University of Helsinki
Dissertationes Universitatis Helsingiensis
11/2023

LANGUAGE ENVIRONMENT AND PARENT-INFANT CLOSE CONTACT IN THE NEONATAL INTENSIVE CARE UNIT, AND EARLY LEXICAL ABILITIES OF VERY PRETERM CHILDREN

METHODOLOGICAL CONSIDERATIONS AND LONGITUDINAL ASSOCIATIONS

Eva Ståhlberg-Forsén

DOCTORAL DISSERTATION

To be presented, with the permission of the Faculty of Medicine of the University of Helsinki, for public examination in Lecture Hall 3, Biomedicum, on 24 November 2023, at 12 noon.

HELSINKI 2023

Supervisors

Associate Professor Suvi Stolt
Department of Psychology and Logopedics
University of Helsinki

MD PhD Reija Latva
Department of Child Psychiatry
Tampere University Hospital

Reviewers

Adjunct Associate Professor Susan Foster-Cohen
Linguistics Department
University of Canterbury

Docent Leila Paavola-Ruotsalainen
Research Unit of Logopedics
University of Oulu

Opponent

Professor Caroline Rowland
Language Development Department
Max Planck Institute for Psycholinguistics

Department of Psychology and Logopedics
Faculty of Medicine
Doctoral Programme in Cognition, Learning, Instruction and Communication

Publisher: University of Helsinki
Series: Dissertationes Universitatis Helsingiensis 11/2023

ISBN 978-951-51-9058-1 (print)
ISBN 978-951-51-9059-8 (online)
ISSN 2954-2898 (print)
ISSN 2954-2952 (online)
PunaMusta, Joensuu 2023

ABSTRACT

Very preterm children (born <32 gestational weeks) are at risk for weak language skills, including delayed lexical processing and development. Because preterm children show broad variation in language development, it is important to develop methods to identify the children who need additional support for their development. More information on factors that may optimize language outcomes in this at-risk group is also needed, including the effects of language environment in the neonatal intensive care unit (NICU).

The present dissertation was performed as part of the Auditory environment by Parents of Preterm infants, Language development and Eye movements research project. The focus of the dissertation was to gain knowledge on the role of early language environment on very preterm children's lexical abilities during the second year of life. The first main aim was methodological, to investigate the validity of the Language Environment Analysis (LENA) system in the neonatal intensive care units (NICUs) in Turku, Finland, and Tallinn, Estonia. The usability and validity of an eye tracking-based processing task, to assess early lexical processing of Finnish-acquiring very preterm children, were also evaluated. The second main aim was clinical, to investigate the longitudinal associations between language environment and parent-infant closeness in the NICU and later lexical abilities of very preterm children.

The total number of participants was 43 very preterm infants. The dissertation is based on three studies. Study I, the LENA validation study, compared LENA and human coder labels and estimated counts. In Study II, very preterm children's lexical processing (reaction time and correct looking time) was assessed with an eye tracking-based processing task at 18 months' corrected age, and the associations between lexical processing and development were investigated. The study also provided information on the lexical processing task. Lexical development was assessed with validated and normed parental report form screening methods at 12, 15 and 18 months' corrected age. Study III investigated the possible associations between the language environment and parent-infant closeness in the NICU and very preterm children's later lexical abilities. LENA was utilized to measure language environment (adult word, conversational turn and child vocalization counts). Parent-infant closeness was documented with parental closeness diaries. Lexical processing was assessed with the eye tracking-based processing task and lexical development with parental report form screening methods.

Study I, the LENA validation study, showed high agreement between LENA and human coder estimated adult and female word counts (r = 0.95 and 0.91), and conversational turn count in Turku (r = 0.73). Based on Study II, the very preterm children's lexical processing was associated with lexical development during the first part of the second year of life (r = 0.43–0.58). In a linear regression model, lexical processing correct looking time and gender explained 40% of expressive lexical development at 18 months. Based on the longitudinal data from Study III, NICU conversational turn count and parent-infant close contact (skin-to-skin contact and holding) were positively associated with lexical development at 15 and 18 months (r = 0.37–0.46). The adult word count was negatively associated with lexical processing correct looking time at 18 months (r = -0.40). In linear regression models, conversational turn count, close contact, and gender explained 34%–35% of receptive lexical development at 18 months.

The main findings showed that LENA provides valid information from the NICU contexts on adult word count. The findings also indicate that the lexical processing task can provide useful and valid information on lexical processing of very preterm children at 18 months. Adult-infant conversational turns and both parents' close contact with the infant in the NICU were positively associated with later lexical development. However, high measures of adult words near the infant in the NICU may not promote later lexical processing. More research is needed to investigate the connections between the NICU language environment and lexical abilities of very preterm children in larger samples and at a later age.

Keywords: eye tracking, language environment, Language Environment Analysis, lexical development, lexical processing, neonatal intensive care unit, parent-infant closeness, skin-to-skin contact, very preterm

SAMMANFATTNING

Mycket för tidigt födda (<32 graviditetsveckan) barn har en ökad risk för språkliga svårigheter, inklusive försenad lexikal processerings- och ordförrådsutveckling. Eftersom för tidigt födda barn uppvisar en stor variation i språkutvecklingen är det viktigt att utveckla metoder för tidig identifikation av de barn som behöver stöd för utvecklingen. Det finns även behov av mer information om de faktorer som kan optimera språkutvecklingen hos denna riskgrupp, såsom om effekterna av den tidiga språkmiljön.

