Long-Term Stability of Language Performance in Very Preterm, Moderate-Late Preterm, and Term Children

Diane L. Putnick[1], PhD, Marc H. Bornstein[1], PhD, Suna Eryigit-Madzwamuse[2], PhD, Dieter Wolke[3], PhD

Affiliations:

[1]*Eunice Kennedy Shriver* National Institute of Child Health and Human Development

[2]Centre for Health Research, University of Brighton

[3]Department of Psychology, and Division of Mental Health and Wellbeing, Warwick Medical School, University of Warwick, Coventry, United Kingdom

Corresponding Author: Diane L Putnick, 6705 Rockledge Drive, Suite 8030, Bethesda, MD 20892, 301-496-6291, putnickd@mail.nih.gov

Financial Disclosure: The authors have no financial relationships relevant to this article to disclose.

Funding Source: DLP and MHB were supported by the intramural program of the NIH, NICHD. The study sponsor had no role in the study design, collection, analysis, and interpretation of data, writing of the report, or decision to submit the manuscript for publication. Data acquisition was supported by grants PKE24, JUG14, 01EP9504 and 01ER0801 from the German Federal Ministry of Education and Science (BMBF) (DW, SEM).

Potential Conflicts of Interest: The authors have no conflicts of interest relevant to this article to disclose.

Abbreviations: VP = Very preterm, MP = Moderate-late preterm, T = Term

Abstract

Objective. Very preterm children are at risk for language delays. Individual differences in language performance are stable from early development in healthy children born at term. This study investigates whether children born very preterm, moderate-late preterm, and term differ in their average level and individual-difference stability in language performance over time.

Study Design. Language in 204 very preterm (< 32 weeks gestation), 276 moderate-late preterm (32-36 weeks gestation), and 268 term (37-41 weeks gestation) children from the Bavarian Longitudinal Study was assessed at 5 and 20 months, and 4, 6, and 8 years of age.

Results. Very preterm children consistently performed worse than term-born children, and moderate-late preterm children scored in between. Language performance was stable from 5 months through 8 years in all gestation groups combined, and stability increased between each succeeding wave. Stability was stronger between 5 months and 4 years in very preterm than moderate-late preterm and term groups, but this differential stability attenuated when covariates (child nonverbal intelligence and family socioeconomic status) were controlled.

Conclusions. Preterm children, even moderate-late preterm, are at risk for poorer language performance than term-born children. Because individual differences in language performance are increasingly stable from 20 months to 8 years in all gestation groups, pediatricians who attend to preterm children and observe language delays should refer them to language intervention at the earliest age seen.

Introduction

Preterm birth accounts for more than 15 million yearly births worldwide.[1] Very preterm children are at increased risk for delays and deficits in various aspects of language.[2-5] As survival rates following a preterm birth have risen due to improvements in obstetrics and neonatology,[6] preterm birth has emerged as a risk factor for poor development in an increasing proportion of the population.

According to the World Health Organization's guidelines,[7] preterm birth can be subdivided into *very preterm*, births before 32 weeks gestation, *moderate preterm*, births at 32 and 33 weeks gestation, and *late preterm*, births between 34 and 36 weeks. Language skills are impaired in children born very preterm.[8] However, findings regarding mean differences in language are less consistent for moderate-late preterm compared to term-born children.[4,9-11] In addition to mean differences, developmental stability of language (consistency in relative standing over time)[12] needs to be investigated because it is prognostic of future ability. There is emerging evidence that individual differences in language are stable from toddlerhood in term-born children,[13-16] but it is unclear whether language is less or more stable across childhood in very or moderate-late preterm children;[17-19] i.e., whether stability differs in children born across the full gestation spectrum. Because pediatricians are generally the first professionals to evaluate language in young children, it is critical to understand how early in development individual differences are predictive of later language performance (or deficits) in children born term and preterm. Therefore, the current study aims to investigate the mean differences and stability of language performance, using multiple age-appropriate measures, in children from 5 months to 8 years of age following a very preterm, moderate-late preterm, or healthy term birth within a population based cohort.

Patients and Methods

Patients

Data were drawn from the prospective Bavarian Longitudinal Study (BLS).[20] Participants were children born alive in a geographically defined area of Southern Bavaria (Germany) over a 14-month period who required admission to children's hospitals within the first 10 days after birth (*N*=7,505; 10.6% of all live births). Healthy infants who were born in the same obstetric hospitals (most born at term), cared for on normal postnatal wards, and discharged with their mothers were recruited as controls (*N*=916). Ethical approval was granted by the Ethical Review Board of the University of Munich Children's Hospital and the Bavarian Health Council in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki). Parents provided informed consent within 48 hours of their child's birth.

Figure 1 describes the BLS participant flow. The full sample was assessed at birth, 5 months, 20 months, and 4 years 8 months of age (hereafter called 4 years); the sample was then reduced (*N* = 1543) prior to 6-year and 8-year assessments. All very preterm children were included in the reduced sample. A random sample of children born at >31 weeks gestation was drawn according to the following stratification variables: sex, family socioeconomic status (low, moderate, high), and degree of neonatal risk (very low, low, moderate, high[21]).

For this study we removed 17 children who were not German speakers, 142 who were born in multiples (twins or higher-order birth; excluded because they have unique reasons for being preterm and have been found to have different language development than singletons[22]), 6 who had language data at only one or no assessments, and 78 with physical or developmental disabilities or unknown status (i.e., blindness, deafness, or cerebral palsy levels 3-4 (unable to move unaided)).[23,24] As the focus of this report is to compare children who were born preterm with healthy children, we also removed 556 children who were born at term but were hospitalized at birth because they had early medical problems that might cloud the findings, and 12 children in the healthy control sample who were born preterm but cared for on normal obstetric wards. Table 1 (online) gives the descriptives of the sample used (*n*=749) by gestation group. We divided the sample into three groups based on gestational age: *N*=205 very preterm, *N*=276 moderate-late preterm, and *N*=268 full-term.[25]

Procedures

Assessments at 5 and 20 months were carried out at term-corrected ages[26] by pediatricians, and at 4, 6, and 8 years at chronological ages by post-graduate clinical psychologists.[27] German versions of assessments were used.

