Psicothema

Psicothema 2020, Vol. 32, No. 1, 92-99
doi: 10.7334/psicothema2019.104

ISSN 0214 - 9915 CODEN PSOTEG

www.psicothema.com

Number processing skill trajectories in children with specific language impairment

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Abstract

Background: A number of contrasting hypotheses have been put forward concerning mathematical performance deficits in children with specific language impairment (SLI). However, debate as to the nature of this deficit continues. The present study analyzed whether the trajectories of SLI-children may be attributed to the use of symbolic vs. linguistic assessment tasks, or to a deficit in the magnitude system. **Method:** SLI-children (N=20) and typically achieving children (N=20) were monitored between kindergarten and first grade. Four tasks were designed, each with varying demands on language, symbolic, and domain-specific skills. **Results:** The groups only differed in the trajectories of those numerical tasks involving high language demand. **Conclusions:** These findings indicate that SLI children present an early deficit in the development of numerical skills that require retrieval from long term memory and articulation of a phonological representation. Number skills involving greater language demand should be included as part of SLI early detection and intervention protocols.

Keywords: Specific language impairment, magnitude processing, developmental trajectories, magnitude comparison.

Resumen

Trayectorias del procesamiento de habilidades numéricas en niños con trastorno específico del lenguaje. **Antecedentes:** diferentes hipótesis sobre las dificultades en matemáticas de niños con trastorno específico del lenguaje (TEL) han sido contrastadas, sin embargo, el debate sobre la naturaleza de este déficit todavía perdura. El presente estudio analizó si las trayectorias de los niños con TEL en habilidades numéricas pueden atribuirse a la naturaleza simbólica de las tareas utilizadas, a la demanda lingüística de las mismas, o a un déficit en el sistema de magnitud. **Método:** niños con TEL (N = 20) y con rendimiento típico (N = 20) fueron monitoreados entre Educación Infantil y el primer curso de Educación Primaria. Se diseñaron cuatro tareas, cada una con una demanda variable de habilidades de lenguaje, información simbólica y de dominio específico. **Resultados:** los grupos se diferenciaron únicamente en las trayectorias de aquellas tareas numéricas que implicaban una alta demanda de lenguaje. **Conclusiones:** estos hallazgos indican que los niños con TEL presentan un déficit temprano en el desarrollo de aquellas habilidades numéricas que requieren recuperación rápida de una representación fonológica de la memoria a largo plazo y su articulación. Las habilidades numéricas que implican una mayor demanda de lenguaje deben incluirse como parte de los protocolos de detección e intervención temprana de TEL.

Palabras clave: trastorno específico de lenguaje, procesamiento de magnitudes, trayectorias evolutivas, comparación de magnitudes.

Learning mathematics involves the development of a wide variety of specific basic skills, such as single digit processing, counting and arithmetic calculation, as well as general cognitive skills and oral language (Cowan & Powell, 2014). Language skills in particular have been found to be a prerequisite for learning certain numeracy skills (Alameda, Salguero, & Lorca, 2007; Duncan et al., 2007; Peake, Jiménez, Rodríguez, Bisschop, & Villarroel, 2015). However, although it is clear that language facilitates the development of numerical skills and mathematical concepts, there does not appear to be sufficient support for a causal relationship between them (Gelman & Butterworth, 2005).

Received: April 11, 2019 • Accepted: October 28, 2019
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The way in which language and numeracy skills interact with each other remains a relevant issue for investigation, and studies of the acquisition of basic numeracy skills in children with specific language impairment (SLI) could represent an opportunity to better understand the language-numeracy skills relationship (Nys & Leybaert, 2013). Few studies to date have addressed the numerical skills of children with SLI (see Cross, Archivald, & Joanisse, 2018, for a review). The present study provides empirical evidence on the issue by monitoring the numerical skills of children with and without SLI from kindergarten to first grade.

According to the Triple-Code Model (Dehaene & Cohen, 1995), three different representation systems are used for processing numbers. The first is the quantitative system, which is required for representation of analogue non-symbolic magnitudes (e.g. dot sets). The second is the verbal code, which enables the individual processing of numbers when they are presented orally or in writing (e.g. "seven"). The third is the visual code, which is involved in processing Arabic number symbols (e.g. "9"). It has been demonstrated that children with SLI struggle with development of certain – but not all – mathematical skills (Cowan, Donlan, Newton, & Llyod, 2005; Donlan, Bishop, & Hitch, 1998; Fazio, 1996; Kleemans, Segers, & Verhoeven, 2012; Koponen, Mononen, Räsänen, & Ahonen, 2006), so it is possible that their mathematical performance could depend on the number code that they have to deal with.