Denna avhandling utfördes som en del av forskningsprojektet the Auditory environment by Parents of Preterm infants, Language development and Eye movements. Avhandlingens övergripande syfte var att utreda den tidiga språkmiljöns roll för lexikala förmågor hos mycket för tidigt födda barn under det andra levnadsåret. Den första huvudmålsättningen var metodologisk. Avhandlingen granskade validiteten hos the Language Environment Analysis (LENA) system som ett instrument för att undersöka språkmiljön på intensivvårdsavdelningarna för nyfödda i Åbo, Finland och Tallinn, Estland. Därtill undersöktes användbarheten och validiteten hos en eye tracking-baserad lexikal processingsuppgift som användes för att undersöka tidig lexikal processingsförmåga hos mycket för tidigt födda barn som lär sig finska. Den andra huvudmålsättningen, med kliniskt fokus, var att utreda det longitudinella sambandet mellan språkmiljö samt föräldra-barn närhet på den neonatala intensivvårdsavdelningen och senare lexikala förmågor hos mycket för tidigt födda barn.

Deltagarna var totalt 43 mycket för tidigt födda barn. Avhandlingen baserar sig på tre studier. Studie I jämförde LENAs och den mänskliga kodarens bedömning av talsegment och antalet ord i omgivningen. I Studie II undersöktes barnens lexikala processeringsförmåga (reaktionshastighet och korrekthet) vid 18 månaders korrigerad ålder med en eye tracking-baserad lexikal processeringsuppgift. Även sambandet mellan den lexikala processingsförmågan och ordförrådsutvecklingen analyserades. Ordförrådsutvecklingen vid 12,15 och 18 månaders korrigerad ålder bedömdes med validerade och normerade föräldraskattningsformulär. Studie III undersökte det möjliga sambandet mellan språkmiljön samt föräldra-barn närheten på intensivvårdsavdelningen för nyfödda och senare lexikala förmågor hos mycket för tidigt födda barn. LENA användes för att mäta språkmiljön (vuxenord, verbala turtagningar och barnyttranden). Föräldra-barn närheten dokumenterades med närhetsdagböcker. Den lexikala processeringen kartlades med processeringsuppgiften och ordförrådsutvecklingen med föräldraskattningsformulären.

Resultaten från Studie I visade ett starkt samband mellan LENAs och den mänskliga kodarens bedömning av antalet ord av vuxna och kvinnor (r = 0.82–0.96) samt verbala turtagningar i Åbo (r = 0.73). Resultaten från Studie II visade ett positivt samband mellan den lexikala processeringsförmågan och den expressiva ordförrådsutvecklingen under det andra levnadsåret (r = 0.43–0.58). I en linjär regressionsmodell förklarade processeringens korrekthet och barnets kön 40 % av den expressiva ordförrådsutvecklingen vid 18 månader. Studie III påvisade att positivt samband mellan verbala turtagningar och föräldra-barn närkontakt på den neonatala intensivvårdsavdelningen och ordförrådsutvecklingen vid 15 och 18 månaders ålder (r = 0.37–0.46). Antalet vuxenord korrelerade negativt med processeringens korrekthet vid 18 månaders ålder (r = -0.40). I linjära regressionsmodeller förklarade verbala turtagningar, föräldra-barn närkontakt och barnets kön 34–35 % av receptiv ordförrådsutveckling vid 18 månaders ålder.

Avhandlingen visade att LENAs beräkningar av antalet vuxenord på intensivvårdsavdelningen för nyfödda är valida. Resultaten tyder även på att den lexikala processeringsuppgiften kan ge användbar och valid information om mycket för tidigt födda barns lexikala processeringsförmåga vid 18 månaders ålder. Avhandlingen visade på ett positivt samband mellan vuxen-barn verbala turtagningar och båda föräldrarnas närkontakt med barnet på intensivvårdsavdelningen för nyfödda och barnets senare ordförrådsutveckling. Resultaten tyder dock på att ett högt antal vuxenord nära barnet på intensivvårdsavdelningen inte är gynnsamt för barnets senare lexikala processeringsförmåga. Mer forskning i större sampel och i senare ålder behövs för att utreda sambandet mellan språkmiljön på intensivvårdsavdelningen för nyfödda och lexikala förmågor hos mycket för tidigt födda barn.

Nyckelord: eye tracking, föräldra-barn närhet, hud mot hudkontakt, intensivvårdsavdelning för nyfödda, Language Environment Analysis, lexikal processering, mycket för tidigt födda, ordförrådsutveckling, språkmiljö

ACKNOWLEDGEMENTS

This work was carried out at the Logopedics department at the Faculty of Medicine at the University of Helsinki. My personal motivation for the research is based on my clinical experience and an urge to contribute to further develop clinical procedures and methods that will benefit young children and their families.

