Early language processing efficiency and pre-literacy outcomes

in children born full term and preterm.

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The data that support the findings of this study are openly available at https://github.com/vmarchman/PTFTPreliteracy

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Research Highlights

- We examined links between language processing efficiency at 18 months and pre-literacy outcomes at 4 ½ years, directly and controlling for expressive language.
- Language processing efficiency (accuracy and speed (RT)) predicted print knowledge and phonological awareness. Expressive language significantly mediated all effects.
- Links between processing speed and phonological awareness remained after controlling for expressive language, suggesting independent effects of processing speed on phonological awareness.
- Associations were comparable in both birth groups, suggesting that early language processing efficiency has cascading effects on learning in children regardless of birth status.

Abstract

Variation in skill at processing language in real time in toddlerhood, i.e., language processing efficiency, has been shown to be associated with variation in later language and non-verbal cognitive outcomes in full term (FT) and preterm (PT) children. However, no studies to date have assessed relations between early language processing efficiency and later pre-literacy skills and whether these relations operate directly on outcomes or indirectly, via relations to other skills, such as expressive language. In this study, participants (n=94, 49 FT, 45 PT) were assessed in the looking-while-listening (LWL) task at 18 months (corrected for degree of prematurity in PT group) and on standardized tests of pre-literacy skills (print knowledge and phonological awareness) and expressive language at 4 ½ years. Early language processing efficiency predicted pre-literacy outcomes (r^2 change ranged from 7.8 to 19.5%, $p < 0.01$) in FT and PT children. These relations were significantly reduced when controlling for children's expressive language abilities. However, processing speed and phonological awareness were also directly related. Parallel relations were observed in both birth groups. Thus, early real-time language processing efficiency in toddler years supports expressive language abilities at preschool age, which in turn supports developing pre-literacy skills in FT and PT children.

In order to comprehend language, listeners must attend to the speech signal and map the information onto referents in the visual or mental world. Studies have shown that both adults and children are efficient at real-time language processing, incrementally parsing the speech signal and extracting meaning within milliseconds after it becomes available (Allopenna et al., 1998; Fernald et al., 1998). The skill with which very young children can integrate auditory and visual information in real-time has been shown to reveal individual differences that have substantial predictive validity. For example, children with more efficient language processing at 18 months can produce more words and learn vocabulary more rapidly over the second and third years of life than children with less efficient processing (Fernald et al., 2006; Fernald & Marchman, 2012; Law & Edwards, 2014; Peter et al., 2019). In addition, early language processing has been shown to be associated with both language-based and non-verbal information processing skills in preschool-aged children (e.g., Marchman et al., 2016, 2018). However, to date, to our knowledge, no studies have explored whether children's early skill in oral language processing is related to the development of literacy during preschool or school age.

Assessing Language Processing Efficiency

The efficiency with which young children process language in real time can be assessed using an experimental eye-tracking procedure known as the "looking-while-listening" (LWL) task (Fernald et al., 2008). In this task, children are shown two pictures while a voice names a target picture (e.g., "Where's the doggy?"). Language processing efficiency is reflected in overall looking time, i.e., *accuracy*, the proportion of time spent fixating the target picture, rather than the distracter picture. Processing speed or *reaction time* (RT) is defined as mean number of milliseconds (ms) to initiate a shift in gaze from the distracter to the target picture in response to the stimulus sentence. Together, measures of early language processing efficiency capture not only what children know, but also how efficiently children can process information in real time (Fernald & Marchman, 2012).

Early language processing efficiency has been shown to be associated with learning outcomes in a variety of domains. For example, individual differences in early language processing efficiency in toddlerhood has been linked to variation in vocabulary development and morphosyntactic skill in preschool-aged children (Jones & Rowland, 2017; Lew-Williams & Fernald, 2007; Peter et al., 2019). Early language processing efficiency has also been shown to be associated with later verbal intelligence quotient and working memory scores in school-aged children (Marchman et al., 2019; Marchman & Fernald, 2008). Associations between early processing efficiency and a range of language and cognitive outcomes suggests continuity between skills involved in early real-time language processing and those involved in a range of later complex thinking, learning, and problem solving skills, including attention, working memory, and processing speed (Fernald & Marchman, 2012). Children with faster processing speed may be more efficient at allocating finite processing resources than children with slower processing speed. Faster speeds allow incoming information in the speech signal to be processed more effectively, leading to faster learning. It is also possible that faster processing enables more effective chunking of information in the incoming speech signal, thereby, requiring less information to encode word form-meaning mappings (Jones & Rowland, 2017; Peter et al., 2019). For children who may be at risk for language delays or disorders, slower and less efficient language processing may have cascading consequences for later learning in a variety of domains and may be an additional risk factor that foreshadows delayed outcomes (Fernald & Marchman, 2012; Venker et al., 2013).

