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Using eye movements to assess language comprehension in toddlers born preterm and full term

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Abstract

Objective—To assess language skills in preterm and full term children using a standardized language test and eye-tracking methods.

Study design—Children born 32 weeks gestation (n = 44) were matched on sex and socioeconomic status to full term children (n = 44) and studied longitudinally. The Bayley Scales of Infant and Toddler Development- Third Edition (BSID-III) were administered at 18-months (corrected for prematurity as applicable). The Looking-While-Listening (LWL) task simultaneously presents two pictures and an auditory stimulus directing the child's attention to one image. The pattern of eye movements reflects visual processing and the efficiency of language comprehension. PT children were evaluated on LWL three times between 18 and 24 months. FT children were evaluated at ages corresponding to chronological and corrected ages of their PT match. Results were compared between groups for the BSID-III and two LWL measures: accuracy (proportion of time looking at target) and reaction time (latency to shift gaze from distracter to target).

Results—PT children had lower BSID-III scores than FT children. PT children had poorer performance than FT children on LWL measures for chronological age but similar performance for corrected age. Accuracy and reaction time at 18 months corrected age displaced PT-FT group membership as significant predictors of BSID-III scores.

Conclusions—Performance and rate of change on language comprehension measures were similar in PT and FT compared at corrected age. Individual variation in language comprehension efficiency was a robust predictor of scores on a standardized language assessment in both groups.

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Keywords

premature; language development; processing efficiency; Bayley Scales; reaction time

Children born preterm are at increased risk for delays and disorders of language development. Meta-analyses confirm lower scores on language tests in PT children over age 2 years compared with full term controls.^{1, 2} Delays in language have been reported before age 2 years,^{3–8} though group differences are not found universally at these ages.^{9–11} Performance on early language assessments is associated with language evaluations 1–3 years later.^{12–14} Language delays can be highly detrimental to children's development because language plays a critical role in learning and reading.^{15, 16} Understanding the underlying processes associated with language skills may elucidate causes and shape treatments of language delays.

Studies of language in children born PT typically rely on standardized measures of global language skills or parent-report questionnaires. These measures do not reveal underlying neuropsychological mechanisms that may accumulate to contribute to rates of development. Eye-tracking methods in tasks of word recognition,¹⁷ lexical understanding,^{18–20} and novel word learning,²¹ have been used in typically developing children to investigate neuropsychological mechanisms of language development, and have recently been applied to examine these processes in studies of clinical populations.^{22, 23}

In this study of children born PT, we administered an eye-tracking procedure to assess language processing efficiency, in addition to a standardized language assessment. The Looking- While-Listening Task (LWL)²⁴ monitors children's eye movements toward pictures in response to verbal stimuli directing attention to one picture. Like other eye-tracking tasks, it generates measures of preferential looking;²⁵ however, it also captures speed of lexical processing. We examined three hypotheses: (1) PT children would show poorer performance on the standardized language assessment and LWL measures in comparison with FT children; (2) differences would remain when the groups were matched by age corrected for the degree of prematurity;⁶ and (3) LWL measures would be strong predictors of scores on the standardized assessment of language.

Methods

The sample included 44 PT-FT pairs (88 participants) from a larger sample that participated in a longitudinal study of early language development. Enrollment criteria for the PT group were gestational age ≥ 32 weeks and birth weight < 1800 gm. Inclusion criteria for the FT cohort were gestational age ≥ 37 weeks and birth weight ≥ 2495 grams. Socioeconomic status (SES) was measured using the Four Factor Hollingshead Index.²⁶ Each child in the PT cohort was matched to a FT child by sex and SES within 7 points. Members of both groups had to be evaluated at each of the study age points. Exclusion criteria for both cohorts were exposure to a non-English language $\geq 25\%$ of the time and major medical conditions. The Institutional Review Board at Stanford University approved the study protocol and parents of participants provided written consent.

The mean gestational age (SD) of the PT group was 29.8 (± 1.9) weeks and 40.0 (± 1.0) weeks in the FT group. The mean birth weight in the PT group was 1246 grams (± 302) and 3499 grams (± 465) in the FT group. Both groups were 54.5% male. Mean Hollingshead Index for the PT cohort was 58.2 and for the FT cohort was 59.5 ($P = \text{NS}$). Medical complications for PT participants were: 18.2% small for gestational age (defined as $<10^{\text{th}}$ percentile for gestational age²⁷), 79.5% respiratory distress syndrome, 27.3% bronchopulmonary dysplasia or chronic lung disease, 25% patent ductus arteriosus, 11.4% necrotizing enterocolitis, 15.9% intraventricular hemorrhage (13.6% grades 1–2, 2.3% grade 4), 2.3% white matter damage, and 27.3% retinopathy of prematurity.