The dissertation would not have been possible without the support of others and collaboration. My deepest gratitude goes to my main supervisor Professor Suvi Stolt, who took me along on this intriguing project. Thank you, Suvi, for all your time and support. Your robust expertise, clear guidance, and structured feedback along the way have been crucial. You have patiently and determinedly helped me to learn and grow as a researcher, and I have learned and experienced more than I could expect. I also very much appreciate our collaboration on developing the lexical processing task.

I also wish to express my warm gratitude to my secondary supervisor Reija Latva, MD PhD. I have truly appreciated your knowledge and guidance, and your important perspectives on the work and the doctoral research process. Further, a very special thank you goes to Professor Jukka Leppänen who played an important role in collaborating on designing the eye tracking-based lexical processing task, analyzed the eye tracking data, and significantly contributed to the article.

I express my sincere gratitude to the Auditory environment by Parents of Preterm infants, Language development and Eye movements research group. I thank the principal investigators Professor Liisa Lehtonen and Professor Suvi Stolt for the opportunity to take part in this international interdisciplinary research project. I thank Professor Liisa Lehtonen and the other co-authors Sari Ahlqvist-Björkroth, PhD, Liis Toome, MD PhD, MD PhD student Anette Aija and Birgit Kaasik, MA, for sharing your expertise and contributing to the studies and publications. Additional thanks to Anette and research nurse Minna Paaso, RN, who conducted the main part of the recruitment and data collection in the neonatal intensive care units. Further, Anette and M.Sc. PhD student Laura Aarnos also conducted part of the data entry.

I am sincerely thankful to Adjunct Associate Professor Susan Foster-Cohen from the University of Canterbury and Docent Leila Paavola-Ruotsalainen from the University of Oulu for conducting the pre-examination of this dissertation. Your expertise and suggestions helped me to improve and deepen the work. Further, I am thankful to Professor Caroline Rowland from the Max Planck Institute for Psycholinguistics for agreeing to serve as my opponent. I also warmly thank my thesis committee members Docent Leila Paavola-Ruotsalainen and Docent Pirkko Rautakoski for your insights and support.

I wish to express my appreciation to the Department of Logopedics at the University of Helsinki, Professor Minna Laakso, Professor Suvi Stolt, and the university lecturers, for interesting seminars, and opportunities to supervise, teach and take part in curriculum planning. I also acknowledge the Biostatistics unit of the University of Helsinki for providing statistical consultations. I warmly thank the staff at the Department of Speech and Language Pathology at Åbo Akademi University, especially Professor Viveka Lyberg Åhlander, Docent Pirkko Rautakoski, and Annette Nylund, PhD, for important support and for the opportunity of being part of the staff. I am also grateful to the Åbo Akademi University researchers who have agreed to comment on my work at the research seminar.

To all the doctoral researchers from the Early Language Development (ELD) research group, thank you for valuable discussions and feedback during the meetings. I especially thank fellow doctoral researchers Sirpa Tarvainen, Riikka Mustonen, Asta Tuomenoksa, Kirsi Neuvonen, PhD, Irina Savolainen, PhD, Inkeri Salmenoja, PhD, Lotta Keitilä, Sanna Lemmetyinen, Sini Peltokorpi, Tone Knapstad and Jenna Sorjonen for sharing the unique experiences of the doctoral journey. Our inspiring discussions, joint writing sessions and conference journeys have been truly memorable.

This section would not be complete without warmly thanking my former co-workers from the pediatric neurology unit of Vasa Central Hospital for the teamwork that has shaped my insights in pediatric neurology and multidisciplinary collaboration. I also thank Helena Törölä, PhD, for sharing her valuable knowledge of working with preterm infants and their families.

I am deeply thankful to the families who participated in the studies. Without your contribution and commitment this research would not have been possible. I also thank the staff at the neonatal intensive care units and the community of international LENA-researchers. This dissertation was conducted through a salaried doctoral researcher position granted by the Doctoral Programme in Cognition, Learning, Instruction and Communication at the University of Helsinki. The Swedish Cultural Foundation in Finland also supported the research. The University of Helsinki, Svensk-Österbottniska samfundet and the Society of Swedish Literature in Finland provided travel grants that enabled my participation in international conferences.

I wish to thank my friends for our deep and long-term friendship and for providing important perspectives on life. Further, I thank my parents for supporting everything I do. Finally, I am infinitely grateful to my husband Tom and my children for standing by me through highs and lows. Thank you also for technical, digital, or statistical advice. Tom, thank you for encouraging me but also for challenging me with brilliant questions and discussions. My children Fanny, Filippa and Frej, thank you for being who you are.