Language assessments. At 5 and 20 months, the Griffiths Mental Development Scales[28] hearing and speech subscale was used to evaluate children's age-appropriate receptive and expressive communication. Scores were standardized to *M*=100, *SD*=15.

At 4 years, the Active Vocabulary Test (AWST)[29] and the Language Comprehension Test (LSVT)[30] were used. The AWST is a reliable and valid vocabulary assessment of expressive language ability of children from ages 3 to 6 years.[31] The LSVT was developed for children aged 4 to 8 years to assess language comprehension. Standardized scores with *M*=100 and *SD*=15 were used for both the AWST and the LSVT.[32]

At 6 years, four subscales of the Heidelberger Sprachenwicklungstest (HSET),[33] were administered to measure (1) grammatical rules (plural-singular rules), (2) language production (sentence production), (3) grammatical structure (understanding of grammatical structures), and (4) language comprehension (correction of semantically inconsistent sentences). T-scores were used for each subtest with *M*=50 and *SD*=10.[27] Next, experimenters observed the quality of children's speech and grammatical correctness during the assessment day and made judgements at the end of the day using consensus ratings based on the Diagnosis of Speech and Language (DSL).[27] Finally, pre-reading skills, including recognition of rhymes, sounds, and knowledge of numbers and letters, were assessed using four pre-reading tasks adapted from the School Maturity Assessment.[27,34]

At 8 years, experimenters administered the HSET,[33] observed the DSL,[27] and administered the Zurich Reading Test[35,36] to assess reading speed and number of reading errors and a Pseudoword Reading Test[37] to measure children's word decoding skills by asking them to read words which have no meaning.

Covariates. Family socioeconomic status (SES), computed as a weighted composite score of parents' education and occupation and grouped as low, middle, and high[38], was used as a general covariate. To control for child nonverbal intelligence, we standardized and averaged multiple measures at each age. At 5 and 20 months, we used the eye-hand and performance subscales of the Griffiths Mental Development Scales.[28] At 4 years, we used the Beery Visual-Motor Integration test[39] and Columbia Mental Maturity Scale.[40,41] At 6 and 8 years, we used the Beery Visual-Motor Integration test[39] and the nonverbal index of the Kaufman Assessment Battery for Children.[42,43] These covariates were used as controls for language performance at each age, and residualized language scores were employed in a covariate controlled model.

Results

A full analytic plan, details about measurement models, and additional statistical details appear in an online Appendix.

Full Sample Language Stability Model

We used latent variables to model the shared variance among language measures. This procedure has the advantage of removing measurement error and specific variance for each scale from the latent factor, leaving a more precise and reliable estimate of language ability at each age.[44] Furthermore, using latent variables allows for developmentally appropriate changes in the measurement of language as children age. Measurement models supported a single language factor at 4 years and second-order factor models with first-order factors for each of the major tests given at 6 and 8 years (see online Appendix for additional details). Using these factors, stability of individual differences was modelled from 5- and 20-month language scales to 4-, 6-, and 8-year language factors. The model of language stability from 5 months to 8 years (Figure 2) had excellent fit. There was small-to-medium stability between 5 months and 20 months and large stabilities between all later time points. The standardized indirect effect from 5-month to 8-year language performance was .13, p<.001, and the standardized indirect effect from 20-month to 8-year language performance was .55, p<.001. From 5 months to 8 years, stability increased significantly between each succeeding time point, $\Delta\chi^2(1)$=19.32-167.17, *ps*<.001, ΔCFI=.002-.016.

Comparison of Stability Coefficients in the Three Gestational Groups

To determine whether stability coefficients were similar in the very preterm, moderate-late preterm, and term-born groups, following establishment of partial metric and scalar invariance (see online Appendix), two multiple group models were compared. The fit of the model with constrained stability coefficients was significantly worse than the fit of the model with no constraints, $\Delta\chi^2(8)$=41.53, p<.001, ΔCFI=.004, indicating that one or more stabilities was different in one or more groups. Modification indices indicated that the language stabilities between 5 and 20 months, and 20 months and 4 years were higher for the very preterm group than the moderate-late preterm and term groups (Figure 3). With these two paths released for the very preterm group, the change in model fit was nonsignificant, $\Delta\chi^2(6)$=10.00, p=.125,

ΔCFI=.001. The standardized paths between 5- and 20-month and 20-month and 4-year language performance were significant for all groups, but larger for the very preterm group than the moderate-late preterm and term groups (Figure 3). Stability coefficients were similar across girls and boys.

Tests of Mean Differences across Groups

The higher stability coefficient in the very preterm group at the early ages is a special concern if language performance of very preterms is at a lower mean level than the other groups. The combination of low mean level and high stability would indicate that very preterm children are unlikely to improve their skills or "catch up" as they age. Saved factor scores from the constrained scalar invariance model were used to test group differences in language performance at the factor level across time. To have variables on a scale that could be compared across age, we standardized (*M*=0, *SD*=1) each variable/factor within age, resulting in mean-deviated scores for each age. Therefore, the main effect of child age should be near 0 and is ignored. However, this method allowed us to test the interaction between child age and gestation group because the effect of being preterm may not be uniform across child age.