Two main hypotheses have been formulated concerning mathematical difficulties in children with SLI. The first suggests that the deficits observed in SLI children – including those to do with mathematics – may be explained by the existence of a general deficit in processing symbolic information (e.g. Kamhi, 1981; Stone & Connell, 1993). The second hypothesis postulates that mathematical deficits in children with SLI are linked to a specific language domain (Johnston, 1994). According to these hypotheses, children with SLI could present difficulties with mathematical tasks that involve managing either visual code or the verbal code of numbers, respectively. Evidence supporting each of the two hypotheses has been reported. Previous research has shown that counting, arithmetic calculation, and number transcoding are impaired in children with SLI (Arvedson, 2002; Cowan et al., 2005; Donlan, Cowan, Newton, & Lloyd, 2007; Fazio, 1996, 1999; Kleemans et al., 2012). Children with SLI have a severe deficit in their ability to count, mostly relating to problems with accurate and fluent number-word sequence retrieval; however, their conceptual knowledge of counting is less impaired (Donlan et al., 2007; Fazio, 1996; Kleemans et al., 2011). Limited achievement in simple arithmetic calculation is consistently found in SLI children, who use less mature counting strategies and are slower and less accurate than their age-matched peers (Cowan et al., 2005; Duncan et al., 2007; Fazio, 1999; Koponen et al., 2006). Even the reading or writing of numbers appear to be more difficult tasks for SLI children than for their age-matched peers, especially when the numbers are large (Fazio, 1996). These tasks are highly dependent on verbal representations of numbers, and some also involve processing Arabic numbers, i.e., visual code (Dehaene, Piazza, Pinel, & Cohen, 2003; Simmons & Singleton, 2008). It is therefore difficult to discern which of the two hypotheses mentioned could best explain the difficulties presented by children with SLI.

According to several findings, the foundational ability upon which acquisition and development of mathematical skills – such as arithmetic fluency – is based is the ability to process magnitudes (Desoete, Ceulemans, Weerdt, & Pieters, 2012). Magnitude processing involves understanding the magnitudes that the different codes represent (Nosworthy, Bugden, Archibald, Evans, & Ansari, 2013). A large number of studies have demonstrated that impairment of magnitude processing constitutes the core deficit in children with mathematics learning disabilities (MLD) (e.g. Halberda & Feigenson, 2008; Vanbinst, Ghesquiere, & De Smedt, 2012). A relevant question, therefore, is whether behind poor performance in mathematical skills among SLI children lies a deficit in magnitude processing. In other words, could mathematical difficulties be domain-specific rather than a consequence of a symbolic or language deficit? Few studies have focused on this issue, and their findings are inconclusive; more research is needed (Archibald, Oram Cardy, Joanisse, & Ansari, 2013).

Magnitude processing is assessed primarily by comparing quantities by means of symbolic (e.g. Arabic numbers) and non-symbolic (e.g. dots) comparison tasks. These tasks, unlike counting, arithmetic calculation or number transcoding, mainly involve analog representations of numbers. Thus, according to the aforementioned hypotheses, SLI children would not be expected to present a deficit in these tasks – at least in the non-symbolic task – given that Arabic number comparison requires subjects to operate using symbols. The findings are heterogeneous in both cases. Some studies have found that SLI children did not differ from their age-matched peers in symbolic number comparison (Cowan et al., 2005; Donlan et al., 1998; Donlan & Gourlay, 1999), although other studies have shown that SLI children are in fact impaired in these symbolic comparison tasks even when language demand was reduced by avoiding a verbal response (Koponen et al., 2016). The findings are less heterogeneous when non-symbolic comparison tasks are used (Alt, Arizmendi, & Beal, 2014; Nys & Leybaert, 2013). Nys and Leybaert (2013) found no differences between SLI children (age range: 7.2-14.4 years old) and their age-matched peers in non-symbolic comparison tasks; however, the results reported by Alt et al. (2014) were inconclusive, as detailed below.

