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ARTICLE

Cognitive predictors of language abilities in primary school children: A cascaded developmental view

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Abstract
This study investigated the longitudinal relationship between children's domain-general cognitive constraints underlying phonological and sentence processing development in a big sample of typically developing children. 104 children were tested on non-linguistic processing speed, phonological skills (phonological short term memory, phonological knowledge, phonological working memory), and sentence processing abilities (sentence repetition and receptive grammar) in 1st grade (aged 6 to 6.5) and one year later. A cross-lagged structural equation model showed that non-linguistic processing speed was a concurrent predictor of phonological skills, and that phonology had a powerful effect on the child's sentence processing abilities concurrently and longitudinally, providing clear evidence for the role of domain-general processes in the developmental pathway of language. These findings support a cascaded cognitive view of language development and pose important challenges for evaluation and intervention strategies in childhood.

Keywords: processing speed; phonological skills; sentence processing; language development

Introduction

Language is the human cognitive ability per excellence. It encompasses complex skills such as coding phonological information (Tallal, 1990), recognizing lexical items in speech and comprehending combinatory rules at sentence level (van der Lely, Jones & Marshall, 2011). These skills pose high challenges to the human cognitive system – however, most children come to understand and use language properly during the first years of linguistic experience. Yet, children with developmental language disorders (DLD) can show phonological, lexical and syntactic difficulties compared to children of the same chronological age and cognitive level, not attributable to low intelligence or neurological damage (Archibald & Gathercole, 2006; Bishop, North & Donlan, 1996).

In fact, most research in this field has focused on clinical samples in order to delimit difficulties at specific language domains. For instance, while some children present deficits in sentence processing skills without evident phonological problems (van der Lely et al., 2004), some others experience phonological problems without showing significant sentence or spoken language deficits (Bishop, 2004; Conti-Ramsden & Botting, 1999). However, there is little empirical evidence of whether dissociation between these domains is present in typically developing children (TD) and of how they interact across development, even when this could provide a basis to promote specific abilities involved in language attainment in childhood. More intriguingly, recent studies have suggested that non-linguistic processing skills might also be associated to language development (Bornstein, Hahn, Bell, Haynes, Slater, Golding, Wolke & ALSPAC Study Team, 2006; Park, Miller, Sanjeevan, van Hell, Weiss & Mainela-Arnold, 2020). This evidence implies a challenge for researchers to explore the developmental constraints and organization of language abilities in normative samples, but to date a causal model of language development in TD children is lacking. This study seeks to respond to this issue by exploring two key questions emerging from current theories of language. Do non-linguistic processing mechanisms influence the developmental trajectory of such skills? Are phonological and sentence processing skills dissociable and causally related?

One theoretical approach has distinguished between domain-specific and domain-general views of language. According to domain-specific accounts, the language system is predetermined by specialized mechanisms implicated in computing linguistic information (Marinis & van der Lely, 2007; Rice & Wexler, 1996; van der Lely, 2005). On this view, the components of language that lie upon this pre-specified computational ability – phonology and morpho-syntax – are the ones impaired in most children with DLD and constitute a domain-specific computational language system. Conversely, domain-general accounts suggest that basic processing skills channel the linguistic developmental trajectory from the onset, so that limitations in non-linguistic processes constrain language skills as well as their manifestation in children with DLD (Bates, 2004; Bishop, Bright, James, Bishop & van der Lely, 2000; Pennington & Bishop, 2009). The conceptualization of a developmental language system settled upon non-linguistic processing skills sets up the main difference between these two accounts.

Another theoretical approach distinguishes between modular and developmental views of language. Modular views assume a pre-specified and stable language system over time (Jackendoff, 2003; van der Lely, 1997), while developmental views assume a progressive and dynamic organization of the language system along development (Bornstein et al., 2006; Pennington, 2006), so that changes in one ability have developmental consequences on other abilities. An important implication derived from these views concerns the role attributed to phonology into the language system. While the first view assumes phonology as one component of a specialized computational language system (van der Lely et al., 2004; van der Lely, 2005), the second view suggests a developmental influence of subtle phonological skills on complex general language abilities (Gathercole, 2006; Gray, Green, Alt, Hogan, Kuo, Brinkley & Cowan, 2017). Most studies exploring these questions however are concurrent, and there is not clear evidence about the separability of phonology and general language abilities or about their reliance on non-linguistic-abilities over time. To date, the developmental role of basic cognitive processes and phonological skills on language development is still an unanswered issue.

Phonological skills and general language abilities

Regarding the relation between phonology and language, modular accounts understand phonology under grammar into the same computational linguistic system. In this line, several authors have found evidence of a DLD phenotype with specific difficulties in the computational mechanisms required to process phonology and morpho-syntax (van der Lely et al., 2004; Rice, Tomblin, Hoffman, Richman & Marquis, 2004). Additionally these difficulties increase with increasing phonological and syntactic task complexity (Marshall & van der Lely, 2007). Although these authors do not argue against the possible separability of phonology and syntax, they suggest that phonological and sentence processing skills are governed by an underlying computational factor. Therefore they assume the existence of one computational module of language committed to both understanding and using the elements that constitute phonological structures, and to processing syntactic dependencies into sentence structures (Friedmann & Novogrodsky, 2011; Marinis & van der Lely, 2007).