A 5 Child age X 3 Gestation group repeated-measures analysis of variance revealed an interaction between Child age and Gestation group, Greenhouse-Geisser $F(3.83, 1387.24)=16.75$, $p<.001$, $\eta^2_p=.044$, as well as a main effect of gestation group, $F(2, 725)=66.96$, $p<.001$, $\eta^2_p=.156$. To understand the interaction, we explored gestation group differences on the language measure or factor at each age. The three groups differed at all time points: 5 months, Brown-Forsythe robust $F(2,555.59)=4.79$, $p=.009$, $\eta^2_p=.014$; 20 months, Brown-Forsythe robust $F(2,594.05)=36.70$, $p<.001$, $\eta^2_p=.095$; 4 years, Brown-Forsythe robust $F(2,542.11)=69.53$, $p<.001$, $\eta^2_p=.166$; 6 years, Brown-Forsythe robust $F(2,550.52)=102.59$, $p<.001$, $\eta^2_p=.228$; and 8 years, Brown-Forsythe robust $F(2,549.11)=49.08$, $p<.001$, $\eta^2_p=.123$. Tukey HSD post-hoc tests indicated that at 5 months the very preterm group scored lower than the term group but the moderate-late preterm group did not differ from either. At age 8, the very preterm group scored lower than the moderate-late preterm and term groups, which did not differ from one another. At 20 months, 4 years, and 6 years, there were differences across the three gestation groups where the very preterm group scored lowest and the term group scored highest. To be sure that the standardization process did not bias these tests, we recomputed these analyses on the unstandardized variables; all statistical decisions were the same.

Covariate Controlled Models

To test whether the stability found was explained by non-language factors, we repeated the stability analysis controlling for child nonverbal intelligence and family SES. This covariate controlled model fit the data adequately, $\chi^2(334)=734.01$, p<.001, CFI=.94, TLI=.93, RMSEA=.040 (90%CI=.036-.044), SRMR=.049. However, the stability coefficients all attenuated. Standardized stability from 5 to 20 months attenuated from .23 to .05 (nonsignificant), stability from 20 months to 4 years attenuated from .61 to .35, stability from 4 to 6 years attenuated from .95 to .77, and stability from 6 to 8 years attenuated from .96 to .74. The standardized indirect effect from 5-month to 8-year language performance was no longer significant at .01, and the standardized indirect effect from 20-month to 8-year language performance attenuated from .55 to .20, $p<.001$.

When multiple group models by gestation group were refit using the covariate-controlled model, the differential stability for the preterm group in the uncontrolled models (Figure 3) was not significant: fit of the model with constrained stability coefficients across groups was not significantly worse than the fit of the model with no constraints, $\Delta\chi^2(8)=9.78$, $p=.281$,

ΔCFI=.000.

Discussion

At all 5 time points across early development, very preterm children had lower language performance than term-born children. At 3 of the 5 ages, moderate-late preterm children also scored lower than term-born children (and better than very preterm children).[4,9-11] This study's novel contribution to the literature is its analysis of the stability of individual differences in the language of preterm children. From very early in development, very preterm, moderate-late preterm, and term children's language abilities were stable.[13-16] Although stability of individual differences was observed from the age of 5 months in the full sample, stability between 5 and 20 months was largely carried by the very preterm children, for whom language performance was more stable than moderate-late preterm and term children. However, once child nonverbal intelligence and family socioeconomic status were controlled, differences in early stability for the very preterm group compared to the moderate-late preterm and term groups attenuated. The stronger stability in the very preterm group was more likely a result of general cognitive difficulties and less likely specific to language performance. This conclusion is consistent with the literature indicating high stability of general cognitive performance from infancy,[45] and low socioeconomic status at birth is a crucial risk factor for child development.[46]

In Bavaria in the 1980s, it was customary for children under 3 to be cared for at home, and 90% of the sample was cared for by parents and/or other relatives in the home at age 2. Most children (78%) in the 3- to 5-year age range attended kindergarten in mixed-age classrooms. Children start school after their 6th birthday in Germany; thus, the tests administered at age 6 were shortly before school entry. However, some children (13%) deemed too immature for school entry by a community pediatrician were held back an additional year and therefore did not start formal schooling until age 7.[47] Children who were assessed as language delayed were referred to speech therapy, and, if the language delay was severe and accompanied by other cognitive deficits, children (7%) were matriculated into a special school to address their delays at diagnosis. It is possible that these early interventions disrupted stability (e.g., improved speech more than expected by development alone) in a small number of children in the sample. Still, stability was large from under 2 to 8 years, and largest for the children with the poorest language skills (i.e., very preterm children), suggesting that these interventions did not affect the overall pattern of stability.

This study has several strengths, including its relatively large samples of 3 gestation levels, prospective long-term longitudinal design, multiple observed language measures at 4, 6, and 8 years, and availability of controls for child nonverbal intelligence and family socioeconomic status. Language manifests differently at different ages. Using latent variables allows for the measurement of language to vary (appropriately) across time (as the construct does – children move from communicative gestures to speaking words to reading), but maintains comparability of the construct across time. This study also has limitations. At 5 and 20 months, only a single language measure was collected; more varied early language measures would strengthen the study. Furthermore, the generalizability of these results is limited to preterm and term children born under similar conditions (e.g., preterm children who required medical care beyond traditional prenatal care, and term children who did not). Furthermore, these data were collected beginning in the mid-1980s, and treatment of preterm children has changed. However, there is evidence that improved care has also led to improved survival of premature infants, and consequently more very preterm children are in the community, while the rate of cognitive disability may not have changed,[48] and older cohorts can be used to predict outcomes in newer cohorts.[49] Nevertheless, these longitudinal findings should be replicated in contemporary cohorts.

Conclusions

This study's findings have several implications for pediatricians, parents, and researchers. First, very preterm children have the lowest language skills, followed by moderate-late preterm and full term children, and these differences are consistent from 20 months to 8 years. Pediatricians and parents should be made aware that preterm-born children, even those born moderate-late preterm, are at risk for delayed language compared to term children. Second, by 20 months of age (preterm adjusted), children who are performing poorly relative to their peers are likely to continue to perform poorly at later ages, suggesting that standard follow-up assessment of language at the end of the second year of life is highly predictive and may indicate the need for intervention. Third, stability in language performance appears to strengthen over time. From age 4 to age 8, about 90% of the variance in children's later language performance was explained by their earlier language performance, suggesting that early intervention (well before school entry) may be critical because language may be less changeable later. In fact, intervention before preterm infants leave the hospital has been shown to improve language outcomes.[50] Through regular checkups in toddlerhood, pediatricians have the opportunity to connect children who have lagging language skills to critical remedial services.