There is still debate, therefore, as to whether poor mathematics performance in children with SLI is due to a language deficit, symbolic deficit, or even a domain-specific deficit. Alt et al. (2014) studied the nature of mathematics learning difficulty in children with and without SLI using numerical tasks that varied in language and symbolic demand (language-heavy vs. language-light; symbol-heavy vs. symbol-light). Children with SLI presented deficits in all tasks except for the language-light and symbol-light task, i.e., in the non-symbolic comparison task. However, according to the authors, this finding must be interpreted with caution given the poor performance in the task of the children with typical development. They suggested that the results could be confounded by impulsivity, probably motivated by the nature of the task (in this case, a race), and so it would be advisable to replicate them using other types of task. Another aspect to consider is that the task types were very different. While the symbolic comparison task (language-light and symbol-heavy) and the non-symbolic comparison task (language-light and symbol-light) were comparable (children were required to touch the dinosaur with the highest number written on its racing bib), the language-heavy and symbol-heavy task comprised subtests from the standardized KeyMath3 (Connolly, 2007) measure which differed greatly from the other two, involving, for example, basic concepts of algebra, geometry, and probability. Thus, the poor performance of SLI children in the language-heavy and symbol-heavy task could be explained by deficits in more general cognitive skills, rather than by a language or symbol processing deficit. Finally, it is important to note that participants of this study were heterogeneous in age (age range: 6.9-9.1 years old), which made it difficult to control differences in mathematical and language experience across the group.

The present study examines whether children with and without SLI differ in their development of basic numerical skills, and whether these differences can be attributed to the symbolic versus linguistic nature of assessment tasks, or instead to a domain-specific deficit in SLI children. To achieve this goal, we studied the trajectories of children with and without SLI moving from kindergarten to first grade, using four tasks that required processing of magnitudes. Two tasks consisted of parallel symbolic comparison, in which children were required to identify which of two numbers was the largest. One of these required a verbal response, and the other asked participants to mark the correct answer with a cross. The third was a non-symbolic comparison task, in which children were required to mark with a cross the larger of two sets of dots. The fourth was a number reading task in which children were asked to vocalize the names of Arabic numbers. If the trajectories of children with and without SLI differ only in symbolic tasks, symbolic deficit would be taken to underlie poor performance in SLI children. Similarly, if the trajectories of children with and without SLI differ only in language tasks, i.e., those requiring a verbal response, this would indicate that language deficit underlies poor performance in SLI children. Finally, if the trajectories of children with and without SLI differ in the non-symbolic comparison task, this would indicate that SLI children present a deficit in magnitude processing, i.e., a domain-specific deficit.

Method

Participants

Nine schools (5 public and 4 private-subsidized) providing elementary education participated in the present study. From the initial sample of 492 kindergarten children (age, M=67.00, SD=9.33; 45.2% girls), a group of 20 children with SLI were identified. An interdisciplinary team consisting of educational psychologists, speech therapists and a physician diagnosed the SLI group. In Chile, the diagnosis of SLI is given when the child has severe problems in receptive and/or expressive language domains (>2 SD below the mean performance of the normative data), and these problems should not be explained by intellectual, sensory, motor or physical impairments, or appear in combination with autistic spectrum disorders. In accordance with Chilean Special Education legislation, at least four language-standardized tests must be administered. The first pair of tests assess receptive language skills: (a) *Test para la Comprensión Auditiva del Lenguaje* (TECAL – Test of Auditory Comprehension of Language) (Pavez, 2006), and (b) a receptive subtest of the *Test Exploratorio de Gramática Española* (Screening Test of Spanish Grammar, STSG [Chilean version], A. Toronto) (Pávez, 2003). The second pair assess expressive language skills: (a) *Test para Evaluar Procesos de Simplificación Fonológica, edición revisada* (TEPROSIF-R – *Test of Phonological Simplification Processes*-revised) (Pávez, Maggiolo, & Coloma, 2008), and (b) expressive subtest of the *Test Exploratorio de Gramática Española* (Screening Test of Spanish Grammar, STSG [Chilean version], A. Toronto) (Pávez, 2003). Of the 20 children, 7 presented expressive deficit, and 14 presented expressive and receptive deficit. Standardized scores for each subtest are presented in Table 1. Children from both SLI groups performed comparably in the expressive tests, but achievement of children with expressive and receptive deficits was lower than that of children with only expressive deficits in the respective tests. A group of 20 typically achieving (TA) children matched in age and IQ were selected from the same schools and classes as a control for instructional method and socioeconomic status. In order to diagnose children as having SLI, they were tested to ensure normal nonverbal capacities; however, Raven's Coloured Progressive Matrices (CPM) (Raven, Court, & Raven, 1998) was administered as a control measure for all groups. The groups did not differ significantly in IQ (TA, M=20.50, SD=3.50; SLI, M=18.05, SD=5.14), $F(1, 39)=2.89$, $p=.097$, or age (TA, M=68.75, SD=3.42; SLI, M=68.35, SD=3.22), $F(1, 39)=.14$, $p=.705$, and were matched in terms of sex (TA, 35% girls; SLI, 35%), $\chi 2$ (1)=.476, $p=.73$. None of the SLI group children had any known history of hearing loss, sensory, motor or physical impairments, or language impairment in combination with autistic spectrum disorders.