The timing of the assessments was structured to allow for a corrected-age comparison for the standardized language assessment and for both chronological- and corrected-age comparisons over time for the LWL measures. The study collected data at 16, 18, 22, and 24 months chronological age from the FT children and at 16, 18, and 22 months corrected age from the PT children (Table I). The data collected at 16 and 22 months corrected age in the PT group were also used for chronological age comparisons (18 and 24 months chronological age).

A standardized language assessment was performed at 18 months (corrected for prematurity where applicable) using the Bayley Scales of Infant and Toddler Development, Third Edition (BSID-III).²⁸ Language Composite Scores were computed using the Receptive and Expressive Communication subtests.

In the Looking-While-Listening Task (LWL),²⁴ each child was seated on the caregiver's lap and viewed pairs of familiar color pictures projected on a screen. Parents wore opaque eyeglasses so that they could not see the visual stimuli. On each trial, a prerecorded voice named one of the objects in a simple sentence, directing the child's attention to the target image (eg, "Look at the ball. Can you see it?"). The child's eye movements were video-recorded. Before the task, parents were presented with a list of the target nouns used in the procedure and were asked to indicate whether or not their child understood each noun. Because the LWL task measures the efficiency of familiar word comprehension, primary analyses were restricted to trials on which the parent reported that the child understood the target noun on a child-by-child basis. Additional criteria for inclusion of the trial was that the child was attentive to the task, was fixated on one of the pictures at the onset of the trial, and made an eye movement within a time window (300–1800 milliseconds [ms]) considered to be appropriate for demonstrating language comprehension in young children.^{29, 30} For children at 16 and 18 months of age, 64 experimental trials were presented with simple sentences such as the example above, counterbalanced for target side. At 22 and 24 months of age, the stimulus set included the same simple sentences and additional stimuli with more complex constructions; only simple sentences were analyzed to allow for longitudinal comparisons (32 trials). Gaze patterns were manually coded offline frame-by-frame. Measures were accuracy (mean proportion of time looking to the target divided by the total looking time to either image from 300–1800 ms after target-word onset) and reaction time (mean latency [ms] measured from the onset of the target noun to the initiation of a shift in eye gaze from the distracter image to the target image on trials on which the child was looking at the distracter image at the onset of the target word).

Children who did not successfully participate in at least 25% of the experimental trials were excluded for that age point, because too few trials could yield inaccurate estimates of the child's abilities. One PT child was excluded from analysis of reaction time at 24-months due to fewer than 2 valid distracter-to-target shifts. Reliability coding was conducted on 20% of total LWL sessions. For accuracy, coders achieved 93–99% reliability at all ages for the proportion of frames identified as target and distracter. For reaction time, coders achieved 97–100% reliability for the proportion of trials on which initial-shift latency agreed within one frame.

Data Analyses

Comparison of the BSID-III Language scores at 18 months was conducted using a linear mixed effects analysis with restricted maximum likelihood estimation in R³¹ using *lme4*.³² The fixed effect was PT-FT group membership. The random effects were exact age at test and SES, z-score transformed. To compare patterns of longitudinal change in PT and FT groups on accuracy and reaction time, two sets of linear mixed effects analyses were conducted for each measure across age points, comparing at both chronological and corrected ages. The fixed effects were PT-FT group membership and age point. The random effects were participant, exact age at test, SES, and number of trials each child contributed to his or her score, all z-score transformed. Multiple linear regression assessed the contribution of PT-FT group membership and LWL measures at 18 months corrected age to variance on the BSID-III Language Scale, controlling for SES because of its known influence on developmental outcomes of PT children.³³ In a separate analysis, the exact age of test and number of trials was added to the models. All tests were 2-tailed; significance was set at $P < .05$.

Results

Using a linear mixed effects model, PT children had significantly lower mean unadjusted BSID-III Language Composite Scores at 18 months corrected age (93.9, SD = 17.9) than the FT group at 18 months chronologic age (103.3, SD = 17.6) ($B = 9.3$, $SE = 3.7$, $P = .015$).