References

1. March of Dimes, PMNCH, Save the Children, WHO. *Born Too Soon: The Global Action Report on Preterm Birth*. Geneva: World Health Organization; 2012.
2. Bhutta AT, Cleves MA, Casey PH, Cradock MM, Anand KJ. Cognitive and behavioral outcomes of school-aged children who were born preterm: a meta-analysis. *JAMA.* 2002;288:728-37.
3. Jaekel J, Baumann N, Wolke D. Effects of gestational age at birth on cognitive performance: A function of cognitive workload demands. *PLoS ONE*. 2013;8:e65219.
4. Quigley MA, Poulsen G, Boyle E, Wolke D, Field D, Alfirevic Z, et al. Early term and late preterm birth are associated with poorer school performance at age 5 years: A cohort study. *Archives of Disease in Childhood-Fetal and Neonatal Edition*. 2012;97:F167-73.
5. Wolke D, Strauss VY-C, Johnson S, Gilmore C, Marlow N, Jaekel J. Universal gestational age effects on cognitive and basic mathematic processing: 2 Cohorts in 2 countries. *The Journal of Pediatrics.* 2015;166:1410-6.
6. Saigal S, Doyle LW. An overview of mortality and sequelae of preterm birth from infancy to adulthood. *The Lancet*. 2008;371:261-9.
7. Blencowe H, Cousens S, Oestergaard MZ, Chou D, Moller AB, Narwal R, et al. National, regional, and worldwide estimates of preterm birth rates in the year 2010 with time trends since 1990 for selected countries: a systematic analysis and implications. *The Lancet*. 2012;379:2162-72.
8. Barre N, Morgan A, Doyle LW, Anderson PJ. Language abilities in children who were very preterm and/or very low birth weight: a meta-analysis. *The Journal of Pediatrics*. 2011;158:766-74.

9. Baron IS, Erickson K, Ahronovich MD, Coulehan K, Baker R, Litman FR. Visuospatial and verbal fluency relative deficits in 'complicated' late-preterm preschool children. *Early Human Development.* 2009;85:751-4.

10. Lipkind HS, Slopen ME, Pfeiffer MR, McVeigh KH. School-age outcomes of late preterm infants in New York City. *American Journal of Obstetrics and Gynecology*. 2012;206:222.e1-6.

11. Nepomnyaschy L, Hegyi T, Ostfeld BM, Reichman NE. Developmental outcomes of late-preterm infants at 2 and 4 years. *Maternal and Child Health Journal.* 2012;16:1612-24.

12. Bornstein MH, Bornstein L. Psychological stability. In Darity WA Jr., ed. *International Encyclopedia of Social Sciences.* 2nd ed. Vol. 8. Detroit, MI: Macmillan Reference; 2008:74-5.

13. Bornstein MH, Hahn C-S, Haynes OM. Specific and general language performance across early childhood: Stability and gender considerations. *First Language.* 2004;24:267-304.

14. Bornstein MH, Hahn C-S, Putnick DL. Stability of core language skill across the first decade of life in children at biological and social risk. *Journal of Child Psychology and Psychiatry*. Forthcoming 2016.

15. Bornstein MH, Hahn C-S, Putnick DL, Suwalsky JTD. Stability of core language skill from early childhood to adolescence: A latent variable approach. *Child Development.* 2014;85:1346-56.

16. Bornstein MH, Putnick DL. Stability of language in childhood: A multiage, multidomain, multimeasure, and multisource study. *Developmental Psychology*. 2012;48:477-91.

17. Ribeiro LA, Zachrisson HD, Schjolberg S, Aase H, Rohrer-Baumgartner N, Magnus P. Attention problems and language development in preterm low-birth-weight children: Cross-

lagged relations from 18 to 36 months. *BMC Pediatrics*. 2011;11:59.

18. Sansavini A, Guarini A, Savini S, Broccoli S, Justice L, Alessandroni R, et al. Longitudinal trajectories of gestural and linguistic abilities in very preterm infants in the second year of life. *Neuropsychologia.* 2011;49:3677-88.
19. Stolt S, Haataja L, Lapinleimu H, Lehtonen L. The early lexical development and its predictive value to language skills at 2 years in very-low-birth-weight children. *Journal of Communication Disorders.* 2009;42:107-23.
20. Wolke D, Schmid G, Schreier A, Meyer R. Crying and feeding problems in infancy and cognitive outcome in preschool children born at risk: A prospective population study. *Journal of Developmental and Behavioral Pediatrics*. 2009;30:226-38.
21. Jaekel J, Baumann N, Wolke D. Effects of gestational age at birth on cognitive performance: A function of cognitive workload demands. *PLoS ONE*. 2013;8:e65219
22. Thorpe K. Twin children's language development. Early Human Development. 2006;82:387-95.
23. Hagberg B, Hagberg G, Olow I. The changing panorama of cerebral palsy in Sweden. VI. Prevalence and origin during the birth year period 1983-1986. *Acta Paediatrica*. 1993;82:387-93.
24. Wolke D, Chernova J, Eryigit-Madzwamuse S, Samara M, Zwierzynska K, Petrou S. Self and parent perspectives on health-related quality of life of adolescents born very preterm. *Journal of Pediatrics.* 2013;163:1020-6
25. Wolke D. Preterm and low birth weight babies. In Howlin P, Charman T, Ghaziuddin M, eds. *The SAGE handbook of developmental disorders*. London, UK: Sage; 2011:497-527.
26. Engle W A. Age terminology during the perinatal period. *Pediatrics*. 2004;114:1362-4.

27. Wolke D, Meyer R. Cognitive status, language attainment and pre-reading skills of 6 year-old very preterm children and their peers: the Bavarian Longitudinal Study. *Developmental Medicine and Child Neurology*. 1999;41:94-109.

28. Brandt I. *Griffiths Entwicklungsskalen (GES zur Beurteilung der Entwicklung in den ersten beiden Lebensjahren)* [The Griffiths Baby Scales (Griffiths Scales for assessing development in the first two years of life)]. Weinheim, Germany: Beltz; 1983.