Instruments

Raven's *Coloured Progressive Matrices* (Raven, Court, & Raven, 1998) was used to assess nonverbal intelligence. This test has shown a high level of reliability among Chilean children (Ivanovic et al., 2003). In the present study, based on a large cohort of 648 Chilean kindergarten students, the average raw score for this sample was 19.54 (SD=5.82). The test was administered in small groups, ensuring a 1:5 examiner-student ratio.

Number reading task. The task required the subject to read aloud as many Arabic numbers as possible in 1 minute. A total of 100 one- and two-digit Arabic numbers (between 0 and 20) were printed on a sheet of paper. Numbers were displayed in 4 columns and 25 rows. Children were instructed to read the numbers aloud, and four practice items preceded the evaluation. The number of correctly read numbers became the subject's score. Based on a randomized subsample of 150 children, the internal consistency of the parallel tasks was .87, .88, and .92 at each time point.

Oral-symbolic comparison task. Oral-symbolic comparison task. In this task, 78 pairs of numbers between 1 and 20 for kindergarten (26 single-digit pairs; 26 single- and two-digit pairs, and 26 two-digit pairs) and between 1 and 99 for first grade (all two-digit pairs except for seven seven single- and two-digit pairs, introduced in Block 1) were used. The pairs were presented on two sheets of paper, with each pair contained within a rectangle. The pairs were distributed across three blocks according to their ratios. Block 1 contained pairs with ratios between (9 and 2.375); Block 2 contained pairs with ratios between (2.33 and 1.46) and Block 3 contained ratios between 1.42 and 1.12. The position of the largest digit was counterbalanced. Children were required to state aloud the larger of the two numbers in each pair, doing so for as many pairs as possible in 1 minute. Two practice items preceded the task. The examiner recorded the children's responses on a score sheet, and the number of correct responses became the final score. Based on a randomized subsample of 150 children, the internal consistency of the parallel tasks was .85, .89, and .81 at each time point.

Cross-out symbolic comparison task. This task is similar to the oral symbolic comparison task, but this time, children were asked to respond by crossing out the larger of the numbers in each

Table 1
Standardized test scores by group

	SLI-E (N=7)		SLI-ER (N=13)		t	p	r
	M	SD	M	SD			
Expressive tests							
TEPROSIF	2.96	2.50	3.38	2.75	-.13	.894	–
STSG-Expressive subtest	-2.09	.74	-2.33	1.45	.33	.741	–
Receptive tests							
TECAL	1.35	.88	-1.76	2.38	3.14	.01	.59
STSG-*Receptive subtest*	.29	.95	-2.44	.68	7.42	.001	.87

Note: SLI-E = SLI children with expressive disorder; SLI-ER = SLI children with expressive and receptive disorder pair. The number of correct responses became the participant's final score. Based on a randomized subsample of 150 children, the internal consistency of the parallel tasks was .89, .92, and .90 at each time point.

Cross-out non-symbolic comparison task. The task comprised 75 pairs of sets of dots (each set consisting of between 1 and 20 dots, each pair including one set of black dots and one set of grey, with each set presented within a small rectangle) that were displayed on 3 sheets of paper. The stimuli were created using Panamath (Halberda, Mazzocco, & Feigenson, 2008; www.panamath.org). Three levels of difficulty were established based on the ratios between the two arrays: simple (ratios: 2.4-4.0; 25 pairs), medium (ratios:1.4-2.4; 25 pairs) and difficult (ratios: 1.1-1.8; 25 pairs). In order to disturb the cue based on area or dot size, three conditions were included: (a) non-size-controlled (sets contained equal-sized dots); (b) size-controlled (sets contained different-sized dots but the total areas of black and grey were equal); and (c) anti-correlated (sets contained different-sized dots, and the array with the smaller number of dots had a greater total surface area). In each case, children were asked to cross out the rectangle that contained the greater number of dots (without counting them) and to do so for as many pairs as possible in 1 minute. If the child hesitated for 5 seconds, they were encouraged to move on to the next pair. The number of larger quantities identified correctly in 1 minute became the participant's score. Based on a randomized subsample of 150 children, the internal consistency of the parallel tasks was .77, 70, and .71 at each time point.