Unadjusted mean scores for accuracy and reaction time on the LWL task for the PT and FT groups are presented in Table I. Longitudinal analyses of these measures are shown in Table II. On the chronological comparison (Figure, A and B), main effects of age point indicated that children in both groups improved in accuracy and in reaction time. Main effects of group indicated that the PT group was less accurate and slower than the FT group.

There was no group by time interaction for either measure, indicating comparable rates of improvement in both groups over age points.

When comparisons were corrected for degree of prematurity (Figure, C and D), main effects of age point indicated again, that children in both groups made gains in efficiency of spoken word comprehension. Though the estimates for the FT group were better than the PT, there were no main effects of group for either measure, indicating that the PT and FT groups demonstrated comparable processing efficiency when the comparisons took the degree of prematurity into account. The group by age point interactions were also not significant for

either measure, indicating that both groups of participants improved at comparable rates over time.

Table III presents the results of multiple regression analyses using the 18 month corrected LWL measures to predict to BSID-III Language scores at the same age. In the Baseline Model, SES was significantly associated with BSID-III. Model 1 demonstrates that PT-FT group membership made a significant, independent contribution to the outcome, after controlling for SES. Models 2 and 3 demonstrate that accuracy and reaction time, respectively, contributed significant, unique variance to the outcome and also displaced group membership as a significant predictive factor. Accuracy and reaction time remained significant predictors of outcome if the exact age of test and number of trials completed were introduced into the models. Accuracy and reaction time each contributed significant unique variance to BSID-III scores when the regression models were run for PT and FT groups separately, suggesting that the results were not primarily driven by one of the groups.

Discussion

We found statistically significant PT-FT group differences in the standardized measure of language knowledge, consistent with other studies that have also found lower scores on standardized languages measures in PT compared with FT children.^{4, 8, 12–14}

The LWL paradigm is an objective, low-demand task that offers a different approach to assessment of language comprehension. The child's response entails either maintaining gaze on a target picture or shifting eye gaze to the correct stimulus. The task is parallel to what children do when they hear verbal language in the real world and must match the verbal signal to an aspect of a visual scene to identify the referent of the word. The measures generated, accuracy and reaction time, reflect a variety of neuropsychological processes. Previous child and adult studies using similar methods have shown that eye-tracking measures relate strongly to efficiency in accessing the meaning of words.^{29, 34} Individual differences in these indices of efficiency in language comprehension have been shown in FT children to correlate with critical measures of language knowledge and skills.^{15, 29} Combining LWL with a standardized assessment provides an opportunity to interrogate neuropsychological contributions to standardized assessments in young PT children whose ability to cooperate with other forms of neuropsychological testing may be limited.

Contrary to our hypothesis, after correcting for the degree of prematurity, group differences on the LWL measures did not achieve statistical significance. At the corrected age comparison, PT and FT children were similar in their efficiency of visual processing and comprehending language. In addition, the rate of increases in accuracy and decreases in reaction time were similar in the two groups. These findings suggest similar underlying neuropsychological processes are at play in both groups. However, at the chronological age comparison, the PT group is not closing the gap in performance, suggesting deficits in processing efficiency may emerge when age correction is not used.

In regression models predicting scores on the standardized assessment, accuracy and reaction time at corrected age each made independent contributions to BSID-III scores after

consideration of PT-FT group membership. In fact, these measures displaced group membership status as a significant contributor to the outcome. Thus, despite the lack of group differences, individual variation in efficiency of language comprehension, as measured by the LWL task, was significantly associated with outcomes on the standardized test across and within groups.

Previous studies have demonstrated the predictive nature of LWL measures in typically developing children.¹⁵ In children born PT, reaction time at 18 months corrected age predicted receptive vocabulary at 36 months chronological age.³⁵ This study extends previous research by showing that processing variables contribute to individual differences in a standardized test of global receptive and expressive language in the toddler years and that the contribution is comparable in the PT and FT groups.

Where do these individual differences come from and are the sources similar in the PT- FT groups? In other studies with children born FT, processing efficiency in the LWL task was associated with the amount of maternal input to children.³⁶ Such findings in PT children might suggest an approach to intervention in those children with poor language processing efficiency. However, in children born PT who have experienced multiple medical and neurological complications, these measures may be correlated with biomedical sources of variation or the interaction of biomedical factors and language environmental quality.