Vasa, October 2023 *Eva Ståhlberg-Forsén*

CONTENTS

LIST OF ORIGINAL PUBLICATIONS

This dissertation is based on the following publications:

I Ståhlberg-Forsén, E., Aija, A., Kaasik, B., Latva, R., Ahlqvist-Björkroth, S., Toome, L., Lehtonen, L., & Stolt, S. (2021). The validity of the Language Environment Analysis system in two neonatal intensive care units. *Acta Paediatrica*, 110(7), 2045–2051. https://doi.org/10.1111/apa.15802

II Ståhlberg-Forsén, E., Latva, R., Leppänen, J., Lehtonen, L., & Stolt, S. (2022). Eye tracking based assessment of lexical processing and early lexical development in very preterm children. *Early Human Development*, *170*, 105603–105603. https://doi.org/10.1016/j.earlhumdev.2022.105603

III Ståhlberg-Forsén, E., Latva, R., Aija, A., Lehtonen, L., & Stolt, S. (2023). Language environment and parent-infant close contact in neonatal care and emerging lexical abilities of very preterm children–a longitudinal study. *Acta Paediatrica*, *112*(4), 659–666. https://doi.org/10.1111/apa.16647

The original articles have been reproduced by permission of copyright holders.

The publications are referred to in the text by their Roman numerals.

ABBREVIATIONS

LENA	Language Environment Analysis
NICU	Neonatal intensive care unit
FinCDI-SF	Finnish short form version of the MacArthur Communicative Development Inventories
FinCSBS-ITC	Finnish version of the Communication and Symbolic Behavior Scales, Developmental Profile, Infant-Toddler Checklist

INTRODUCTION

Annually in Finland, approximately 400 children are born very preterm, that is, before 32 gestational weeks of age (Kiuru et al., 2022). Preterm birth is linked to neurodevelopmental outcomes (Vohr, 2010) and induces an elevated risk for delayed language development and weak language skills (Barre et al., 2011; van Noort-van der Spek et al., 2012). To optimize the language outcomes in this group of children it is important to investigate the factors that may influence development. However, individual variation in the language development of preterm children is broad, and the group of children is heterogeneous (Nguyen et al., 2018; Stolt et al., 2016). Thus, to find the children that need support for language development, it is also important to develop sensitive methods of measuring early language abilities.

Multiple complex factors impact the language development of preterm children. Very preterm infants are born during a sensitive period of brain development (Cheong et al., 2020; DeMaster et al., 2019). Due to the neuroplasticity of the developing brain, both early intrinsic and extrinsic factors may influence neurodevelopment (Cheong et al., 2020; DeMaster et al., 2019). The time before term age especially is a period of rapid brain development (Cheong et al., 2020). Identification of the environmental factors that may influence very preterm children's neurodevelopmental outcomes, either positively or negatively, is important to optimize the development (Cheong et al., 2020). Further, language acquisition occurs in an interactive social context, influenced by the amount and type of language input in the environment (Rowe & Weisleder, 2020). Very preterm children spend weeks or months in neonatal intensive care, and the language environment in the neonatal intensive care unit (NICU) may influence their language development (Caskey et al., 2014). However, to evaluate the impact of the NICU language environment, valid methods are needed to measure and analyze different factors in the environment.

The Language Environment Analysis (LENA®, Boulder, Colorado) system is a method of measuring and analyzing the natural language and sound environment of young children (Gilkerson & Richards, 2020). The method has been utilized in some non-English languages, including in one study with Finnish-acquiring children aged 6–12 months (Elo, 2016) and in one study with Estonian-acquiring children aged 3–4 years (Tulviste & Tamm, 2021). Further, the method has been used in a limited number of studies to investigate the language environment in the NICU (Best et al., 2018; Caskey et al., 2011, 2014). However, the method has not been examined in Finnish or Estonian NICU settings. More information on the validity of the method from less-studied languages and different NICU settings is needed.

The second year of life is an active phase in the development of lexical processing (Fernald et al., 2006) and lexical growth (Stolt et al., 2008). Very preterm children show slower early lexical processing (Marchman et al., 2019) and lexical development (Foster-Cohen et al., 2007; Sansavini, Guarini, & Caselli, 2011; Stolt et al., 2009) than full-term children, and both abilities are predictive for later language performance (Marchman et al., 2018; Stolt et al., 2016). Preterm children's early lexical processing and development are interrelated (Marchman et al., 2019). Still, the connections are complex and not yet fully known. Early lexical processing reaction time (speed) and correct looking time (accuracy) can be measured and analyzed by utilizing eye movements in the looking-while-listening paradigm (Fernald et al., 2006; Fernald et al., 1998). However, the adaptation or usability of the procedure for assessing early lexical processing of Finnish-acquiring children has not previously been described.

A body of evidence demonstrates that parental talk (Filippa, 2017; Filippa et al., 2013; Saliba et al., 2018; Saliba et al., 2020; Williamson & McGrath, 2019) and parent-infant closeness (Flacking et al., 2012; Gonya et al., 2017; Pineda et al., 2018; Vohr, 2019; Yrjölä et al., 2022) in the NICU provide benefits for the preterm infant. However, studies on the potential long-term associations between adult talk and parent-infant closeness in the NICU, and preterm children's later language development, are still very limited. In one study, reported in two articles (Caskey et al., 2011, 2014), the LENA-estimated adult word count in the NICU at 32 weeks of gestational age was positively associated with language scores at 18 months. Also, findings from another study suggest that maternal NICU involvement (kangaroo care, skin-to-skin contact) was positively associated with the language development of preterm children at 18 months (Lester et al., 2016). Still, knowledge of the longitudinal associations is scarce and many factors may influence the findings. Homogenous guidelines for the optimal type and amount of adult talk in the NICU for language outcomes are still missing (Best et al., 2018). Furthermore, more information on the long-term effects of parental involvement in the NICU on preterm children's developmental outcomes is needed (Pineda et al., 2018).