More recently, however, Ramus, Marshall, Rosen and van der Lely (2013) provided interesting evidence that phonological abilities can reflect an independent dimension from sentence processing abilities in childhood. The authors aimed to explore the degree of phonological, morphological and syntactic deficit in 64 children with DLD –with and without dyslexia- and 65 TD children between 5 and 12 years, in order to define clinical profiles. Children were assessed with a battery of tests tapping into cognition and language abilities. A factor analysis demonstrated that measures clustered into three main factors: phonological representations (nonword repetition and discrimination, naming and articulation), phonological monitoring skills (phonological knowledge, backward digits and rapid naming), and non-phonological language abilities (receptive grammar, sentence repetition, vocabulary, and syntax). Interestingly, children with DLD presented significant deficits in the three factors compared to TD children. This outcome is in line with comparative studies in the same age range showing that children with DLD are impaired in phonological storage (phonological short term memory, pSTM henceforth) and monitoring skills (phonological working memory and phonological knowledge, pWM and pKnowledge henceforth) compared to TD children of the same chronological age or cognitive level (Archibald & Gathercole, 2006; Gathercole & Baddeley, 1990; Gray, 2004; Mainela-Arnold & Evans, 2005; Weismer, Tomblin, Zhang, Buckwalter, Chynoweth & Jones, 2000). Although this view has provided essential evidence to delimit DLD phenotypes, its main caveat -apart from the fact that it is based on clinical samples-, is that it makes no claim about any possible influence between phonological and non-phonological language abilities to result in different linguistic developmental endpoints.

Developmental accounts have addressed this issue, and stress the developmental influence of phonology on general language abilities (Joanisse & Seidenberg, 1998; Pennington, 2006; Pennington & Bishop, 2009). This claim was explored by Montgomery (2000; see also Montgomery & Evans, 2009) who found a concurrent relation between representational (pSTM), monitoring phonological skills (pWM and pKnowledge) and sentence processing among children with DLD aged 5 to 12 years. The authors suggested that a functional working memory measure that encompasses these phonological skills might give account of the spoken language difficulties experienced by these children (see Montgomery, 2003). The few longitudinal studies with clinical samples provide evidence in this direction but the scope of study has limited to phonological storage exclusively (Conti-Ramsden & Durkin, 2007; Weismer et al., 2000).

An important question is whether the data obtained with clinical and non-clinical samples provide a unitary picture. Interestingly, the results obtained with TD children seem to go in the same direction. Longitudinal studies have directly related early pSTM performance –measured with the nonword repetition task- to vocabulary growth and sentence comprehension abilities in middle childhood (Bowey, 2001; Gathercole & Baddeley, 1989; Gottardo, Stanovich & Siegel, 1996). Concurrent studies exploring the role of phonological monitoring skills provide additional and suggestive data. These studies have shown that pWM abilities -generally measured with the backward digit task- are linked to children's sentence processing development in middle childhood (Cowan, Elliott, Saults, Morey, Mattox, Hismjatullina & Conway, 2005; de Abreu, Gathercole & Martin, 2011; Marchman & Fernald, 2008). TD children who report higher pWM scores show better performance in sentence completion (Gray et al., 2017) or grammatical knowledge tasks (McDonald, 2008; Verhagen & Leseman, 2016). Expanding the scope of research into this relation, some authors have also observed that pKnowledge is another concurrent predictor of sentence processing abilities in typical developing children (Gathercole, Alloway, Willis & Adams, 2006; Mainela-Arnold, Misra, Miller, Poll & Park, 2012; McDonald, 2008). A possible interpretation from these findings is that an early ability to represent and mentally operate with small linguistic subunits might underlie the reported association between phonological and non-phonological language abilities. Nonetheless, the lack of longitudinal studies makes it impossible to establish conclusive statements about the developmental role of phonology on non-phonological general language abilities in TD children.

The role of domain-general processes on language development

Another important debate between theories concerns the issue of a possible underlying cause of phonological deficits that could explain not only the developmental trajectory of language in TD children, but also the different phenotypes observed in DLD children (Pennington, 2006). While domain-specific accounts do not argue for this causal link, domain-general accounts claim that basic mechanisms that operate at a lower processing level in the developmental chain could be foundational for language acquisition and therefore shape the phonological deficit and its manifestation (Pennington & Bishop, 2009). The rationale is that general processing mechanisms might constitute the cognitive infrastructure for linguistic abilities that are built on optimal perceptual coding grounds (Bishop, Adams & Norbury, 2006; Norbury, Bishop & Briscoe, 2002).