29. Kiese C, Kozielski PM. *Aktiver Wortschatztest fur drei- bissechsja hrige Kinder* [Active Vocabulary Test for 3–6 year olds. AWST 3-6.]. Weinheim, Germany: Beltz; 1979.

30. Wettstein P. *LSVT: Logopädischer Sprachverständnis-Test* [LSVT: Language Comprehension Test]. Zurich, Switzerland: Heilpädagogisches Seminar; 1983.

31. Kiese-Himmel C. *AWST-R: Aktiver Wortschatztest fur 3-5-jahrige Kinder* [AWST-R: Active Vocabulary Test for 3 5 year olds]. Gottingen, Germany: Hogrefe; 2005.

32. Gutbrod T, Wolke D, Söhne B, Ohrt B, Riegel K. The effects of gestation and birthweight on the growth and development of very low birthweight small for gestational age infants: A matched group comparison. *Archives of Disease in Childhood Fetal and Neonatal Edition*. 2000;82:F208-14.

33. Grimm H, Schöler H. *Der Heidelberger Sprachentwicklungstest H-S-E-T (2. verbesserte Auflage)* [Heidelberger Language Development Test H-S-E-T]. 2nd ed. Göttingen, Germany: Hogrefe; 1991.

34. Skowronek H, Marx H. *Die Bielefelder langsschnittstudie zur fruherkennung von risiken der lese-rechtschribschwache: Theoretischer hintergrund und erste befunde*. [The Bielefeld longitudinal study for early detection of risks associated with the reading delay: Theoretical background and first results.] *Heilpadagogische Forschung*, 1989;15:39-49.

35. Linder M, Grissemann H. *Zürcher Lesetest* [Zurich Reading Test]. 4th ed. Bern, Switzerland: Verlag Hans Huber; 1980.

36. Linder M, Grissemann H. *Zürcher Lesetest* [Zurich Reading Test]. 6th ed. Bern, Switzerland: Verlag Hans Huber; 2000. http://testzentrale.de

37. Leon-Villagra J, Wolke D. Pseudoword reading test. Munich: Unpublished Manuscript; 1993.

38. Bauer A. *Ein Verfahren zur Messung des für das Bildungsverhalten relevanten Status* (BRSS) [A method of measuring relevant for the formation of behavior status]. Frankfurt: Deutsches Institut für Internationale Pädagogische Forschung; 1988.

39. Beery KE. *Revised Administration, Scoring, and Teaching Manual for the Developmental Test of Visual-Motor Integration*. Toronto, Canada: Modern Curriculum Press; 1982.

40. Burgemeister BB, Blum LH, Lorge I. *The Columbia Mental Maturity Scale (Manual).* New York: Yonkers-on-Hudson; 1954.

41. Eggert D. Die Columbia Mental Maturity Scale als individualtest für normalentwickelte Kinder im alter von 3–10 jahren. [The Columbia Mental Maturity Scales as an individual test for normally developing children aged 3–10 years.] In Eggert D, ed. *Zur Diagnose der Minderbegabung*. Weinheim, Germany: Beltz; 1972.

42. Kaufman AS, Kaufman N. *Kaufman Assessment Battery for Children*. Circle Pines, MN: American Guidance Service; 1983.

43. Melchers P, Preuss U. Kaufman battery for children: Deutschsprachige fassung. Frankfurt am Main, Germany: Swets & Zeitlinger; 1991.

44. Kline RB. Principles and practice of structural equation modelling (4th ed.). New York: Guilford Press; 2015.

45. Breeman LD, Jaekel J, Baumann N, Bartmann P, Wolke D. Preterm cognitive function into adulthood. *Pediatrics*. 2015;136:415-23.

46. Eryigit Madzwamuse S, Baumann N, Jaekel J, Bartmann P, Wolke D. Neuro-cognitive performance of very preterm or very low birth weight adults at 26 years. *Journal of Child Psychology and Psychiatry*. 2015;56:857-64.

47. Jaekel J, Strauss VY, Johnson S, Gilmore C, Wolke D. Delayed school entry and academic performance: A natural experiment. *Developmental Medicine & Child Neurology*. 2015;57:652-9

48. Moore T, Hennessy EM, Myles J, Johnson SJ, Draper ES, Costeloe KL, et al. Neurological and developmental outcome in extremely preterm children born in England in 1995 and 2006: the EPICure studies. *BMJ*, 2012;345:e7961.

49. Wolke D, Strauss VY-C, Johnson S, Gilmore C, Marlow N, Jaekel J. Universal gestational age effects on cognitive and basic mathematic processing: 2 cohorts in 2 countries. *The Journal of Pediatrics*. 2015;166:1410-6.e2.

50. Caskey M, Stephens B, Tucker R, Vohr B. Adult talk in the NICU with preterm infants and developmental outcomes. *Pediatrics*. 2014;133:e578-84.

Figure 1. Participant flow.