The main focus of the present dissertation was to gain knowledge on the role of early language environment in the NICU on very preterm children's lexical abilities during the second year of life. The dissertation had two main aims. The first aim was methodological. The dissertation investigated the validity of the LENA system in the NICUs of Turku University Hospital, Finland and Tallinn Children's Hospital, Estonia. Further, the dissertation examined the usability of an eye tracking based lexical processing task to assess the lexical processing of Finnish-acquiring very preterm children at 18 months of corrected age and provided validity information on the task. The second aim was clinical; to study the longitudinal associations between language environment and parent-infant closeness in the NICU, and lexical abilities of very preterm children during the first part of the second year of life.

1 REVIEW OF THE LITERATURE

1.1 Preterm children and their language development

1.1.1 Preterm children

A preterm born child is born before 37 gestational weeks of age or with a birth weight of 2 500 grams or less. The degree of prematurity can be categorized based on the gestational age at birth or based on birth weight. The sub-categories based on gestational age at birth are as follows: moderate to late preterm children are born at 32–37 weeks, very preterm children are born at <32 weeks, and extremely preterm children are born at <28 weeks of gestation (Shapiro-Mendoza & Lackritz, 2012; World Health Organization, 2022). The classification of prematurity based on birth weight is as follows: low birth weight is defined as <2500 grams, very low birth weight as <1500 grams, and extremely low birth weight as <1000 grams (Mikkola et al., 2009). Some preterm children also have a low birth weight compared to their gestational age at birth and thus, are born small for gestational age (SGA). The birth weight of children born SGA can be defined as falling below 2 standard deviations (SDs) of the reference population (Mikkola et al., 2005). Annually, of all children born in Finland, approximately 3000 children (6%) are born preterm and approximately 400 (1%) are born very preterm or with a very low birth weight (Kiuru et al., 2022). Further, multiple gestation increases the risk of preterm birth (Shapiro-Mendoza & Lackritz, 2012). In a Finnish cohort study, approximately 30% of extremely low birth weight preterm children were twins (Mikkola et al., 2005).

1.1.2 Language development

Preterm children are at risk for delayed language development and language impairments (Barre et al., 2011; Nguyen et al., 2018; van Noort-van der Spek et al., 2012; Vohr, 2014). However, the group is heterogeneous with a broad individual variation in language development (Nguyen et al., 2018; Stolt et al., 2016). Weak language skills in preterm children are often observed in combination with other impairments, such as cerebral palsy (CP) and hearing impairments (Vohr, 2014). However, importantly, weak language skills are also frequent in preterm children without major neurological disabilities (Sansavini, Guarini, Savini, et al., 2011; Stolt et al., 2009; Stolt, Matomaki, et al., 2014; van Noort-van der Spek et al., 2012; Wolke & Meyer, 1999). Studies reveal delays or impairments of preterm children in both receptive and expressive language skills and in a range of different language domains, including lexicon (Foster-Cohen et al., 2007; Sansavini, Guarini, Savini, et al., 2011; Stolt et al., 2009), syntax and morphology (Foster-Cohen et al., 2007; Stolt, Matomaki, et al., 2014), semantics (Barre et al., 2011) and social communication (Dudova et al., 2014; Ritchie et al., 2015; Sanchez et al., 2019; Sansavini, Guarini, & Caselli, 2011). The percentage of preterm children at risk for weak language skills (defined as below the 10th percentile value of the control group) is reported to increase with age, from 16%–18% at age 2 to 20%–27% at age 5 (Stolt, Matomaki, et al., 2014). In other samples, weak language skills were found in 25%–30% of the preterm children at 24 months (Sansavini, Guarini, & Caselli, 2011) and 31% at age 4 (Foster-Cohen et al., 2007).

Language difficulties in preterm children are demonstrated to be persistent, and at school age, preterm-born children still show weak skills in complex language assignments (Barre et al., 2011; Putnick et al., 2017; van Noort-van der Spek et al., 2012; Vohr, 2014). In a Finnish cohort study, extremely low birth weight preterm children at age 5 showed significantly poorer language performance than those in the full-term population, and 26% were enrolled in speech-language therapy (Mikkola et al., 2005). However, other studies have not found significant differences between preterm and full-term children's early language development (Cattani et al., 2009; Perez-Pereira, 2021; Perez-Pereira et al., 2014), which may be related to differences in the characteristics of the preterm children in the different samples (Perez-Pereira et al., 2014). Additionally, inconsistencies between studies in reported percentages of weak language skills of preterm children may also be related to differences in age points of language assessments, assessment instruments used, or environmental factors in different NICUs (Stolt, Matomaki, et al., 2014).

Due to the elevated risk of language impairments in preterm children, studies emphasize the importance of early language assessments (Nguyen et al., 2018; Stolt et al., 2009; Vohr, 2014). According to the European Standards of Care for Newborn Health, standardized language assessments and evaluations of preterm children are recommended to be conducted by 2 years of age (Sansavini et al., 2018). Early identification of preterm children with weak language skills might be challenging. Their early language development might be within low average, but their performance will not catch up and will remain on a lower level than the language functioning of same-aged peers (Nguyen et al., 2018). Thus, studies recommend the use of language-sensitive methods, specifically developed to detect language impairments, to ensure early identification of preterm children with weak language skills (Stolt, Matomaki, et al., 2014).