Why do PT children perform more poorly than FT peers at older ages if their processing efficiency is similar? One possibility is that differences become significant at older ages when we cease to make correction for the degree of prematurity. In this study, we found significant differences at the chronological age comparison. Another possibility is that PT-FT differences become more evident on complex rather than simple tasks. Such findings have been reported previously in studies of language.²

In conclusion, compared with FT children, PT children showed poorer performance on standardized measures of language but comparable performance and rates of developmental progress on eye-tracking measures of language comprehension after correction for the degree of prematurity. Individual variation in the LWL measures was a stronger predictor of standardized test scores than was PT-FT group membership. Individual differences in language comprehension efficiency at young ages reflect fundamental neuropsychological processes that may accumulate to explain long-term trajectories of language skill in PT and FT children.

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Abbreviations

BSID-III Bayley Scales of Infant and Toddler Development-Third Edition

LWL	Looking-While-Listening Task
ms	milliseconds
SES	socioeconomic status

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Figure. Plots of linear mixed effects models of accuracy (proportion) and reaction time (ms) on the Looking- While-Listening (LWL) task in Preterm and Full Term children for chronological (Panels A and B) and corrected (Panels C and D) age comparisons.

Mean scores on the Looking-While-Listening Task as a function of corrected and chronologic ages in the PT and FT groups

Table 1

	FT	PT	FT	PT	FT	PT	FT
Number							
Age at test, months [*]		18.5 (0.5)					24.5 (0.5)
	16.3 (0.6)	16.1 (0.6)	18.7 (0.5)	18.6 (0.5)	22.2 (0.7)	22.2 (0.6)	24.6 (0.6)
Accuracy ^a	.61 (.08)	.59 (.09)	.65 (.10)	.63 (.10)	.71 (.10)	.68 (.10)	.75 (.10)
Reaction Time ^b (ms)	852 (164)	853 (217)	757 (139)	819 (190)	713 (182)	751 (171)	664 (174)

^{*} Presented as the mean (standard deviation). For preterm infants, the first line is the chronologic age at test and the second line is the corrected age.

^a Mean proportion of time (standard error) looking at the target compared with total looking time

^b Mean latency (standard error) to shift eye gaze from distracter to target picture

Unstandardized estimates (B, Standard Error [SE]) of Looking-While-Listening Task measures from linear mixed effects analyses in preterm (PT) and full term (FT) participants. Group comparisons are based on chronological ages and on corrected ages.

Table 2

	Chronological Age Comparison						Corrected Age Comparison					
	Accuracy			Reaction Time			Accuracy			Reaction Time		
	B	SE	P	B	SE	P	B	SE	P	B	SE	P
Intercept	0.6	0.02	<.001	863.2	33.3	<.001	0.5	0.01	<.001	873.3	29.5	<.001
Age Point	0.01	0.004	<.001	-21.1	6.9	.004	0.01	0.003	<.001	-22.9	6.4	<.001
Group	0.06	0.02	<.01	-93.9	38.8	.017	0.02	0.01	.263	-24.1	35.0	.491
Group x Age Point	0.002	0.004	.640	2.6	7.4	.730	0.002	0.004	.673	-3.7	6.7	.580

Table 3

Multiple regression models with Bayley Scales of Infant and Toddler Development – III Language Scale as the outcome variable and demographic and language processing measures at 18 months corrected age for the preterm group and chronological age for the full term group ($n = 86$) as predictor variables. Unstandardized B (SE).

	Baseline	Model 1	Model 2	Model 3
Demographic Measures				
SES; HI ^a	0.66 (0.22) **	0.63 (0.21) **	0.45 (0.20) *	0.48 (0.19) *
PT versus FT	--	-7.52 (3.62) *	-6.23 (3.31)	-4.62 (3.24)
Looking-While-Listening Measures				
Accuracy ^b	--	--	74.47 (17.64) ***	--
Reaction Time ^c	--	--	--	-0.05 (0.01) ***
r^2 change	-	4.5% *	15.3% ***	19.8% ***
Total R^2	9.9% **	14.4% **	29.7% ***	34.2% ***

* $P < .05$,

** $P < .01$,

*** $P < .001$; r^2 change for Model 1 is in reference to Baseline; r^2 change for Models 2 and 3 in reference to Model 1.

^a Socioeconomic Status (SES) Hollingshead Four Factor Index of (HI)

^b Mean proportion of time looking at the target compared with total looking time

^c Mean latency (ms) to make an initial shift in eye gaze from distracter to target picture on applicable trials