Early Language Processing Efficiency in Children born Full Term and Preterm

Premature birth affects approximately 10.2% of all births in the US (March of Dimes, 2020) and is associated with increased risk of adverse neurodevelopmental outcomes. Risks are higher for those infants born very (birth at < 32 weeks gestation) or extremely (birth at < 28 weeks gestation) preterm (PT) compared to children born at term (birth > 37 weeks gestation (Adams-Chapman et al., 2018). Compared to their full-term (FT) peers, studies have shown that children born PT are at increased risk for language-related deficits, including poor literacy outcomes (Borchers et al., 2019; Guarini et al., 2010; Kovachy et al., 2015; McBryde et al., 2020; Pascal et al., 2018; Sansavini et al., 2011). Neurobiological risks associated with PT birth, including injury to white matter tracts in the brain and the resulting characteristics of white matter pathways, have been implicated as one possible source of the delays associated with clinical language outcomes in toddlerhood (Dubner et al., 2020) and in prekindergarten (Zuk et al., 2021).

An important line of inquiry has been the degree to which the LWL task yields reliable and valid prediction of later skills in children at increased risk for language delays, such as children born PT, compared to children who are typically developing (Venker et al., 2013; Venker & Kover, 2015). Recent studies suggest that age-related changes in language processing efficiency are comparable in children born FT and PT during the critical period between 18 and 24 months of age (Loi et al., 2017). Moreover, there are similar associations between early processing efficiency in the LWL task and vocabulary growth in children born PT and FT (Marchman et al., 2019). Most recently, in previous studies, we have shown similar relations between early language processing efficiency and later school-relevant outcomes especially in the domains of vocabulary comprehension and expressive language (removed for blinding).

However, relations between early language processing efficiency and later non-verbal skills were stronger in children born PT than children born FT (removed for blinding). We interpreted the results as suggesting that language processing skills in children born PT may be associated with global abilities, rather than with specific component skills in the domain of language (see also Ortiz-Mantilla et al., 2008). Moreover, children born PT may recruit a broader set of component processes when learning language skills than their FT counterparts (Borchers et al., 2019).

Preliteracy Skills in FT and PT Children

Learning to read is a particularly important pre-academic skill that has tremendous consequences for academic and life success (National Reading Panel, 2000). Previous studies assessing relations between early performance in the LWL paradigm and later outcomes have focused on language outcomes, but not on specific skills that form the foundation for later literacy. Early literacy skills are supported by children's ability to recognize and name letters and numbers (i.e., print knowledge) and to manipulate sounds and syllables (i.e., phonological awareness). While these early literacy skills are generally highly correlated with oral language abilities (Dickinson et al., 2010; Rose et al., 2014), little is known about continuities between these skills and those involved in spoken language processing.

Previous studies have documented that early spoken language processing correlate strongly with later skills directly related to spoken language. We do not yet know the strength of association with pre-literacy skills. One possibility is that the associations are weak. Such findings might result if non-language related skills are critical for the development of pre-literacy skills, such as visual processing skills which might allow the child to identify and differentiate letters and words (Hulme et al., 2012). Another possibility is that the associations are strong. Such findings might result if language skills are most influential in pre-literacy development. In that case, language skills may mediate the associations of early language processing efficiency and later pre-literacy skills. However, pre-literacy skills such as phonological awareness rely heavily on attention and working memory, component skills that are also strongly implicated in real-time language comprehension (Gorman, 2012; Gresch et al., 2018; Peter et al., 2019). In that case, we might find strong associations of early language processing efficiency and later pre-literacy skills but language skills may not fully mediate the association.

Children born PT are particularly susceptible to delays in the development of reading skills (Guarini et al., 2010; Kovachy et al., 2015; Pérez-Pereira et al., 2020). Despite these delays, it is possible that the associations of early language processing efficiency and later pre-literacy skills may be very similar in children born PT and FT. In older children, the construct of processing speed has been implicated as a component of language and reading deficits in school-aged children and adolescents born PT (Lee et al., 2011), leading to expectations that early language processing efficiency, or at least early reaction time, may connect with early literacy skill. However, if children born PT need a broader set of skills to learn pre-literacy tasks than do FT then the association of early language processing to pre-literacy may be reduced. Alternatively the associations may be similar but language skills may not fully mediate the association. No studies have explored literacy-based outcomes in relation to early spoken language processing speed in either children born FT or PT.

The Current Study.