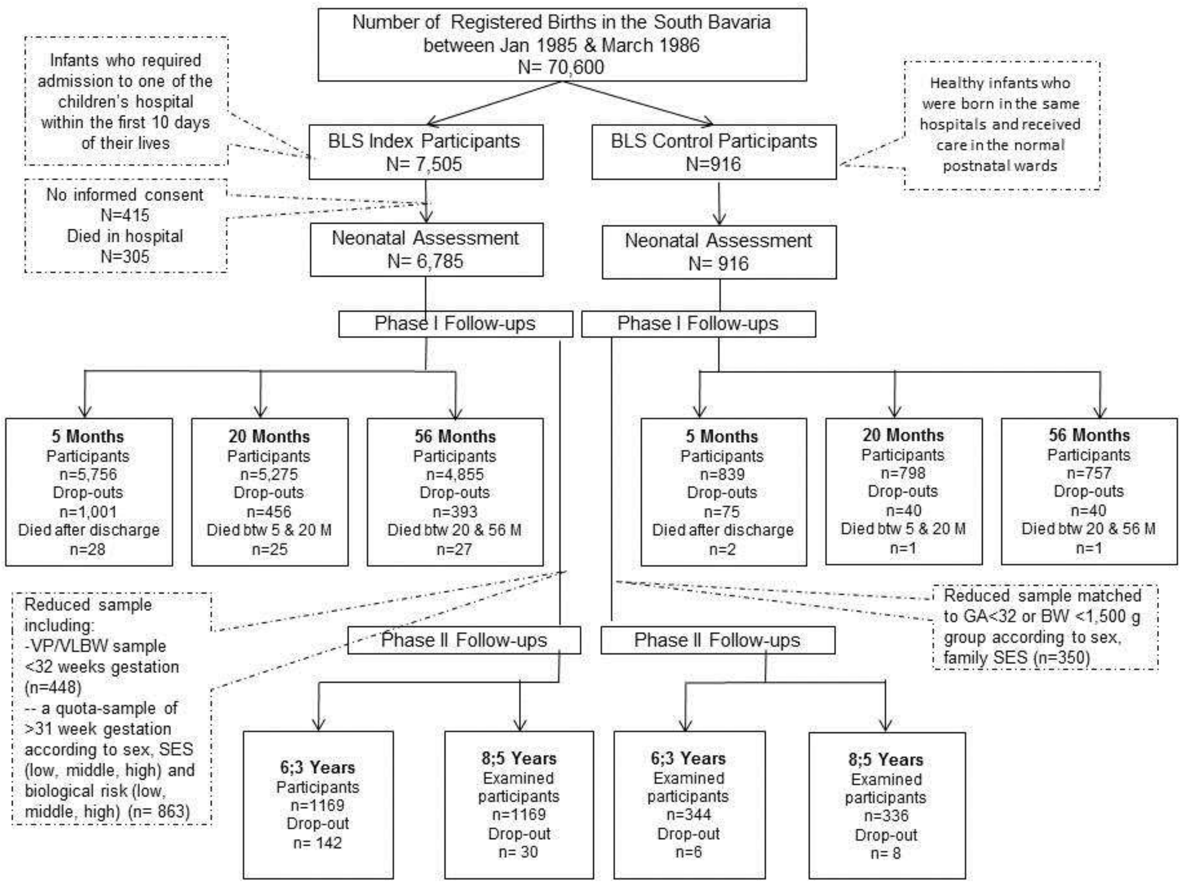
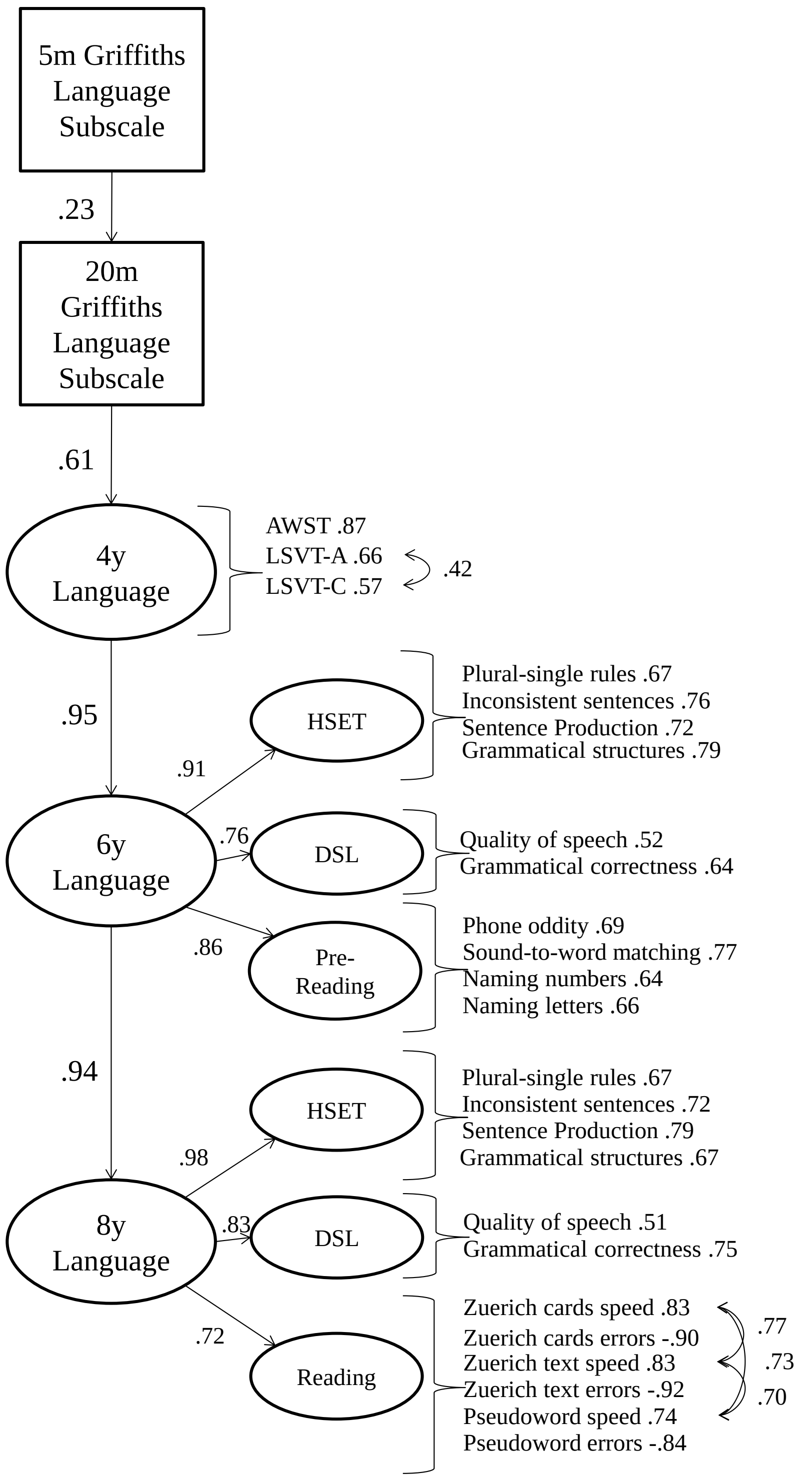