Processing speed has been suggested as a key constraint for children with DLD (Montgomery, 2004). This claim was founded on the observation that sentence processing difficulties in these children decreased when sentences were presented at a slow-rate. This hypothesis was confirmed by further studies showing that children with DLD show significantly greater times in speed tasks compared to TD children (Montgomery & Windsor, 2007; Park, Miller & Mainela-Arnold, 2015; Windsor, Kohnert, Loxtercamp & Kan, 2008). Consistent with domain-general accounts, processing speed in non-verbal tasks has proved to be concurrent predictor of expressive and receptive language in children with DLD between 8 and 14 years (Leonard, Weismer, Miller, Francis, Tomblin & Kail, 2007; Park et al., 2020). Interestingly, recent works have found evidence for a direct relation between processing speed in early infancy and further vocabulary and sentence processing in TD children (Fernald & Marchman, 2012; Peter, Durrant, Jessop, Bidgood, Pine & Rowland, 2019). In another longitudinal study, Newbury, Klee, Stokes and Moran (2016) observed that processing speed and verbal monitoring abilities independently predicted later language abilities, a finding that goes in line with a previous concurrent study with children aged 6 to 13 (Poll, Miller, Mainela-Arnold, Adams, Misra & Park, 2013). Additionally, some authors suggest a possible cascaded relation between processing speed, phonology and spoken language. Marchman and Fernald (2008) showed that auditory detection times at the age of 2 predicted verbal expressive language abilities at the age of 8 – interestingly, language abilities were modulated by phonological storage and monitoring skills at that age (digit span and word order tasks). A possible interpretation is that greater speed at an early age makes phonological representations in memory easily available, and frees resources for sentence processing in a later developmental period. However, to date no work has tested the role of non-linguistic processing speed in the reported phonology-to-general language relation in middle childhood, and thus, a domain-general "cascaded" view for language development has not been fully accounted for.

The present study

The present work was designed to provide an explanatory framework for a cascaded view of language development by testing a large sample of TD children aged 6 concurrently and one year later with two aims: i) to test the separability of phonology and sentence processing abilities over time; ii) to explore the predictive relations of nonverbal processing speed and phonology to sentence processing abilities concurrently and over time incorporating the assumptions of domain-general accounts. According to modular accounts (van der Lely, 2005), phonological and sentence processing might constitute one stable computational factor, and although these views do not make any claim about how this factor changes over time, only autoregressive effects on computational abilities should be expected. According to developmental accounts, however, phonological skills not only would be separable but also would act as strong predictors of sentence processing abilities concurrently and over time (Gathercole et al., 1989, 2006). Additionally, according to domain-general views, non-verbal processing speed might predict phonological skills (Marchman & Fernald, 2008) and sentence processing abilities (Park et al., 2020; Peter et al., 2019), a relation that is not accounted by domain-specific views. Whether this relation is mediated by phonological skills is a question of interest since a "cascaded" developmental model has not been previously tested. Such model might be critical to determine if the developmental route of language dissociates from nonverbal processing speed longitudinally, and could give account to the normative developmental trajectory of language in childhood.

Method

Participants

One hundred and twelve 1st graders recruited from six different schools located on the suburban areas of Bilbao (Basque Country) took part in the study. All children entering first grade in these schools were invited to participate. Informed consent from parents was received from the 112 children. The sample was composed by a majority of Basque–Spanish bilinguals (98%), whose main language was Spanish. Amount of Basque–Spanish exposure was measured with a parent questionnaire and this factor was controlled in the study. Children met the following inclusionary criteria for typical development: a) were enrolled in first grade; b) had no history of neuropsychiatric disorders (ADHD, autism

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spectrum disorder); c) no history of special education services; d) no record of speech and language therapy; e) no signs or diagnosis of DLD. Based on these criteria eight children showed signs of language impairments – 2SD in two or more language measures – and were excluded from the analysis. The final sample comprised 104 children. SES was controlled by a questionnaire filled in by parents and was ranked in the middle range (income between 1500-3000€). We report here data for two phases: time 1 (first grade in school, *M* age=6.4 years, *SD*=0.36; *N*=104) and twelve months later at Time 2 (second grade in school, *M* age=7.5 years, *SD*=0.35). All children were subject to the same phonics and reading instruction policy.

Tasks and testing procedure

All children completed a battery of cognitive and linguistic measures that was administered in two sessions in the beginning of the academic course (November-December). Each child made all the tasks individually, in a silent room and following the instructions of the experimenter. Tasks were administered in a fixed order to all children.

Non-verbal IQ

Matrices task of the Kaufman Brief Intelligence Test (K-BIT, Kaufman & Kaufman, 1990) was used to control for the non-verbal reasoning score across participants. According to the test manual, internal consistency estimates for the subtest range from .74 to .93. The task requires the child to point to the missing figure from a logical sequence or set. Trials are grouped in eight sets of five items each. Testing is discontinued when the child responds incorrectly to all of the items in one set.

Processing speed

Processing speed tasks included the Symbol Detection Subtest in the WISC-IV (Wechsler, 2003) and a Visual Search Task similar to the one employed by Leonard et al. (2007). Although these tasks involve multiple processes such as attention, memory, stimulus location coding and even executive processes (Sweet et al., 2005) they have been used as part of a processing speed subtest index both in predictive (Gomez, Vance & Watson, 2016) and factor analysis studies (Weiss, Keith, Zhu & Chen, 2013). In the WISC Symbol Detection Task each child had to detect whether one presented symbol was embedded in a symbol array as fast as possible. In the Visual Search Task children were presented a target symbol on the computer previous to a five-symbol array. Children were asked to scan the array and decide, as soon as possible, if the previously presented target was present or absent by pressing a blue or red key in the keyboard. This task included five conditions corresponding to the different positions in the array, counterbalanced across 50 present and 50 not present trials. Mean response reaction time for correctly detected items was taken as an index of each participant's processing speed.