Procedure

Data collection was carried out by eight previously trained examiners. The numerical tests were administered separately and in a fixed order during three rounds of evaluation, each of which occurred approximately three months apart. The tests were administered in October/November of kindergarten, and in April/May and August/September of first grade the following year. The break between the first two rounds exceeded three months because the summer vacation in Chile covers January and February; however, three months of instruction did take place in the interim. Each round of experimental number tests was administered individually in a single 20-minute session. The first round also included IQ tests, which were applied collectively during a second session.

Data analysis

Analyses were conducted in R (R Core Team, 2016) using ULLRToolbox (Hernández & Betancort, 2016). Firstly, the scores for each numerical task were subjected to a multivariate analysis of variance (MANOVA) to compare the groups' performance in all of the number tasks at each time point. Growth curve analyses (Mirman, 2014) were then conducted to analyze the development of the children's scores in each number task over the course of one year between kindergarten and first grade.

Results

The results of the MANOVA yielded a significant group effect between the SLI and TA groups in the numerical tasks: Λ=.411, $F(12,23)=2.74$, $p<.05$, $\eta^2=.59$. Table 2 shows group measurements and inter-group comparisons across numerical tasks. The TA group performed faster and more accurately overall than the SLI group. With the exception of the oral number comparison task, the TA and SLI groups did not differ at the kindergarten level; however, the TA group performed significantly better than the SLI group during the last measurement made for all numerical tasks during the first grade. Reviewing the group means over time, neither group appears to improve their number skills between Middle Kindergarten and Fall Grade 1. However, there was a highly notable increase at Middle Grade 1. In other words, there seems to be a quadratic tendency in the development of number skills, probably due to the two instruction-free months between the first two measurements. This trend is tested in the growth curves analysis.

Table 2
Descriptive statistics of the sample by group

Tasks	SLI		TA		F	p	d
	M	SD	M	SD			
NR_T1	16.55	8.55	21.65	11.07	2.66	.111	–
NR _T2	13.75	6.69	20.25	11.14	5.00	.031	.727
NR _T3	21.50	10.14	36.55	15.16	14.25	.000	1.228
OSC_T1	8.44	6.60	16.50	9.17	9.47	.004	.998
OSC _T1	8.50	4.10	12.40	7.71	3.99	.057	–
OSC _T2	13.30	7.30	21.65	14.29	5.41	.025	.755
CSC_T1	14.95	7.15	17.45	6.76	1.22	.276	–
CSC _T2	15.70	8.09	20.00	5.94	3.67	.063	–
CSC _T3	17.40	4.23	23.95	7.66	11.06	.002	1.078
CNSC_T1	16.10	5.39	16.20	4.42	.00	.949	–
CNSC _T2	14.90	8.40	18.65	7.38	2.25	.142	–
CNSC _T3	16.70	6.91	22.26	6.87	6.35	.016	.406

Note: SLI = SLI-children; TA = TA-children; NR=Number reading; Oral-symbolic comparison=OSC; Cross-out symbolic comparison=CSC; Cross-out non-symbolic comparison=CNSC; T1 = Middle Kindergarten; _T2 = Fall Grade 1; _T3 = Middle Grade 1

Table 3
Likelihood ratio tests comparing the full models and the simplified models in all numerical tasks

	df	AIC	BIC	log-Likelihood	χ^2	df_{χ^2}	p
NR							
Unconditional	6	913.09	929.81	-450.54			
Random slope	8	915.00	937.30	-449.50	2.09	2	.352
Second-order additive	7	895.66	915.17	-440.83	19.43	1	.001
OSC							
Unconditional	6	852.50	869.12	-420.25			
Random slope	8	853.90	876.06	-418.95	2.60	2	.272
Second-order additive	7	843.66	863.06	-414.83	10.84	1	.001
CSC							
Unconditional	6	796.31	812.98	-392.15			
Random slope	8	798.21	820.44	-391.11	2.10	2	.350
Second-order additive	7	798.03	817.48	-392.01	.28	1	.597
CNSC							
Unconditional	6	794.67	811.34	-391.33			
Random slope	8	796.17	818.40	-390.08	2.49	2	.287
Second-order additive	7	795.89	815.35	-390.95	.77	1	.379