In this study, we relate early language processing efficiency at 18 months to pre-literacy and expressive language skills at 4 ½ years in children born FT and PT. Our main interest is to explore patterns of both direct and indirect relations between measures of language processing efficiency (accuracy and RT) and pre-literacy outcomes. We asked:

- Do children born PT show delays in pre-literacy skills (print knowledge, phonological awareness) at pre-kindergarten, relative to their FT peers?
- Does accuracy and/or speed of language processing at 18 months predict individual variation in pre-literacy skills in PT and FT children? Does birth group moderate these relations?
- Does expressive language skill mediate the relation between early language processing efficiency and pre-literacy outcomes? Does birth group moderate these relations?

Method

Participants

Participants were 49 children (24 females) born full term (FT) and 45 children (23 females) born preterm (PT) who were participating in a longitudinal study. Descriptive data on some measures used in the current analyses have been previously reported for a subset of these children (Adams et al., 2018; Loi et al., 2017; Marchman et al., 2016, 2018). Families were recruited via the Neonatal Intensive Care Unit, the High-Risk Infant Follow-up Clinic, an intervention service provider, parent groups, or a research registry. Exclusionary criteria were conditions that would limit participants from actively engaging in the study's tasks at 18 months, such as seizure disorder or visual/auditory impairments. All children were primarily English learners, exposed to < 25% of another language based on a comprehensive parent interview. The research protocol was approved by a university institutional review board and parents gave signed consent at each visit.

As shown in Table 1, all children born FT had gestational ages (GA) ≥ 37 weeks, whereas, all children born PT were GA ≤ 32 weeks and birth weight (BW) < 1800 grams. Most of the mothers in both groups were college-educated. Socioeconomic status (SES) was also estimated using a modified version of the Hollingshead Four Factor Index (HI) (Hollingshead, 1975), which is a composite based on parents' education and occupation (possible range = 8–66). The difference by group in HI was marginally significant, however, participants in both groups came from primarily higher-SES backgrounds.

At Time 1, children were approximately 18 months of age, adjusted for the degree of prematurity in the PT group. Receptive vocabulary, expressive language, and pre-literacy assessments were administered at Time 2 when the children were approximately 4 ½ years old chronological age. Because participants in the FT group were significantly older than participants in the PT group, age at test is included as a covariate in all analyses. A total of 35 additional participants were tested at 18 months but did not return for testing at 4½ years because of the conclusion of funding.

Time 1: Language processing efficiency

At 18 months, corrected for prematurity, each child was tested in the looking-while-listening (LWL) task (Fernald et al., 2008). In this task, the child sits on the caregiver's lap facing a screen. On each trial, two pictures are presented and a prerecorded voice names one of the pictures. A video camera placed between the pictures provides a video-record of the child's looking responses that is later coded frame-by-frame. Children were tested in two 5-minute sessions conducted approximately one week apart. During the testing sessions, caregivers' vision was blocked so that they could not inadvertently bias their child's responses.

On each trial, color pictures of familiar objects were displayed on the screen for 2 seconds prior to speech onset and for 1 second after sound offset. Pictures were displayed in fixed pairs matched for animacy and salience, with target picture position counterbalanced across trials. Auditory stimuli were simple well-formed sentences that named the target noun in sentence-final position, followed by an attention-getter (e.g., "Where's the doggy? Do you like it?"). Each of the nouns was presented four times as the target and four times as the distracter, with 4 filler trials interspersed between the 64 test trials. The stimulus words were selected based on familiarity to children of this age range (ball–shoe, birdie–kitty, baby–doggy, and book–car) since the LWL task is intended to capture individual differences in the speed with which children process words that are familiar to them (Fernald et al., 2008). As in earlier studies (e.g., Fernald et al., 2006; Fernald & Marchman, 2012), trials with target words that the parent reported their child did not understand were excluded from analysis on a child-by-child basis. Children in the PT group were reported to understand significantly fewer of the test words (M = 7.5, SD = 1.0) than children in the FT group (M = 7.9, SD = 0.5), $t(92) = 2.4$, $p = 0.02$, although all children were reported to know at least five (of 8) target words.

All videorecordings of the testing sessions were later coded offline by trained research assistants blinded to the position of the target picture. Prior to coding, all sessions were prescreened to exclude trials where the participant was inattentive or where there was parental interference. Eye gaze was coded at 33-millisecond (ms) resolution to indicate fixations on one of the images (left or right), between the images, or not looking at either image. Trials were later designated as target- or distracter-initial based on which picture the child was looking at target noun onset. Trials were excluded from analysis if the child was not looking at one of the pictures at target noun onset.