1.1.3 Factors influencing language development

Complex factors and mechanisms contribute to children's language development. Very preterm infants are born during the third trimester of the pregnancy when neural migration and differentiation are still progressing, and the development of the networks of the brain is in an active phase (Cheong et al., 2020). Due to this critical phase of development, the brain is especially vulnerable to both compromised maturation and brain injuries (Cheong et al., 2020; DeMaster et al., 2019). During such a period of vulnerability and neuroplasticity, the developing brain can be affected by harmful incidents, but can also adapt to positively influencing factors (DeMaster et al., 2019).

Low gestational age and low birth weight are risk factors for language impairments in preterm children (Foster-Cohen et al., 2007; Gayraud & Kern, 2007; Putnick et al., 2017; Vohr, 2014; Yaari et al., 2018). Children born very preterm exhibit a higher risk for language impairments than children born moderately or late preterm (Putnick et al., 2017). The risk of brain injury is also often related to degree of prematurity (Vohr, 2010). Intraventricular hemorrhage (IVH) may cause secondary brain injuries of different grades of severity. A severe grade of IVH especially may cause neurodevelopmental impairments or CP (Mikkola et al., 2005). In a Finnish cohort study, 14% of the extremely low birth weight preterm children were diagnosed with CP (Mikkola et al., 2005). In the same study, the children born SGA scored lower in language tests at 5 years of age than the children born appropriate for gestational age (Mikkola et al., 2005).

Other comorbidities related to language or neurodevelopmental disabilities in preterm children are hearing impairments and eye disease retinopathy of prematurity (Mikkola et al., 2005; Månsson et al., 2015; Vohr, 2010, 2014). Moreover, research shows that the chronic lung disease bronchopulmonary dysplasia (BPD) contributed to an increased risk for delayed language development of preterm children at 24 months (Sansavini, Guarini, Savini, et al., 2011). Further, another study reported that preterm children with BPD exhibited especially weaker receptive language skills at 8 years than preterm children without BPD (Lewis et al., 2002). Male gender is also considered a risk factor for an adverse neurodevelopmental outcome in preterm children (Mikkola et al., 2005) and studies report poorer early language skills in preterm boys than in preterm girls (Månsson et al., 2015; Sanchez et al., 2019; Sansavini et al., 2006). It is proposed that the male preterm brain may be more at risk for early injuries (Vohr, 2010) or that the impact of preterm birth on boys is amplified by other risk factors associated with the male gender (Sansavini et al., 2006). In contrast, other studies have not found significant gender differences in the early language development of preterm children in the samples investigated (Foster-Cohen et al., 2007; Gayraud & Kern, 2007; Stolt et al., 2007). However, the male gender is still an established risk factor for language impairments in full-term children (Rudolph, 2017).

Models on neuroplasticity describe how environmental factors may influence the developmental outcomes of preterm children (DeMaster et al., 2019). Early environmental factors include the language environment (Caskey et al., 2014; Vohr, 2014) and caregiver-infant closeness or interaction (Cheong et al., 2020;

DeMaster et al., 2019) in the NICU. Further, studies also recognize the influence of family factors and parent-child interaction (Foster-Cohen et al., 2010; Nguyen et al., 2019) and parental education level (Nguyen et al., 2019) on preterm children's language skills later in childhood. Moreover, the research emphasizes the significance of comorbidity (Mikkola et al., 2005; Vohr, 2014), for example, factors such as brain maturation, brain injury, and environment may jointly contribute to language outcome in the preterm child.

To conclude, considering the substantial risk of persistent weak language skills in preterm children, it is important to investigate the early language environment of preterm children to fully understand its' possible effects on the language development of very preterm children. Additionally, it is essential to modify and validate assessment methods, to ensure reliable and efficient identification of the individuals that need early follow-up and support.

1.2 Language environment and parent-infant closeness in the neonatal intensive care unit

1.2.1 Language environment

The language and sound environment in the NICU are significant factors because preterm children are born during a critical period of auditory development. The maturation of the auditory system and auditory development start during pregnancy (Graven & Browne, 2008; McMahon et al., 2012). The function of the auditory system commences around 25 weeks of gestation, which is the onset of the most essential time of auditory development (Graven & Browne, 2008). In utero, the fetus receives auditory stimuli through bone conduction and high-frequency sounds are filtered by tissues and fluid (Graven & Browne, 2008). The intrauterine auditory environment consists of prosodic speech characteristics and low-level sounds (Moon, 2017; Philbin, 2017). The most prominent part of the sound environment is the maternal voice (Kisilevsky et al., 2009). Additionally, the fetus experiences sound of maternal cardiac and digestive functions (Moon, 2017).