Phonological abilities.

Phonological short-term memory was measured using the nonword repetition task, based on the classical paradigm (Hulme & Tordoff, 1989), consisted in presenting sets of syllabic nonwords auditorily, which had to be repeated by the child in the same order.

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For this purpose, four sets of six nonwords each were constructed using the Syllabarium database (Duñabeitia, Cholin, Corral, Perea & Carreiras, 2010). Nonwords and sets were paired in bigram frequency (mean bigram frequency per set = 1.8), syllable frequency (mean syllable frequency per set = 12.1) and syllable complexity, half of them including simple CV syllables and half complex CVC syllables. The first set consisted of two syllable chains, and each set implied an additional syllable up to five. Total span was obtained counting total of correct remembered items.

Phonological working memory

This ability was measured with the backward digit span in the WISC-IV (Wechsler, 2003). Seven sets of two trials each were presented. Each set implied an additional digit starting with a two digit trial. The higher number of well-recalled digits was taken as the digit span indicator. PHONOLOGICAL KNOWLEDGE was measured with the phoneme deletion subtest in the CELF-4 (Semel, Wiig, Secord & Langdon, 2006). In this task the child had to delete the first sound of the words presented auditorily. One point was given for every correct answer and no point when the response was incorrect. This task was chosen not only to text phonological monitoring abilities, but also because it is an important reading predictor.

Sentence processing

THE SENTENCE REPETITION TASK, included in the CELF-4 (Semel et al., 2006), was used to measure the ability to use the lexical and syntactic knowledge stored in memory under increasing linguistic constraints (see Klem et al., 2015). This subtest is composed by 32 items which were administered consecutively until more than three mistakes were made on the repetition of the same item in six consecutive sentences. Scoring followed these criteria: verbatim repetition summed three points; one mistake on sentence repetition was scored with two points; two or three mistakes on repetition were scored with one point; and more than three mistakes involved no point. Mistakes were considered when one (or more) word within the original sentence was omitted, repeated, added, transposed or substituted for another one. RECEPTIVE GRAMMAR was measured using the standardized SENTENCE STRUCTURE SUBTEST from CELF-4 test (Semel et al., 2006). The child heard a sentence and had to select the picture that conveyed its meaning from a set of four. One point was given for each correct response and no point was given otherwise. The RECEPTIVE GRAMMAR score comprises the sum of correct responses.

Analytical approach

Before calculating the descriptive statistics, the children's scores were examined for outliers, normality and missing data. In this study, all children reached IQ scores over 85 (Rice, 2016). The data were screened for univariate outliers, which were defined as cases more than 2 *SD* above or below the mean. The final dataset for subsequent analyses consisted of 104 children. Data analysis was based on raw scores of correct responses in each task. As a first step, we conducted a Pearson correlation analysis for each time point. All correlation coefficients were below .50. Additionally, all variance inflation factors in the conducted regressions were below 2. This suggests that multicollinearity was not overly problematic in this study (Tabachnick & Fidell, 1996).

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As a second step, we tested a cross-lagged cascaded developmental model using structural equation modelling (SEM, Satorra & Bentler, 2001). A first tentative analysis explored the statistical fit of a model including a computational factor including pSTM, pKnowledge and pWM, sentence repetition and receptive grammar. The final model incorporated a processing speed factor as predictor of phonology and sentence processing factors. To assess how different skills were related to each other longitudinally, a latent variable autoregressive path model with cross-lagged effect was fitted to the data for the whole sample. This allowed exploring whether either of the components predicted additional variance in the other key components across the two time points. Of particular interest was testing which were the predictive influences from earlier to later variables after controlling for autoregressive effects. Additionally, the scarce longitudinal evidence, suggesting that both phonology (Marchman & Fernald, 2008; Metsala, Stavrinos & Walley, 2009) and processing speed measures (Peter et al., 2019) can be modulated by increasing language knowledge, justifies the cross lagged paths in the model. The model fit was evaluated using various fit indices. As a rule of thumb, model fit is considered good if chi-square is non-significant, the Root Mean Square Error of Approximation (RMSEA) is below .08 and the Comparative Fit index (CFI) is above .90 (Kline, 2005).

Results

Descriptive statistics and correlational analyses

The descriptive statistics for all of the variables at each time point are shown in Table 1. Reliability was calculated by analysing split-half coefficients, based on the percentage of correct items in each task. Percentiles processing speed measures were calculated for regression analyses and are included in Table 1. In all cases, reliability was adequate, and moderate to high in value. Skewness and kurtosis values for all measures indicated normal distributions of scores, with one estimate exceeding 2 (this being the kurtosis value for visual attention and working memory at Time 2). A series of repeated measures analyses of variance established that there was significant growth in every variable ($p < .001$) over time except IQ.