Two measures of spoken language processing efficiency were computed. Accuracy was the mean proportion looking to the target picture assessed from 300-1800 ms from target noun onset on all target- and distracter-initial trials. Reaction time (RT) was the mean latency (in ms) to initiate a gaze shift from the distracter to target image on all distracter-initial trials from 300 to

1800 ms after target noun onset. Shifts that were initiated prior to 300 or after 1800 ms from target noun onset were not included in the computation of RT since these shifts were not likely to be in response to the verbal stimulus. A total of 25% of the sessions were randomly selected and recoded to establish reliability. Inter-coder agreement was 98% for the proportion of frames within 300–1800 ms from noun onset that were correctly identified as on the target vs. the distracter picture. Proportion of trials on which RT agreed within one frame was 95%.

Pre-literacy and expressive language outcomes at Age 4½ Years

Print knowledge and phonological awareness skills were assessed using the subscales of the Test of Early Preschool Literacy (TOPEL) (Lonigan et al., 2007). Print awareness examines children's ability to recognize and name letters and numbers. Phonological awareness assesses word elision and blending abilities. Children were also assessed with the expressive language composite on the Clinical Evaluation of Language Fundamentals-Preschool-2 (CELF-P2) (Semel et al., 2004). This battery is comprised of the Word Structure, Expressive Vocabulary, and Recalling Sentences sub-tests, which yields a comprehensive assessment of children's lexical and morphosyntactic expressive language skills. Following standard practice not to adjust for degree of prematurity in children older than 2 years of age, standard scores for all measures were derived based on the child's chronological age at test.

Analysis Plan

All statistical analyses were run using R (version 4.0.3) (R_Core_Team, 2020). Descriptive statistics are first presented for demographic, predictor, and outcome variables. To explore group differences as a function of birth group, we conducted independent sample t-tests. To explore the contribution of language processing efficiency at 18 months to pre-literacy outcomes at 4½ years, we conducted a series of hierarchical multiple regressions with language processing efficiency (Accuracy and RT) as predictors of print knowledge and phonological awareness, after the covariates of age at test, SES, and birth group. To assess whether relations differed as a function of birth group, we then introduced the corresponding interaction term. Finally, we tested whether expressive language skills mediated the relations between early processing efficiency and pre-literacy outcomes and whether any mediation effects were moderated by birth group. All mediation models include age at test, SES, and birth group as covariates. All mediation models were run using the PROCESS (Hayes, 2022) in R (version 4.3.1), with bootstrapped estimated confidence intervals. Levels of significance were set at $p < 0.05$, two-tailed.

Results

Characteristics of the sample

Scores on the behavioral assessments for both FT and PT infants at 18 months of age, (adjusted for prematurity) are presented in Table 2. As previously reported (removed for blinding), differences in processing efficiency between the FT and PT children in the LWL task did not achieve statistical significance. At 4 ½ years, scores on all outcome measures were significantly higher in the children born FT than children born PT.

Pre-literacy outcomes at pre-kindergarten

Models predicting print knowledge from processing efficiency at 18 months are presented in Table 3. Model 1a shows that group differences in print knowledge scores remained significant after accounting for the covariates of age and SES. Model 1b shows that language processing efficiency as measured by accuracy in the LWL task predicted significant variance beyond the covariates and group, accounting for an additional 14% of the variance. Model 1c shows that adding the interaction term did not significantly increase the overall model fit, suggesting that the relations between early processing efficiency and print knowledge were similar in FT and PT children. A similar pattern is seen with RT. Model 1d shows that RT added nearly 8% additional variance beyond the covariates. Model 1e confirms that the interaction term did not significantly increase model fit, indicating that birth group did not moderate these relations.

Models predicting phonological awareness from processing efficiency at 18 months are presented in Table 4. Model 2a shows that the covariates accounted for approximately 18% of the variance in phonological awareness. Models 2b and 2d show that accuracy and RT significantly predict phonological awareness, beyond age, SES, and group, accounting for nearly 14% and 20% additional variance, respectively. Models 2c and 2e again show that these patterns are not significantly moderated by language group. Taken together, early language processing efficiency predicted significant variance in both pre-literacy outcomes, and the strength of those relations were similar for children born FT and PT. These effects are illustrated in Figures 1 and 2.

Does expressive language skill mediate these relations?

Figure 3 displays the hypothesized path model for expressive language as a mediator of relations between early language processing efficiency and later print knowledge. As shown in Table 5, we first establish that both processing measures (accuracy and RT) were significant predictors of the mediator (a path), expressive language. We also established that expressive language significantly predicted print knowledge, controlling for each processing efficiency measure (b path). Further, both accuracy and RT were significant predictors of print knowledge, indicated by the total effects (c path). These effects were no longer significant when controlling for the mediator, expressive language (i.e., direct effects, c’ path). Since the strengths of the relations between processing efficiency and print knowledge were significantly reduced when controlling for expressive language, i.e., the indirect effects (c – c’), mediation is established. In both cases, direct effects were no longer significant when including expressive language in the models, suggesting that expressive language completely mediated the effects of processing efficiency on print knowledge. Each model accounted for more than 35% of the variance in print knowledge.