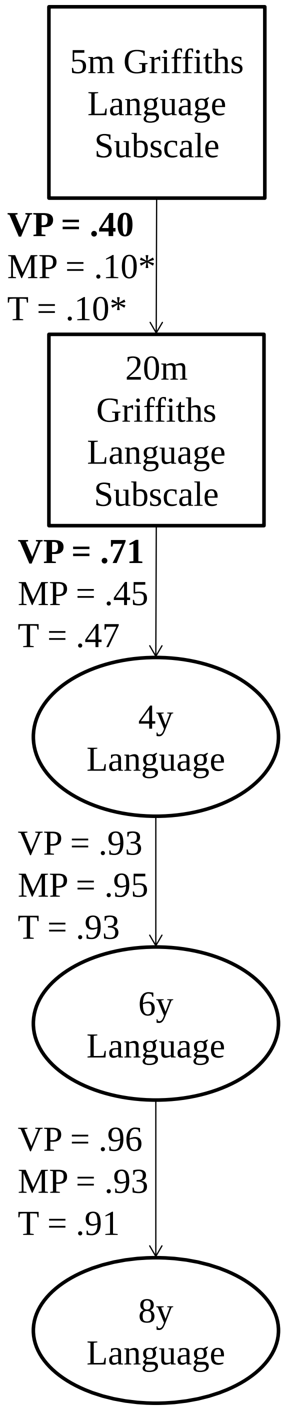
Figure 2. Model of language stability from age 5 months to 8 years in the full sample.



Note. Standardized coefficients are presented. All coefficients were significant at *p*<.001.

Indicators of first-order latent variables are listed next to their factors along with the standardized loadings. Model fit: $\chi^2(312)=747.88$, $p<.001$, CFI=.96, TLI=.96, RMSEA=.043 (90%CI=.039-.047), SRMR=.043. AWST = Active Vocabulary Test. LSVT-A = Language Comprehension Test - Part A. LVST-C = Language Comprehension Test – Part C. HSET = Heidelberger Sprachenwicklungstest. DSL = Diagnosis of Speech and Language.

Figure 3. Model of language stability from age 5 months to 8 years by gestation group.



Note. VP=very preterm. MP=moderate-late preterm. T=term. Bolded coefficients were significantly different from other gestation groups. All coefficients were significant at p<.001 unless otherwise noted. * $p < .05$.

Appendix

Method

Analytic Plan

Prior to analysis, all variables were examined for outliers and deviations from univariate normality.[1] Standard transformations were applied as needed for variables to approximate a normal distribution.

Previous studies of language development in preterm children have explored individual aspects or measures of language. However, evidence from term children suggests that different aspects of language (e.g., vocabulary comprehension, production, grammar, reading) form single latent variables that assess core language ability from early in development. Consequently, when multiple language measures were available, we explored measurement models to determine whether the different language measures at 4, 6, and 8 years formed a single latent variables (factor) that indicated language performance at that age. If model fit of a single-factor model was not supported, alternative structures (method factors, correlated residual terms) were explored as guided by theory and modification indices. Stability of child language across age was examined via structural equation modelling as implemented in M*plus* version 7.2.[2] In all models, full information maximum likelihood (FIML)[3] within M*plus* was used to account for missing data (6.92% of the data points were missing). A model was considered to have good fit if the χ^2 test was nonsignificant ($p > .05$), the Comparative Fit Index (CFI) and Tucker-Lewis Index (TLI) $\geq .95$,[4,5] the Root Mean Sqaure Error of Approximation (RMSEA) $\leq .06$, and the Standardized Root Mean Square Residual (SRMR) < .08,[4] but we gave greater weight to the incremental fit indices than to the significance of the χ^2 because the χ^2 value is known to be sensitive to sample size[6] and the size of the correlations in the model.[7] Standardized path coefficients range from 0 to 1 and are presented in text and figures. Standardized path coefficients were interpreted with respect to Cohen's[8] estimates of small (.10), medium (.30), and large (.50) effects. Following a test of the stability of language performance in the full sample, we established at least partial metric and scalar invariance (i.e., constraining the loadings of observed variables on factors and first-order factors on second-order factors, and constraining intercepts of observed and latent first-order factors across groups)[9,10] to make sure the factors had the same meaning in the very preterm moderate-late preterm and term groups. Then we computed two additional multiple-group models, constraining the structural paths to be equal across the three gestation groups in the first model and releasing these paths in the second model to determine whether the stability model fit equally well for very preterm, moderate-late preterm, and term children. Following Cheung and Rensvold[6], if the differences in χ^2 values for the two nested models were nonsignificant, and the change in CFI $\leq$ .01, we could be reasonably certain that the structural paths were similar for the three gestation groups. If the change in model fit indicated poor fit, structural paths were incrementally released to determine which group(s) had differential stability across age.

Because stability has different implications for low- and high-performing children (e.g., high stability is good if the child performs well, but bad if the child performs poorly), we saved latent variable scores from the main model of language stability and tested mean differences across gestation groups by child age. We also computed a covariate controlled language stability model and multiple group models that accounted for nonverbal intelligence at each age and family SES. Observed language variables at each age were computed removing the variance associated with nonverbal intelligence (i.e., residual scores), and the model was refit using these residual scores. Family SES was added as an observed variable to the models, and language stability coefficients were compared to the uncontrolled models.

Results

Measurement Models

At 4 years, the 3 variables from the Active Vocabulary Test and Language Comprehension Test loaded on a single factor of 4-year language performance. A measurement model indicated that there was additional variance shared by the two Language Comprehension Test indicators (method variance) that was not accounted for by the latent variable. Consequently, a covariance was added between the residual terms for these two indicators. At 6 and 8 years, the best fitting and most parsimonious measurement models were second-order factor models with first-order factors for each of the major tests given, and a single second-order factor for total language performance. (We also tested models with only a single factor for 6- and 8-year language performance and models with the three first-order factors with covariances among them. The higher-order models were a better fit to the data.) At 8 years, the three reading speed variables from the Zuerich Reading Test shared additional variance (method variance, or processing speed variance) that was not accounted for by the reading factor. Hence, covariances were added between the residual terms for these three indicators.