The correlation coefficients between all the main measures at Times 1 and 2 are shown in Table 2. Pearson correlation coefficients with Bonferroni correction for multiple comparisons revealed that, at Time 1, both processing speed measures were moderately associated, $r(102) = -.29$, $p = .001$, and WISC processing speed was related to pKnowledge, $r(102) = -.205$, $p = .003$. Also the associations between pWM and pSTM , $r(102) = .32$, $p = .001$, and between pWM and pKnowledge, $r(102) = .30$, $p = .001$, were significant. Moderate associations were also found between pSTM and pKnowledge, $r(102) = .81$, $p = .001$, and between sentence repetition and receptive grammar $r(102) = .34$, $p = .001$. Finally, pKnowledge showed significant associations to sentence repetition, $r(102) = .22$, $p = .003$, and grammar, $r(102) = .26$, $p = .001$. At Time 2 a relation was found between both processing speed measures, $r(102) = -.20$, $p = .002$; and between pSTM and pKnowledge, $r(102) = .26$, $p = .006$, although these associations were weaker than at Time 1. Again, pWM was related to pKnowledge, $r(102) = .32$, $p = .001$; as well as to sentence repetition and grammar, $r(102) = .31$; and $r(102) = .30$, respectively, both p=.002, and the relation between sentence repetition and receptive grammar was similar to that found at Time 1, $r(102) = .31$, $p = .001$. Also the associations reported in Time 1 between pKnowledge and sentence repetition, $r(102) = .28$, $p = .002$, and grammar, $r(102) = .23$, $p = .003$, were significant at Time 2.

Table 1. Descriptive data of performance on experimental measures at Time 1and Time 2.

Type of task	*Mean*	*SD*	*Reliability*	*Skew*	*Kurtosis*
Time 1					
Processing speed (WISC RT)	*2438.5*	*390*	*0.60*	*−.54*	*.188*
PS WISC RT percentile	*52.6*	*27.2*	*0.60*	*.004*	*−1.01*
Processing speed (Visual Search RT)	*1197.1*	*420*	*0.62*	*.391*	*−.710*
PS Visual Search RT percentile	*68.7*	*32.2*	*0.61*	*.731*	*−.131*
Verbal WM (WISC back digit span)	*2.5*	*1*	*0.59*	*−1.21*	*1.22*
Phono STM (Nonword rep %corr)	*63.5*	*17*	*0.68*	*−.02*	*−.476*
Phono knowledge (CELF deletion % corr)	*40.2*	*34.1*	*0.89*	*.122*	*−1.51*
CELF (Sentence rep)	*48.2*	*15.1*	*0.95*	*−.452*	*.202*
Receptive grammar (Sent. struc)	*22.7*	*3.5*	*0.60*	*−.172*	*−.609*
K-BIT matrices percentile	*62.2*	*23.1*	*0.76*	*−.150*	*−.928*
K-BIT matrices typified	*106.1*	*14.6*	*0.78*	*−.67*	*.64*
Time 2					
Processing speed (WISC RT)	*2156.1*	*403*	*0.95*	*−.32*	*−.674*
Processing speed RT percentile	*53.8*	*28.1*	*0.92*	*.007*	*−1.21*
Processing speed (Visual Search RT)	*1210.2*	*449*	*0.60*	*.598*	*1.20*
PS Visual Search RT percentile	*67.5*	*39.1*	*0.63*	*.840*	*.703*
Verbal WM (WISC back digit span)	*3.2*	*0.8*	*0.69*	*−.334*	*2.03*
Phono STM (Nonword rep % corr)	*71.3*	*14.1*	*0.60*	*−.078*	*−.73*
Phono knowledge (CELF deletion % corr)	*72.5*	*29.5*	*0.87*	*−1.03*	*.036*
CELF (Sentence rep)	*56.9*	*12.08*	*0.90*	*−.340*	*−.101*
Receptive grammar (Sent. struc.)	*25.5*	*2.7*	*0.59*	*−.819*	*.752*
K-BIT matrices percentile	*58.2*	*23.8*	*0.75*	*−1.21*	*−.733*
K-BIT matrices typified	*104.2*	*16.1*	*0.76*	*−1.17*	*1.08*

Note. Sample $N = 104$.

Longitudinal Predictive path models

For the full sample of 104 children, we tested whether predictive relations among the language components were fitted to one factor model including a single computational component, or whether a three factor model, including processing speed, phonology and sentence processing components, provided better fit supporting the predictions made by a cascaded cognitive view for language development. Negative regression values were avoided using higher percentiles for better % correct responses and better reaction times. IQ and age were included in the model as control variables, since age is related to changes in both IQ and processing speed (Fry & Hale, 2000). In addition, controlling these variables makes it possible to identify predictive effects independent of nonverbal IQ (see Rice et al., 2004; Bishop et al., 2000). Due to the lack of variability in SES, this variable

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Table 2. Correlation coefficients among all measures at Time 1and Time 2.

	1	2	3	4	5	6	7
1. Processing speed WISC		-.201**	-.137	-.036	-.141	-.060	-.051
2. Processing speed Visual Search	-.292**		-.080	-.018	-.147	-.133	.007
3. Verbal working memory	-.127	-.026		.129	.320*	.319**	.302**
4. Phonol short-term memory	-.164	-.140	.325**		.260**	.258*	.089
5. Phonological Knowledge	-.205*	-.184	.306**	.810**		.282*	.235*
6. Sentence repetition	-.036	.040	.141	.245*	.228*		.312**
7. Receptive grammar	-.156	.093	.183	.247	.263**	.345**	

Note. Sample *N*= 104. Values in the lower triangle represent correlations at Time 1 and values in the upper triangle represent correlations at Time 2.
* $p \leq .05$; ** $p \leq .01$.