Note: NR=Number reading; Oral-symbolic comparison=OSC; Cross-out symbolic comparison=CSC; Cross-out non-symbolic comparison=CNSC

The growth curve analyses were conducted in three stages. First, we calculated the unconditional model (random intercept–fixed slope model) for each task, with Group (SLI, TA) and Time (Middle-Kindergarten=T1, Fall-Grade1=T2, Middle-Grade 1=T3) as factors. Then, two different models were tested and compared with the unconditional model. The first model allowed

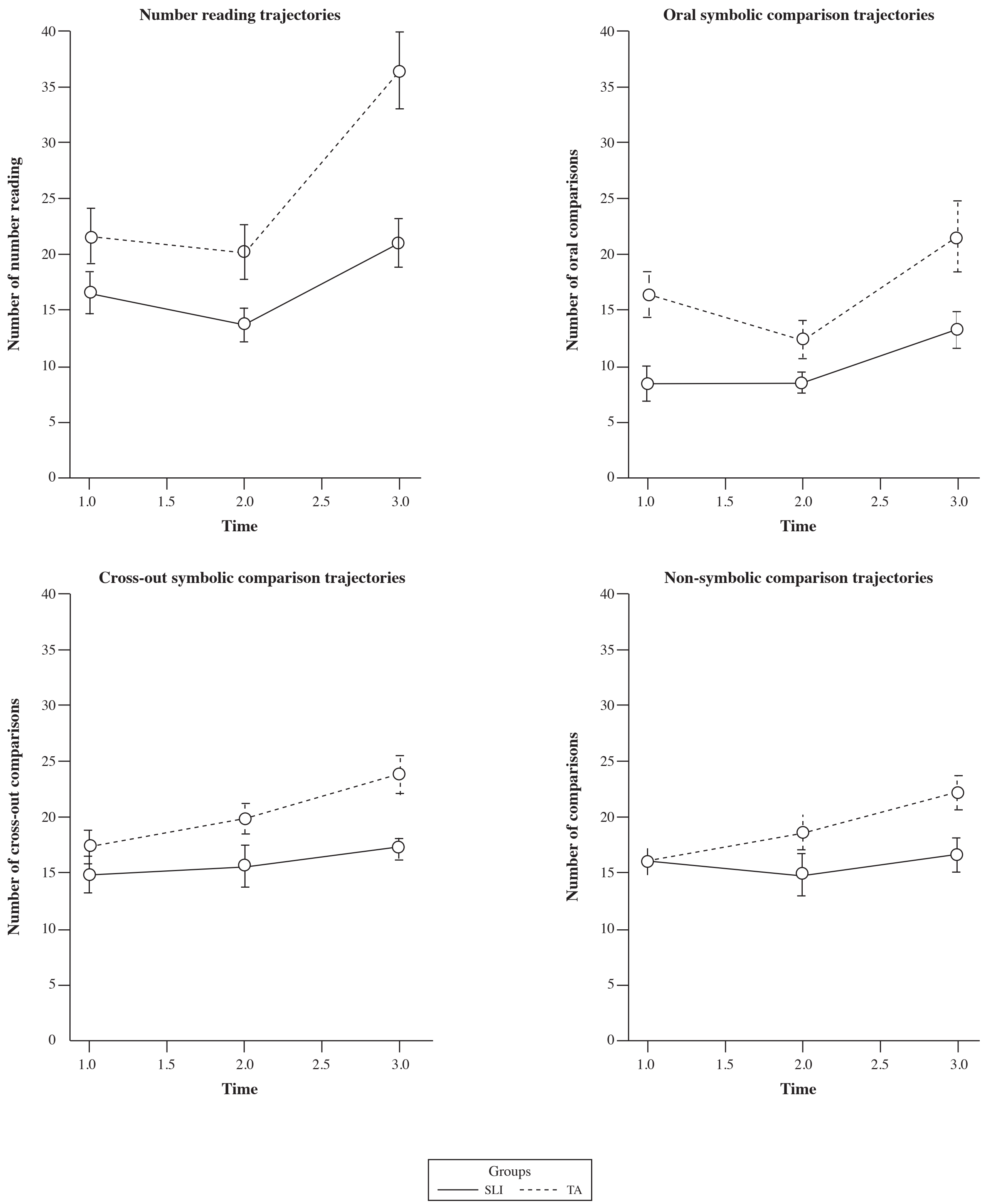

Figure 1. Developmental trajectories of numerical processing skills per group from kindergarten to first grade. Lines represent the mean number of correctly solved items in 1 minute by group and time