Metric and Scalar Invariance across Gestation Groups

To ensure measurement equivalence of the language latent variables across groups, we tested metric invariance of the first- and second-order factor loadings and scalar invariance of the observed and first-order intercepts. A baseline configural invariance model with no constraints fit the data, $\chi^2(936)=1401.31$, $p<.001$, CFI=.95, TLI=.95, RMSEA=.045 (90%CI=.040-.049), SRMR=.058. Full metric invariance of the observed variable loadings was not supported, $\Delta\chi^2(36)=85.58$, $p<.001$, ΔCFI=.005, but once 2 loadings were released (8-year Zuerich text speed on the reading factor in the term group and 8-year Zuerich cards errors on the reading factor in very preterm group), the model fit was acceptable, $\Delta\chi^2(34)=40.95$, $p = .192$, $\Delta CFI=.000$. Full metric invariance of the second-order factor loadings was not supported, $\Delta\chi^2(8)=51.92$, $p<.001$, $\Delta CFI=.002$, but once 3 loadings were released (the loadings on the 6-year and 8-year DSL on the 6- and 8-year language factors for the term group, and the loading of the 6-year HSET on the 6-year language factor for the very preterm group), the model fit was acceptable, $\Delta\chi^2(5)=10.46$, $p = .063$, $\Delta CFI=.001$. Full scalar invariance of the observed variables was not supported, $\Delta\chi^2(36)=118.23$, $p<.001$, $\Delta CFI=.008$, but once 5 intercepts were released (6-year plural-single rules and 8-year Zuerich cards errors in the very preterm group, and 4-year LSVT-C, 6-year inconsistent sentences, and 8-year Zuerich text speed in the term group), the model fit was acceptable, $\Delta\chi^2(31)=42.76$, $p = .078$, $\Delta CFI=.001$. Finally, full scalar invariance of the first-order factors was not supported, $\Delta\chi^2(8)=74.61$, $p<.001$, $\Delta CFI=.007$, but once 3 intercepts were released (6-year and 8-year DSL in the term group and 6-year HSET for the very preterm group), model fit was acceptable, $\Delta\chi^2(5)=6.32$, $p = .276$, $\Delta CFI=.000$. These findings suggest that partial metric and scalar invariance were supported across the 3 gestation groups and it was appropriate to test for differential stability across these groups.[11]

References

51. Tabachnick BG, Fidell LS. Using multivariate statistics. 6th ed. Boston: Allyn & Bacon; 2013.

52. Muthén LK, Muthén BO. *Mplus® statistical analysis with latent variables: User's guide*. 5th ed. Los Angeles, CA: Muthén & Muthén; 2009.

53. Arbuckle JL. Full information estimation in the presence of incomplete data. In Marcoulides GA, Schumacker RE. eds. *Advanced structural equation modeling: Issues and techniques*. Mahwah, NJ: Erlbaum; 1996: 243-77.

54. Hu LT, Bentler PM. Cut-off criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling*. 1999;6:1-55.

55. Marsh HW, Balla JR, Hau K-T. An evaluation of incremental fit indices: A clarification of mathematical and empirical properties. In Marcoulides GA, Schumacker RE. eds. *Advanced structural equation modeling: Issues and techniques*. Mahwah, NJ: Erlbaum; 1996: 315-53.

56. Cheung GW, Rensvold RB. Evaluating goodness-of-fit indexes for testing measurement invariance. *Structural Equation Modeling*. 2002;9:233-55.

57. Miles J, Shevlin M. A time and a place for incremental fit indices. *Personality and Individual Differences*. 2007;42:869-74.

58. Cohen J. *Statistical power analysis for the behavioral sciences*. 2nd ed. Mahwah, NJ: Erlbaum;1988.

59. Vandenberg RJ, Lance CE. A review and synthesis of the measurement invariance literature: Suggestions, practices, and recommendations for organizational research. *Organizational Research Methods*. 2000;3:4-70.

60. Putnick DL, Bornstein MH. Measurement invariance conventions and reporting: The state of

the art and future directions for psychological research. *Developmental Review*. Forthcoming 2016.

61. Byrne BM, Shavelson RJ, Muthén B. Testing for the equivalence of factor covariance and mean structures: The issue of partial measurement invariance. *Psychological Bulletin*. 1989;105:456-66.

Table 1. Sample descriptives

	Very Preterm (*n*=205)	Moderate-late Preterm (*n*=276)	Term (*n*=268)	Group Differences
	M (SD)	*M (SD)*	*M (SD)*	F^{a}
Gestational age (weeks)	29.56(1.58)	34.33(1.39)	39.71(1.04)	3577.30***
Birthweight (g)	1318.40 (359.37)	2090.72 (563.09)	3491.53 (389.70)	2018.22***
Prenatal risk	2.15(1.26)	1.79 (1.13)	.71 (.85)	135.43***
Maternal age (years)	28.60 (5.34)	29.33 (5.53)	28.67(4.74)	1.48
Hospitalization (days)	80.97 (40.50)	34.41 (23.36)	7.16 (3.61)	486.51***
	N (%)	*N (%)*	*N (%)*	χ^2
Sex – Female	82 (40.0)	130 (47.1)	134 (50.0)	4.82
Family SES				17.75***
Upper-class	43 (21.1)	89 (32.2)	81 (30.2)	
Middle-class	87 (42.6)	85 (30.8)	116 (43.3)	
Lower-class	74 (36.3)	102 (37.0)	71 (26.5)	

Note. Prenatal risk represents the total number of pregnancy complications, such as preeclampsia, bleeding, pathological CTG, and is expected to be higher in the very preterm samples compared to children who were born later in gestation. For variables with significant *F* tests, all group means significantly differed in Games-Howell post-hoc tests that correct for inequality of variance across groups. Very preterm children were born between 25 and 31 weeks gestation, moderate-late preterm children were born between 32 and 36 weeks gestation, and term children were worn between 37 and 41 week gestation.

[a] *F*-tests are robust Welch (1951) tests that correct for inequality of variance across groups.