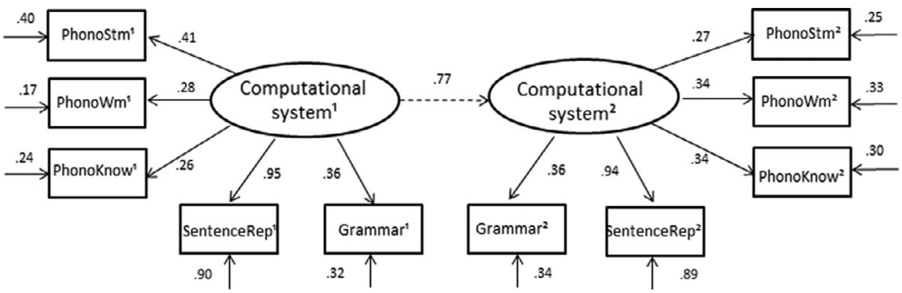

Figure 1. One factor cross-lagged path model based on cascaded developmental account

could not be entered in the model. The first tentative path model included one latent variable including pSTM, pKnowledge, pWM, sentence repetition and receptive grammar (see Figure 1). Cross-lagged paths explored longitudinal predictions including autoregressive effects. This model did not provide good fit to the data (χ^2 =97.97, df = 34, p = .002, CMIN = 2.88, CFI = .75, RMSEA = .135), and reflected a non-significant relation from Time 1 to Time 2.

The final model, presented in Figure 2, included three latent variables: processing speed (processing accuracy and reaction time), phonology (pSTM and pKnowledge, and pWM) and sentence processing (sentence repetition and receptive grammar). Direct and indirect concurrent predictive paths were included following a developmental cascaded view, and cross-lagged paths were included to explore longitudinal relations among all latent variables. This model provided an excellent fit to the data (χ^2 =75.78, df = 63, p = .130, CMIN = 1.00, CFI =.97, RMSEA = .044), and reflected a concurrent indirect effect of processing speed on sentence processing mediated by phonology at Time 1, although this relation became non-significant at Time 2. Turning to longitudinal effects, the model reflected predictive cross-lagged relations between phonology and sentence processing from Time 1 to Time 2, even when autoregressive effects were taken into account. Including a direct longitudinal path from Time 1 processing speed to Time 2 sentence processing did not lead to substantial changes in model fit (χ^2 =76.35, df = 63, p = .120,

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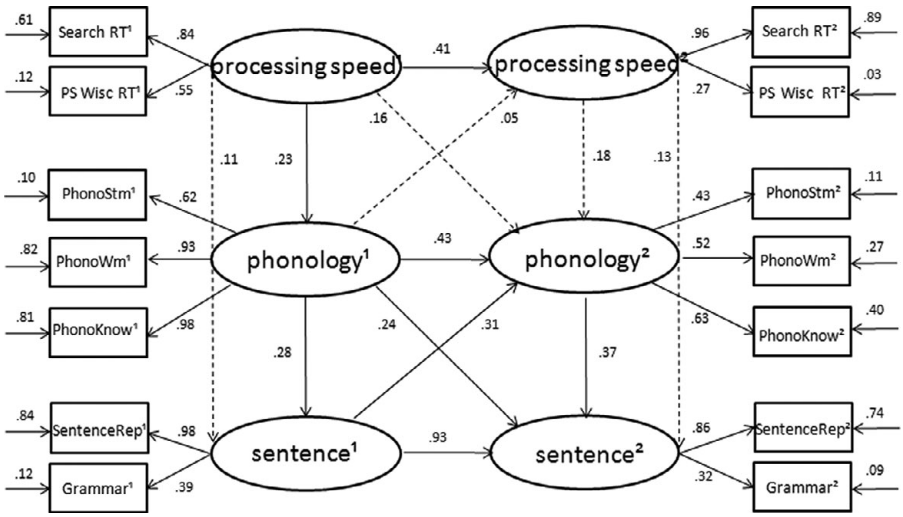

Figure 2. Three factor cross-lagged path model based on cascaded developmental account

CMIN = 1.00, CFI =.97, RMSEA = .045), but this relation was not significant $\beta = .012$; $p = .89$) – therefore, for the sake of simplicity, a simple model with cross-lagged paths was depicted in the Figure 2. Statistical power for SEM models was calculated (Westland, 2010). The resulting value was .82 with an optimal sample size range of 50-177.

The model showed a strong and stable relation over time between phonology and sentence processing and demonstrated that processing speed determines the child's potential to acquire phonological abilities at the age of 6. It also reflected a change from Time 1 to Time 2 due to the loss of strength from processing speed to phonology at the second evaluation time, as well as reciprocal interactions between phonology and sentence processing across the two time points (once autoregressive effects were controlled).