the linear slope to vary by child (random intercept–random slope model). The second model was a second-order additive growth model (random intercept–fixed slope model), due to the tendency observed previously, particularly in the number reading task and oral symbolic comparison task. For each task, Table 3 shows the differences in the -2 log likelihoods among the first three models (without a covariate) compared to a chi-square distribution, and AIC and BIC were also considered. The best-fitting model for number reading and oral symbolic tasks was the second-order additive growth model, while the unconditional lineal model was the best fit for the cross-out symbolic comparison and cross-out non-symbolic comparison tasks (see Figure 1).

For the number reading task, model 1 showed a significant effect of Time and Group, and an interaction between the two factors (see Table 4). Both groups show similar performance at the intercepts or starting points (TA=21.02 and SLI=17.17), but a significant difference between groups was found in the growth rate. This means that, despite the fact that the groups did not differ in number reading initially, over the year the TA group developed faster in this skill than the SLI group. Moreover, as has been mentioned previously, there was a positive quadratic trend, as the growth rate remained stable between Middle Kindergarten and Fall Grade 1, changing in magnitude at the last measurement. This quadratic trend is again probably due to the lack of instruction during two months over the summer (see Figure 1).

With regard to the oral symbolic comparison task, the model showed a significant effect of Time and Group, but no interaction between the factors (see Table 4). This means that both groups grew at the same rate, but from different starting points (TA=15.80 and SLI=9.37). As with the number reading task, there was a significant decrease in growth trajectories between Middle Kindergarten and Fall Grade 1 for both groups, which supports the significant and positive quadratic parameter in the model (see Table 4 and Figure 1).

Table 4
Growth curve results for effects on all numerical tasks

	Estimate	SE	t	p
NR				
Intercept	35.82	5.95	6.13	.001
Intercept on TA-group	-1.30	4.45	-.29	.241
Slope	-25.60	6.18	-4.14	.051
Quadratic Slope	6.97	1.52	4.60	.001
Slope on TA-group	5.15	1.75	2.94	.004
OSC				
Intercept	13.30	6.17	2.15	.035
Intercept on TA-group	20.65	8.56	2.41	.019
Slope	-7.20	6.68	-1.08	.029
Quadratic Slope	2.40	1.63	1.46	.014
Slope on TA-group	-16.92	9.34	-1.81	.077
Quadratic Slope TA-group	4.27	2.28	1.87	.069
CSC				
Intercept	13.57	2.17	6.24	.001
Intercept on TA-group	.348	3.07	.11	.910
Slope	1.22	.95	1.29	.202
Slope on TA-group	2.06	1.35	1.52	.132
CNSC				
Intercept	15.30	2.18	7.02	.001
Intercept on TA-group	-2.29	3.09	-.743	.459
Slope	.30	.98	.308	.759
Slope on TA-group	2.71	1.39	1.95	.055

Note: NR=Number reading; Oral-symbolic comparison=OSC; Cross-out symbolic comparison=CSC; Cross-out non-symbolic comparison=CNSC

For the cross-out symbolic task, the two groups showed similar trajectories (see Table 4 and Figure 1). There were no significant differences in starting point between the groups (TA=17.20 and SLI=14.79), and both grew at the same rate (TA=3.29 and SLI=1.23); however, the growth rates were not significant in either of the groups.

Finally, the results from the non-symbolic comparison task were similar to those of the cross-out symbolic task. Groups presented no differences in their trajectories; in other words, both groups performed similarly in kindergarten (TA=16.01 and SLI=15.06) and improved at similar rates (TA=3.01 and SLI=.03) (see Table 4).

Discussion

The present study compares the development of early numerical skills in children with and without SLI. To that end, the numerical skills of the two groups of children were monitored during the transition from kindergarten to first grade. The authors were especially interested in establishing whether the trajectories of the children were affected by the application of symbolic versus linguistic tasks, or by the need to use domain-specific skills. Four tasks were designed for this purpose, three of which required magnitude processing skills, and the other measured transcoding skills from Arabic numbers to verbal code (reading numbers). Of the tasks that required processing of magnitudes, two were symbolic and one non-symbolic. Finally, of the two symbolic tasks, one involved greater linguistic demand than the other.