For phonological awareness, each processing measure again significantly predicted expressive language and the mediator, expressive language, significantly predicted phonological awareness, after controlling for processing efficiency. Evidence for mediation was established since the introduction of expressive language significantly reduced the strengths of the relations between processing efficiency and phonological awareness. In the case of RT, the direct effect remained significant, suggesting that expressive language and RT were each uniquely contributing to variation in phonological awareness. Full models accounted for more than 50% of the variance.

Finally, we tested whether group status moderated these mediation effects. For print knowledge, results indicated significant indirect effects in both the FT (Accuracy: 21.4, CI: 2.2 – 49.1; RT: -0.02, CI: -0.03 - -0.01) and PT (Accuracy: 37.4, 13.1 – 61.2; RT: -0.02, CI: -0.04 - 0.01) groups, and no significant group difference between the conditional indirect effects (Accuracy: 16.0, CI: -14.2 – 41.9; RT: -0.01, CI: -0.02 – 0.02). For phonological awareness, indirect effects were also observed in the FT: (Accuracy: 29.7, CI: 3.3 – 67.3; RT: -0.02, CI: -0.04 - -0.01) and PT (Accuracy: 51.9, CI: 19.7 – 79.0; RT: -0.02, CI: -0.05 – -0.01) groups, with no significant differences between the conditional indirect effects (Accuracy: 22.2, CI: -19.8 – 54.1; RT: -0.01, CI: -0.02 – 0.03). Thus, birth group did not moderate the mediated effects, suggesting that expressive language mediated the relations between processing efficiency and pre-literacy outcomes to a similar extent in children born FT and PT.

Discussion

In this study, we explored continuities between early language processing efficiency, as indexed in the LWL task, and later pre-literacy skills at 4 ½ years, captured in terms of two critical sub-component skills, print knowledge and phonological awareness. Early language processing efficiency showed substantial continuities with later academic-relevant skills in two populations of children, those born full term and preterm. Our results revealed three major findings. First, early language processing efficiency, assessed at 18 months, significantly predicted children's scores on pre-literacy skills. Thus, early language processing efficiency assessed in toddlerhood indexes variation in early information processing abilities that are continuous with skills that form the foundation for school-relevant pre-reading accomplishments several years later. This finding strengthens the theory that early language processing skills, not acquired knowledge, is consistently predictive of later functioning.

Our next major finding indicated that these relations were not direct, but instead were mediated by expressive language. In other words, children's expressive language abilities explained the link between early language processing efficiency and later pre-literacy skills by demonstrating that it was the variance shared by expressive language and pre-literacy skills that was linked to early processing efficiency. Such mediation effects suggest that supporting early development of expressive language skills may have broad and cascading consequences not only for oral language abilities, but also for early phonological awareness and print knowledge skills. This finding is consistent with a vast literature, summarized in a national report, that finds that oral language skills are a powerful predictor of later literacy skills ("Developing Early Literacy: Report of the National Early Literacy Panel," 2010). It is interesting that the neural basis of reading has identified functional networks where oral language processes are recruited for phonological analysis of written language (Cattinelli et al., 2013) Moreover the connectome for language and reading are also highly overlapping (Ben-Shachar, Dougherty, & Wandell, 2007; Shekari & Nozari, 2023; Wandell & Yeatman, 2013).

Our third main finding was that the strength and pattern of these relations were similar in children both FT and PT children. Although children born PT scored lower than their FT peers in pre-literacy skills at 4 ½ years, variation in early language processing efficiency was associated with variation in pre-literacy outcomes in both groups of children. Moreover, there was no evidence that the mediation effects were moderated by birth group. Thus, supporting early expressive language skills is important for supporting later literacy development in children in both birth groups. Further, the skills invoked in early language processing efficiency in young children born FT share fundamental properties with those that support language learning in children born PT, who may show a broader range of ability levels. Given the particular limitations that have been observed in children both PT in the reading domain (Feldman et al., 2012; Kovachy et al., 2015), the evidence that reading skills are linked to early language processing and the development of expressive language skills has implications for clinical evaluation and treatment.

Finally, expressive language significantly mediated all relations between early language processing efficiency and later pre-literacy skills. Additionally, there was evidence for direct relations between early processing speed and later phonological awareness abilities. These results indicate that a component of the skills that are assessed in terms of processing speed at 18 months relate to phonological awareness independently of the association with expressive language skills. This finding is consistent with other literature on the importance of speed of processing to reading, for example, evidence that preliteracy skills are linked to speed of naming (Dickens et al., 2015; McWeeny et al., 2022) However, at a neurobiological level, speed of processing and phonological awareness may be independent, with phonological awareness associated with visual processing pathways but speed of processing as independent (Ben-Shachar, Dougherty, Deutsch, et al., 2007).