Discussion

This study was designed to explore how the language system is configured in childhood by testing different theoretical accounts of language. Modular views assume that phonological and sentence processing abilities fall beyond the same computational language factor (van der Lely, 2005). Conversely, developmental accounts claim for the separability of these abilities based on the evidence that children's phonological skills are precursors of their performance on complex language abilities (Bishop et al., 1996; Marchman & Fernald, 2008). Additionally, in the light of domain-general accounts, basic non-linguistic processes such as processing speed can constrain phonological skills and sentence processing abilities (Bayliss, Jarrold, Baddeley, Gunn & Leigh, 2005; Newbury et al., 2016; Peter et al., 2019). Although the relation between phonology and language has been mainly explored in middle childhood, the influence of processing speed on language has not been fully examined at this age. To address these issues, we explored the potential predictive role of non-linguistic processing speed in language attainment longitudinally using a big sample of 6 year old TD children. Our results reveal that i) the configuration of

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the child's language system is compatible with the idea of a multicomponent system organized in a cascaded manner; ii) non-verbal processing speed provides the cognitive architecture to support language; iii) phonological and sentence processing abilities grow into highly organized language subsystems less dependent of domain-general processes over time.

A developmental cascaded model of language: how can different accounts be reconciled?

Our primary question was to examine whether a cascaded developmental model including non-verbal processing speed and two distinct language skills -phonology and sentence processing- represents the child's language system. We tested two models based on the major claims provided by the extant developmental literature – namely, that human language is organized around a computational system that operates with specific rules and representations such as phonemes or word phrases; or that there are basic non-linguistic processes that constrain how each child's cognitive system computes such rules and representations at two different levels, phonology and non-phonological language abilities. Firstly, our results indicate that a language system with a phonological component including storage and monitoring abilities, and a sentence processing component, represent relatively well the language system of 6 to 7 year old children (see Ramus et al., 2013). Additionally, our model provided support for the concurrent influence of phonology on sentence processing abilities, and more interestingly, of a reciprocal influence of grammatical abilities and phonology over time. This clearly goes in line with a developmental view.

Secondly, in agreement with a domain-general view, the incorporation of a non-linguistic processing speed component to the language system provided excellent fit to the data, revealing that basic underlying processes were a concurrent predictor of phonological skills at the age of 6. In line with the findings of Leonard et al. (2007) and Majerus, Heiligenstein, Gautherot, Poncelet and van der Linden (2009), this outcome supports a "cascaded" view of language development. Evidently, the model is not at odds with the factor structure proposed by Ramus et al. (2013), since it was built on decoupling phonological from sentence level abilities in two components, but extends this evidence since it demonstrates that the ability to understand and process grammar is indirectly predicted by basic, non-linguistic processes through phonology at the first evaluation time. This outcome is important for two reasons. On the one side, it supports the idea that domain-general processes can drive the development of phonological skills directly, and of further linguistic abilities indirectly, assuming that some general constraints set the ground for the language acquisition process. On the other side, it favours the view that subtle phonological skills (particularly, phonological monitoring skills, see next section) modulate the development of sentence processing abilities. As seen, our model does not conflict with the claim that there are some skills specialized to process elements specific to language as assumed by domain-specific accounts; yet, it goes beyond this view by suggesting a key role of non-linguistic cognitive skills on language processing, as well as a dynamic influence of distinct language abilities along development (see Bishop, Nation & Patterson, 2014). A brief look at concurrent and longitudinal relationships can shed light on the two mentioned issues.

Concurrent predictors of complex language abilities

A key finding in our study is the role of children's non-linguistic processing speed in the reported association between phonology and language outcomes. Concretely, the significant influences of phonological skills on sentence processing at 6 were influenced by children's processing speed at that age. A similar effect was previously found in TD children between 6 to 13 years (Poll et al., 2013), showing that processing speed predicted verbal working memory and this skill predicted sentence repetition abilities concurrently. Also interrelations between processing speed, verbal working memory and language have been reported in children with DLD (Leonard et al., 2007; Montgomery & Windsor, 2007), suggesting that children's response efficiency is linked to developmental changes in general language abilities because it facilitates perceptual selection and coding of those linguistic representations – phonemes, words, word-phrases – the child needs to operate with (Majerus et al., 2009; van Dijck, Abrahamse, Majerus & Fias, 2013).

Notably, our outcome expands on previous evidence by demonstrating that proficiency in one domain (non-linguistic processing speed) can directly predict proficiency in another domain (phonology). This outcome is consistent with the findings that phonological skills are regulated by basic underlying cognitive resources in childhood (Bayliss et al., 2005; Kail & Park, 1994; Marchman & Fernald., 2008) and sustains the notion that the child's ability to codify, select and monitor linguistic information might depend on the speed to complete these operations before information decays (Leonard et al., 2007; Park et al., 2020).

One explanation for this interplay is that a child's processing potential determines the amount and quality of information coded or retrieved during a certain time-window (Kail, 2007), which goes in line with the reported indirect influence of processing speed on expressive language tasks through phonological skills in TD children (Marchman & Fernald, 2008). Although the nature of the connections is unclear, we speculate that good performance on automatic processing speed tasks may be a direct indicator of a child's ability to compute verbal information non-dependent on linguistic knowledge. Thus, slower children who suffer cognitive load during retrieval and rehearsal processes might be more easily detected in phonological tasks rather than in tasks depending on linguistic knowledge (Evans, Saffran & Robe-Torres, 2009; Park et al., 2015). In turn, the importance of phonological skills as predictors of sentence processing derives from the fact that these skills provide a window on the ability to operate with the linguistic representations a child possesses. Potentially, children with higher phonological monitoring skills would have more resources to retrieve and organise their language knowledge.