We analyzed the growth rate of TA and SLI children in all number tasks. For the number reading task, there were differences between the groups in the intercept and in the growth rate. This means that kindergarten children with SLI already exhibited difficulties with reading numbers and, more importantly, these difficulties increased with time. This finding is consistent in part with the literature. Cowan et al. (2005) found that third grade SLI children presented poorer performance than their control group in reading numbers from two to five digits, while in the study carried out by Fazio (1996) with first graders (6-7 years of age), no differences were found in the ability to read numbers ranging from 11 to 50 between the SLI group and its age-matched control group. We believe that the difference in findings between the latter study and ours is due to the fact that we used timed tasks, whereas Fazio (1996) used untimed tasks. It is possible that when the difference between groups is not very large, typically during early stages of instruction, use of timed measures may affect presentation of differences.

In terms of the trajectory of the groups in the symbolic comparison tasks, the results varied according to whether the answer was verbal or not. In the symbolic comparison task that required a verbal response, the groups differed in the intercepts, but showed similar growth rates. This means that the initial differences found in kindergarten remain stable until the first grade. However, when the task required subjects to mark their response with a cross, the groups presented no differences in either slopes or intercepts. In other words, performance in kindergarten was similar in both groups, as was development of this skill up to the middle of the first year. It is worth noting that in none of the previous studies was a symbolic comparison task with verbal response used, so the results of this task are discussed in combination with the results of the other symbolic comparison task. The cross-out symbolic number comparison results are consistent with previous findings in which no differences in performance were observed between SLI children and children with typical development (Donlan et al., 1998; Donlan & Gourlay, 1999; Nys & Leybaert, 2013), with the only exception being the study conducted by Koponen et al. (2006). The latter suggested that inconsistency with previous studies was due to the magnitude of the numbers used. Most of the previous studies in which children of similar ages had been assessed used numbers of only one or two digits (Donlan & Gourlay, 1999; Nys & Leybaert, 2013), while Koponen et al. (2006) used numbers of up to five digits. In the present study, one- and two-digit numbers were used for 5- to 6-year-old children – which is a level of complexity appropriate to these ages – and the findings are consistent with those reported by Donlan et al. (1998), whose participants were children of 6 to 7 years old. In sum, these findings, together with those of number reading, provide evidence that SLI children present deficits in symbolic tasks only when these require a verbal response. Furthermore, in light of the results obtained in both of the symbolic comparison tasks, we can conclude that the difficulties exhibited by SLI children in the oral symbolic comparison task are due to verbal demand, and not to a deficit in processing of symbols or magnitudes. Based on our results, we can also suggest – in accordance with other authors (e.g. Barth, La Mont, Lipton, & Spelke, 2005) – that approximate number skills do emerge or develop independently of language. This statement is confirmed by the absence of differences in the trajectories of the two groups in the non-symbolic magnitude comparison task. There were no differences in either the intercepts or the development of these skills, which remained stable over time. This is backed up by previous studies in which SLI children performed comparably to their typically achieving peers in non-symbolic magnitude comparison tasks (Alt et al., 2014; Nys & Leybaert, 2013).

Two limitations of the present study should be considered. Firstly, the sample sizes of the groups of children were small, so group comparisons could not easily reach significance. Interpretations of group differences should be made with caution. Secondly, the fact that the summer vacation occurred between the first and second measurement did not allow us to properly obtain the growing tendency of the skills, due to the lack of instruction. The tasks that required a verbal response were more strongly affected, showing a quadratic tendency. Future research involving longer study periods and larger sample sizes would be desirable.

In conclusion, children with SLI present a deficit in the development of numerical skills at a very early stage of formal instruction. SLI children show difficulties in developing those numerical skills that involve high verbal processing demand – such as those that require retrieval from long term memory and articulation of a phonological representation – compared to TA children, a finding which is in line with the language deficit hypothesis. These skills are involved in the development of some later mathematical abilities, such as number fact retrieval; thus, it may be inferred that these children will present problems with such abilities in the future. On the other hand, SLI children present typical development of magnitude processing skills and perform similarly to their TA peers in the symbolic task, as they are not required to handle language. These results represent a contribution towards early identification and intervention in number skills deficits in children with SLI. Number skills that require a verbal response should be included as part of SLI early detection protocols. It would also be particularly relevant to develop interventions that promote automaticity in retrieval of number words from long-term memory.

Acknowledgements

Funding for this research was provided by CONICYT [grant: FONDECYT REGULAR no. 1161213] and the Spanish Ministry of Economy and Competitiveness [grant: Programa Ramón y Cajal, RYC-2014-16948] to the first author.

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