Limitations

Limitations include the facts that most of the children in this small sample came from higher-SES backgrounds and thus, do not represent the full range of SES in children born FT or PT. They also were highly competent in pre-literacy skills, though the combining of the FT and PT children increased the variability in scores. Pre-literacy skills were assessed prior to school entry and it is not clear whether the predictive relations between early processing efficiency and later outcomes would persist into the school years. Finally, we limited our assessment of pre-literacy skills to two key domains, print knowledge and phonological awareness. We cannot make any claims about the role of processing efficiency in relation to other literacy-related skills.

Conclusion.

Being able to name letters and numbers and manipulate the phonological units of language are critical skills that form the foundation for literacy development. Our results suggested that children's burgeoning skill at processing language during real-time interactions with other in toddlerhood already forms that foundation for later pre-literacy skills, operating mostly through the development of expressive language. Patterns of relations were similar in FT and PT children, even though children born PT had consistently lower scores on pre-literacy skills at 4 ½ years than their FT peers. Thus, the underlying processing mechanisms and component skills that are reflected in these relations are generally similar across these birth groups. Supporting early language processing efficiency and other skills that may buttress expressive language skills may have important consequences for outcomes in all children. Clinical assessment of children should begin early and focus on a range of component skills as well as birth group status.

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Table 1. Descriptives (M (SD)) and tests of group differences in demographic variables for FT (n = 49) and PT (n = 45) children.

	FT	PT	χ^2 or t	p
Male (%)	51.0	50.0	0.04	1.0
Gestational Age (wks)	40.1 (1.1)	29.6 (1.9)	32.7	0.001**
Birth Weight (g)	3550.7 (457.7)	1256.3 (277.3)	29.7	0.001**
Maternal Education (yrs)	16.7 (1.4)	16.3 (1.9)	0.9	0.36
SES	59.7 (7.2)	56.6 (8.8)	1.9	0.06
Age: Time 1 (mos)	18.8 (0.6)	18.7 (0.6)	0.6	0.53
Age: Time 2 (mos)	55.5 (2.7)	54.4 (1.4)	2.5	0.01*

Note: SES: Scores on an updated version of the Hollingshead Four Factor Index of Social Status (Hollingshead, 1975).

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

Table 2. Descriptives (M (SD)) and tests of group differences on behavioral assessments in FT (*n* = 49) and PT (*n* = 45) children at 18 months and 4 ½ years

	FT	PT	*t*	*p*
18 mos				
Acc	0.66 (.10)	0.63 (.11)	1.50	0.14
RT	724 (147)	771 (167)	1.44	0.15
4 ½ years				
Print Knowledge	112.0 (13.1)	105.3 (15.2)	2.30	0.025*
Phonological Awareness	113.0 (13.6)	101.4 (19.0)	3.41	0.001***
Expressive Language	116.5 (14.0)	107.6 (14.7)	3.00	0.004**

Note: Acc: Proportion looking to target on the looking-while-listening task (Fernald et al., 2008); RT: Mean response time on the looking-while-listening task (Fernald et al., 2008); Print Knowledge/Phonological Awareness: Standard scores on the Test of Preschool Early Literacy (TOPEL) (Lonigan et al., 2007); Expressive Language: Standard scores on the Clinical Evaluation of Language Fundamentals-Preschool, 2nd Edition (CELF-P2) (Semel et al., 2004)

*p < 0.05, **p < 0.01, ***p < 0.001

Table 3. Multiple regression models (unstandardized coefficients (SE)) predicting print knowledge (TOPEL) at 4 ½ years in FT (*n* = 49) and PT (*n* = 45) children from early language processing efficiency at 18 months (corrected for prematurity).

	Model 1a	Model 1b	Model 1c	Model 1d	Model 1e
Age	-0.58 (0.68)	-0.37 (0.63)	-0.42 (0.64)	-0.47 (0.66)	-0.47 (0.66)
SES	0.25 (0.18)	0.15 (0.17)	0.13 (0.17)	0.20 (0.18)	0.23 (0.18)
Group	-6.54 (3.07)*	-4.91 (2.87)	-17.49 (17.59)	-5.35 (2.98)	-18.26 (13.96)
Acc	--	54.01 (13.42)	43.90 (19.36)*	--	--
Acc x Group	--	--	19.39 (26.74)	--	--
RT	--	--	--	-0.03 (0.01)**	-0.04 (0.01)**
RT x Group	--	--	--	--	0.02 (0.02)
R^2	8.2	22.4***	22.9***	16.1**	16.9**
r^2-change	--	14.2***	0.5	7.9**	0.8

Note: r^2-change for Models 1b and 1d in reference to Model 1a; Models 1c and 1e in reference to Models 1b and 1d, respectively.

