас суттєво відрізнявся від інших класів у всіх випадках. Виявлено, що чим вищий клас школи, тим краще учні виконували завдання на судження про темпоральній порядок. Візуально-лінгвістичні завдання були легшими, ніж аудіально-лінгвістичні.

Висновки. У цьому дослідженні наводяться дані, що свідчать про прогресивний характер часової обробки у дітей молодшого шкільного віку. Ця траєкторія розвитку особливо помітна для учнів молодших класів початкової школи. Крім того, завдання на визначення часового порядку (Temporal Order Judgment, TOJ) отримало надійну експериментальну підтримку, що робить його цінним інструментом для оцінки часової обробки у звичайних шкільних популяціях. Це завдання дає змогу оцінити ТП у слуховій та/або зоровій модальностях, з різними типами стимулів (лінгвістичними та нелінгвістичними). Нарешті, слухова модальность, і особливо слухова лінгвістична модальность, показала більшу чутливість залежно від шкільного класу.

Ключові слова: психолінгвістика, темпоральний процес, сприйняття, діти молодшого шкільного віку, когнітивні процеси.