Auditory input from the environment is crucial for the development of the auditory cortex (McMahon et al., 2012). From 28–29 weeks of gestation, the hair cells in the cochlea can start capturing different sound frequencies, beginning with low-frequency sounds (Graven & Browne, 2008). For the fine development of the hair cells and the neural connections in the cochlea, the infant needs to hear familiar voices and meaningful sounds (Graven & Browne, 2008). Studies report that fetuses of 33–41 weeks of gestation recognized their mothers' voices and their native language (Kisilevsky et al., 2009). Further, in another study, the fetuses responded to the mothers' voices by moving or with changes in heart rate at 36 weeks of gestation (Voegtline et al., 2013).

The language and sound environment of preterm infants in the NICU differs considerably from the intrauterine environment of full-term peers at the same gestational age (Best et al., 2018). Preterm birth induces spatial hearing and enables exposure to high-frequency sounds (Graven & Browne, 2008). Besides different human voices, preterm infants in the NICU experience silence, and environmental sounds of various duration, including sounds from medical equipment (Philbin, 2017). Preterm infants are sensitive to acoustic stimuli (Kuhn et al., 2017; Rand & Lahav, 2014). Research argues that due to the very early experiences of hearing different voices in the NICU, very preterm infants possess a higher level of auditory processing of human voices at term age, compared with full-term new-borns (Adam-Darque et al., 2020).

Already in the NICU, the preterm infants learn communication and language in a social and interactive context (Gratier & Devouche, 2017). The NICU language environment contains different amounts or types of parental or adult talk. Studies describe how different features in the NICU language environment elicit different reactions in the preterm infants. The preterm infant reacts differently to familiar and unfamiliar voices (Kuhn et al., 2017) and prefers the mother's voice (Filippa et al., 2013). Further, preterm infants are sensitive to the infant-directed speech of both parents (Saliba et al., 2020).

The language environment in the NICU may influence the early vocalizations of preterm infants. During the first months of life, infants produce vegetative sounds (e.g., coughs, burps), fixed vocal signals (e.g., cries) and primary speech-precursor vocalizations (protophones) (Oller, 2000; Oller et al., 1999). Studies performed in the NICU report that very preterm infants already vocalize by producing protophones, i.e., vocants, squeals, and growls, by 32 weeks of gestational age (Caskey et al., 2011; Caskey & Vohr, 2013; Oller et al., 2019). In the study by Oller et al. (2019), the infants produced protophones more frequently than cries at 32 weeks of gestational age. Other utterances of the infants consisted of vegetative sounds, i.e., burps, hiccups and sneezes, and cries, which included wailing and whimpering (Oller et al., 2019).

Very preterm infants at 32 gestational weeks' age have been reported to vocalize more when parents are present (Caskey & Vohr, 2013), but also to exploratively vocalize when they are alone in the room (Oller et al., 2019). Further, studies from the NICU report that caregivers are already engaging infants conversationally at 32 weeks of gestational age (Caskey et al., 2011; Caskey & Vohr, 2013; Oller et al., 2019). Also, more adult talk and more adult-infant conversational turns were measured in the NICU when the parents were visiting (Caskey et al., 2011).

The sound and language environments may differ in different types of NICU units. An open-bay NICU unit may be noisy and obstruct relevant language input (Rand & Lahav, 2014). Single-family rooms are found to be more silent than the open-bay NICU environment and to elicit more meaningful adult words (Pineda et al., 2017). However, other studies argue that a single-family room unit may not provide enough language stimuli (Rand & Lahav, 2014). Nonetheless, a systematic review and meta-analysis on the language environment in the NICU concluded that the sound environment in both open-bay and single-family room units often contains low amounts of talk and high sound levels (Best et al., 2018). Importantly, besides the mere physical environment, the activities of the adults near the infant are the important factors in providing the auditory experiences of the preterm infant (Best et al., 2018; Vohr, 2019). Still, more information on the preterm infant's early auditory perception and on the impact of different types of auditory experiences on development is needed (Kuhn et al., 2017).

The auditory sensitivity of the preterm infant and the considerable impact of early auditory stimuli highlight the significance of modulating the auditory input in the NICU (Adam-Darque et al., 2020). Elevated noise levels in the NICU environment are connected with negative short-term effects on preterm infants' cardiac and respiratory functions (McMahon et al., 2012) and possible long-term effects on later neurodevelopment (Wachman & Lahav, 2011). Continuous background noise at 60 dB levels can compromise the fine-tuning of auditory development, the discrimination of sound frequencies and the recognition of meaningful sounds (Graven & Browne, 2008). Thus, the preterm infant needs to be protected against harmful noise, and caregivers need to sensitively monitor and respond to the infant's reactions to auditory stimuli (McMahon et al., 2012).

Very preterm children spend weeks or months in the NICU at a critical and sensitive developmental stage, and protective guidelines are necessary. NICU environment standards strive to establish optimal medical care and facilities for the infant, the families, and the hospital staff (White, 2020). The acoustical environment standards include guidelines to prevent background noise and distractive sounds, and assure speech privacy and intelligibility in infant facilities (White, 2020). However, a consensus regarding the optimal type and amount of adult talk and language environment in the NICU for later language outcome has not yet been reached (Best et al., 2018).