Acc: Proportion looking to target on the looking-while-listening task (Fernald et al., 2008); RT: Mean response time on the looking-while-listening task (Fernald et al., 2008).

**p* < 0.05, ***p* < 0.01, ****p* < 0.001

Table 4. Multiple regression models (unstandardized coefficients (SE)) predicting phonological awareness (TOPEL) at 4 ½ years in FT (*n* = 49) and PT (*n* = 45) children from early vocabulary and language processing skills at 18 months (corrected for prematurity).

	Model 2a	Model 2b	Model 2c	Model 2d	Model 2e
Age	-0.24 (0.77)	0.01 (0.71)	-0.09 (0.72)	-0.04 (0.68)	-0.03 (0.68)
SES	0.53 (0.21)*	0.41 (0.19)*	0.38 (0.19)	0.43 (0.18)*	0.39 (0.19)*
Group	-10.27 (3.48)**	-8.37 (3.23)*	-33.41 (19.67)	-8.03 (3.09)*	9.99 (14.38)
Acc	--	62.93 (15.07)***	42.80 (21.65)	--	--
Acc x Group	--	--	38.60 (29.91)	--	--
RT	--	--	--	-0.05 (0.01)***	-0.04 (0.01)**
RT x Group	--	--	--	--	-0.02 (0.02)
R^2	17.6**	31.1***	32.4***	37.1***	38.3***
r^2-change	--	13.5***	1.3	19.5***	1.2

Note: r^2-change for Models 2b and 2d in reference to Model 2a; Models 2c and 2e in reference to Models 2b and 2d, respectively.

Acc: Proportion looking to target on the looking-while-listening task (Fernald et al., 2008); RT: Mean response time on the looking-while-listening task (Fernald et al., 2008).

**p* < 0.05, ***p* < 0.01, ****p* < 0.001

Table 5. Multiple regression models (unstandardized coefficient (SE)) testing mediation effects of expressive language (CELF-4) on relations between language processing skill at 18 months and pre-literacy skills at 4 ½ years in FT (n = 45) and PT (n = 49) children, controlling for age at test, SES, and group.

	Print Knowledge		Phonological Awareness	
	Accuracy	RT	Accuracy	RT
Predictor on Mediator (a path)	65.8 (12.8)**	-0.04 (0.01)***	65.8 (12.8)***	-0.04 (0.01)***
Mediator on Outcome (b path)	0.45 (0.1)***	0.51 (0.1)***	0.64 (0.1)***	0.58 (0.10)***
Total Effects (c path)	54.0 (13.4)***	-0.03 (0.01)**	62.9 (15.1)***	-0.05 (0.01)***
Direct Effects (c' path)	24.1 (13.8)	-0.01 (0.01)	21.0 (14.5)	-0.03 (0.01)**
Indirect Effects (c – c')	29.9 (10.1)	-0.02 (0.01)	41.9 (13.4)	-0.02 (0.01)
CI	11.4 – 51.1*	-0.03 - -0.01*	17.3 – 69.9*	-0.04 - -0.01*
R^2	37.1%***	35.3%***	51.4%***	54.6%***

Note: *CI does not cross zero, ***p* < .01, ****p* < .001, Following Hayes (2013), the (a), (b) and (c) paths establish the conditions for mediation. The (c) path (the total effect) captures the predictor on the outcome and the (c') path (the direct effect) reflects the predictor on the outcome, controlling for the mediator. Evidence for mediation is achieved if the indirect effect (c – c') is significantly greater than zero.

Figure 1. Predicted relations between language processing speed at 18 months and print knowledge (TOPEL) at 4 ½ years in children born FT (*n* = 49) and PT (*n* = 45).