Consistent with this, an important finding to emerge from our data is the key role of phonological monitoring skills in the improvement of sentence processing abilities. It is worthy of note that within the phonological domain, the two measures that required monitoring phonological information showed greater loading values compared to phonological storage in the model, demonstrating the operational nature underpinning pWM and pKnowledge tasks (see Alloway, Gathercole, Willis & Adams, 2004). This finding fits well with previous evidence showing that the proficiency in operating with sublexical units drives the ability to process long and complex language structures (Baddeley, 2000; Conway, Cowan, Bunting, Therriault & Minkoff, 2002; Saffran & Wilson, 2003). While storage abilities have been directly related to vocabulary learning (Bowey, 2001; Chrysochoou, Bablekou, Masoura & Tsigilis, 2013; Gathercole, 2006; Jarrold, Thorn & Stephens, 2009; Verhagen & Leseman, 2016), verbal monitoring abilities give account of language planning (Acheson & MacDonald, 2009) or sentence processing abilities (Mainela-Arnold et al., 2012; McDonald, 2008).

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These observations suggest that language acquisition is clearly a complex process which may fail for a number of different reasons. The reliance of sentence processing abilities on processing speed and phonological skills highlights that these aspects may be particularly problematic in early stages of development (Bishop et al., 2000, 2014). These aspects might hinder or facilitate complex linguistic abilities such as internalizing syntactic frames, retrieving prior syntactic knowledge or resolving online dependencies, all aspects that can affect receptive and expressive aspects of language.

An issue of interest is whether the boundaries between specific DLD phenotypes might be explained in terms of difficulties in basic processes driving phonology, or whether a deficit on a specific phonological skill could accommodate clinical heterogeneity. Studies with clinical samples reveal that verbal monitoring impairments are concurrently linked to sentence processing difficulties (Montgomery & Evans, 2009). Whether this link is attributable to the developmental influence of basic domain-general cognitive processes or simply a result of impaired linguistic skills might deserve further inquiry.

Longitudinal predictors of language abilities

The main motivation of the study was to explore how predictive relations evolve over time, grounded on the claim that both basic cognitive processes and language abilities change developmentally (Fry & Hale, 2000; Kail, 2007). The significant predictive relations observed in our model provide support for the notion of a flexibly organized system. Our results suggest a common processing mechanism sustaining phonological and sentence processing abilities early in childhood, but also reveal that the weight of basic processes decreases as language abilities increase. In fact, cross-lagged effects indicated that speed of processing at 6 did not predict growth in phonological performance beyond autoregressive effects. This finding certainly questions the view that growth in one domain has longitudinal effects on the other at least across this age range (6 to 7), but does not rule out the possibility that this relation could be found at earlier ages. A fact that can be clearly drawn from the data is that phonological skills become less dependent on speed of processing over time.

A potential explanation might be that, by the age of 7, children have acquired ceiling levels speed measures so that their predictive value decreases. However this alternative seems implausible since processing speed does not peak until late childhood (see McAuley & White, 2011). Another explanation could be that children have learnt to apply their basic processing resources specifically to linguistic tasks so that verbal abilities become less related to domain-general resources with time (Alloway, Gathercole & Pickering, 2006; Gathercole, Pickering, Ambridge & Wearing, 2004). This might indicate a developmental trajectory of language in which once a certain level of specialization is achieved, the contribution of nonverbal abilities is diluted or no longer plays a substantial role.

Considering this outcome in relation to strength of associations between variables across time points, data suggest that the language system can be reasonably dynamic over time. One key finding was a strong and stable predictive role of phonology on sentence processing at the two time points and longitudinally. This symmetry in the relative contribution made by phonology on sentence processing abilities demonstrates the pre-eminence of phonological skills as determinants of success in language development. Interestingly, sentence processing abilities in Time 1 also contributed to the development of phonological skills in these children one year later, reporting a reciprocal influence of grammatical knowledge on phonological skills. The longitudinal effects of language

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knowledge on phonological performance have been already reported in TD children (Bowey, 2001; Marchman & Fernald, 2008) and in children with DLD (Conti-Ramsden & Durkin, 2007). However, long-term longitudinal studies are required to provide an explanation of how linguistic experience changes the developmental influence of specific cognitive and linguistic abilities over time.

In sum, using a variety of tasks in a large non-impaired sample, we provided support for a cascaded cognitive view of language acquisition. Our findings come to sustain the view that language is not a unitary construct, and that component skills can be channelled by domain-general underlying processes (see Karmiloff-Smith, 1998). Tracing the development of these processes is therefore worthwhile to understand how language components become specialized during development. Two important limitations offer a cautionary note for the generalization of these findings. First, this sample was tested in two developmental times and children were about 6 years old when they were tested first. It is likely that, if the first evaluation was extended to younger children, processing speed might have a longer developmental influence on phonology. Future studies should test this model in a broader developmental period to provide a picture of the long term effect of phonological speed and phonology on later sentence processing skills. Second, given the relative high proportion of children who experience language difficulties, this model should be tested in a big sample of children with DLD, in order to pinpoint if the cognitive constraints of the language system in DLD differ from those observed in TD children concurrently and longitudinally. This is an important direction for future work if well-targeted preventive interventions are to be put in place.

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