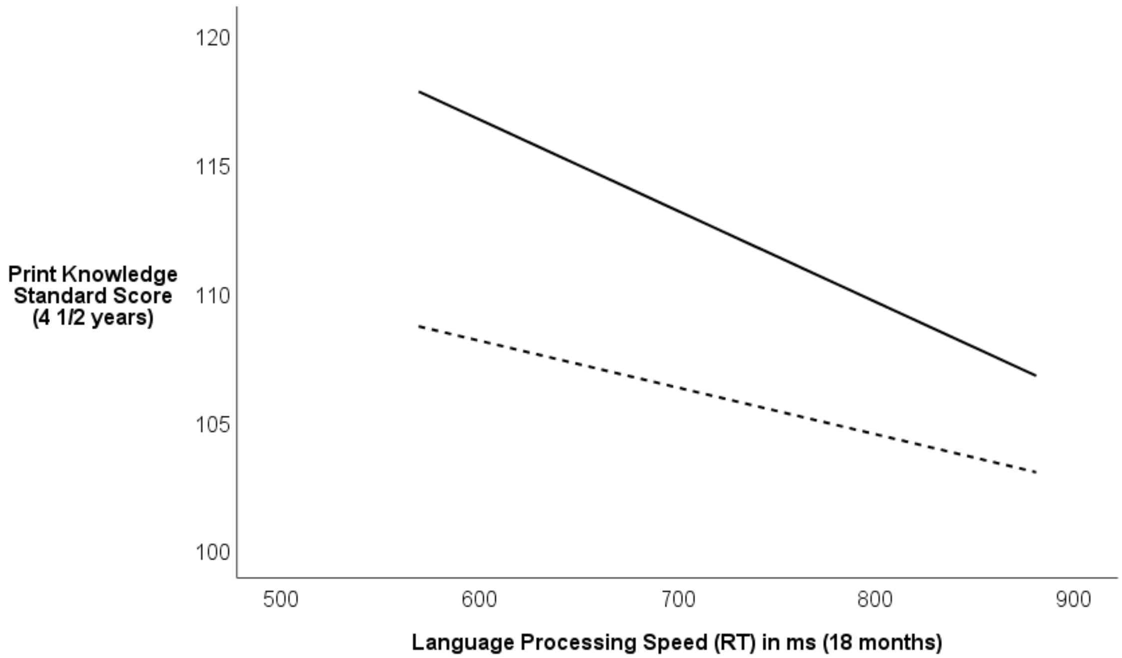

Figure 2. Predicted relations between language processing speed at 18 months and phonological awareness (TOPEL) at 4 ½ years in children born FT (n = 49) and PT (n = 45).

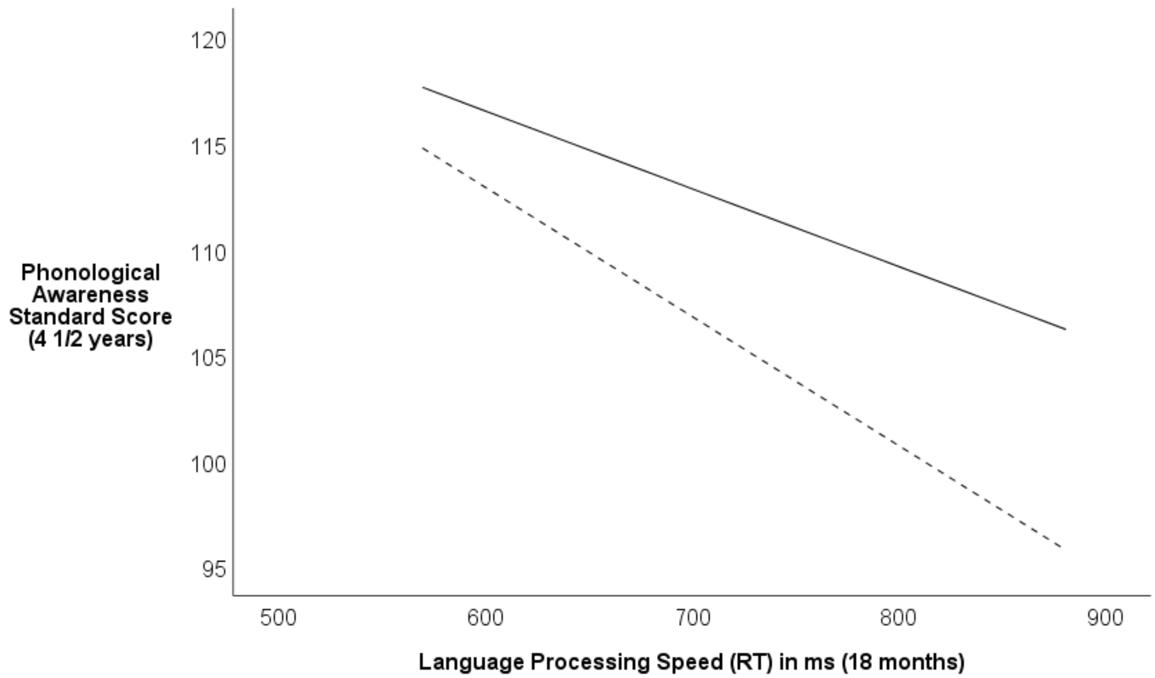

Figure 3. Schematic of expressive language as a mediator of the relation between language processing efficiency at 18 months and pre-literacy skills at 4 ½ years.