1.2.2 The Language Environment Analysis system

The Language Environment Analysis (LENA®, Boulder, Colorado) system is a method developed for recording and analyzing the natural language and sound environment of young children (Gilkerson & Richards, 2020). The original aim of the method was to measure language environment (Gilkerson et al., 2017), to identify adult words and child vocalizations, and to provide feedback on adult behavior (Gilkerson & Richards, 2020). Based on speech-identification algorithms, the LENA system categorizes sounds into speech segments and provides automatic estimates of the number of adult words, adult-child conversational turns, and child vocalizations along with the duration of non-speech environmental sounds and silence near the child (Gilkerson & Richards, 2020; Xu et al., 2008). The LENA system was originally validated in the American-English language setting for children ages 2–48 months. The development and standardization process and the validity and reliability of the method have been described in studies and technical reports (Gilkerson et al., 2008; Gilkerson & Richards, 2008; Gilkerson et al., 2017; Xu et al., 2009; Xu et al., 2008).

The advantages of the LENA system include being an unintrusive and easily administered instrument for gathering data on environmental factors that influence language development (Caskey & Vohr, 2013; Wang et al., 2017). Furthermore, LENA can be used as a tool to monitor the efficacy of intervention programs (Bredin-Oja et al., 2018; Caskey & Vohr, 2013; Wang et al., 2017). However, the LENA system also has limitations. Overlapping noise or talk may compromise the validity of the estimates (Ganek & Eriks-Brophy, 2018b; Wang et al., 2017). Moreover, the LENA system does not provide a complete picture of the child's language environment, because the system does not measure nonverbal or quality aspects of language or communication (Caskey & Vohr, 2013; Wang et al., 2017). Accordingly, the LENA system does not differentiate overheard speech from infant-directed speech (Gilkerson & Richards, 2020; Gilkerson et al., 2017). Infant-directed speech, which caregivers typically use with young children, is characterized by varied intonation, clarified phonology, simplified grammar, and multiple repetitions, and is found to support language acquisition (e.g. Rowe & Snow, 2020; Zauche et al., 2016). The conversational turn count, the LENA variable that measures adult-child conversational turn-taking, is more likely to contain infant-directed speech and include a higher degree of adult-child interaction than the adult word count (Gilkerson et al., 2018; Wang et al., 2020).

Validity information on the automatic estimates of the LENA system is needed to interpret the data from different groups of children, settings, and language contexts (Ganek & Eriks-Brophy, 2018b; Gilkerson et al., 2017). Because different languages possess different word properties, grammatical structures, and prosodic and fundamental voice frequency features, the validity of the LENA system's measures may vary in different language settings. The validity or reliability of the LENA-provided automated estimates has been investigated in some non-English language contexts (Bruyneel et al., 2021; Canault et al., 2016; Elo, 2016; Ganek & Eriks-Brophy, 2018a; Gilkerson et al., 2015; Pae et al., 2016; Schwarz et al., 2017). Generally, the findings have shown high agreement for LENA-estimated adult word count (r = 0.64–0.95) compared to human-provided estimates (Bruyneel et al., 2021; Canault et al., 2016; Schwarz et al., 2017; Weisleder & Fernald, 2013). A few studies have reported lower agreement for the conversational turn count than for the adult word count, and the conversational turn count appears to be sensitive to disturbances of noise or overlapping speech in the environment (Bruyneel et al., 2021; Pae et al., 2016). However, to my knowledge, the validity of the LENA estimates of vocalizations of very preterm infants in the NICU has not been evaluated.

A recent evaluation of the accuracy of the LENA automatic measures from five different corpora, including a sample of older children from a language setting in Bolivia, reported relatively high accuracy for the LENA-estimated adult word and child vocalization counts (Cristia et al., 2021). However, the identification of male speech and the accuracy of LENA-estimated conversational turn count was shown to be weaker (Cristia et al., 2021). Further, the LENA system tended to underestimate the number of conversational turns and child vocalizations (Cristia et al., 2021). The evaluation concluded that the LENA measures are particularly suitable for comparing numbers of adult words during the day or in different settings. However, the information provided by the LENA system has to be used with caution, for example when comparing the numbers of female and male words (Cristia et al., 2021). Still, the agreement between the LENA automatic estimates and human coder estimates cannot be expected to be as high as the agreements between two human coders (Cristia et al., 2021).

Thus far, the LENA system has been used only in one study in the Finnish language setting, investigating the language environment of 6–12-month-old children (Elo, 2016). According to the findings, the LENA system reliably identified female and child speech, while the LENA measurements of male speech showed less reliability (Elo, 2016). In the Estonian language context, the LENA system has been used in a study with children 3 and 4 years of age (Tulviste & Tamm, 2021). However, to my knowledge, the validity of LENA automatic estimates in the Estonian language setting has not been reported.

The Finnish and Estonian languages both belong to the Finno-Ugric language group and share several linguistic features. Both languages are rich in diphthongs (Karlsson, 2008; Remes, 2015). The word stress is typically placed on the first syllable of a word (Karlsson, 2008; Remes, 2015) and the intonation is falling towards the end of the sentence (Karlsson, 2008). The fundamental voice frequency of Finnish-speaking female university students is described as lower than the frequency reported in international samples (Leino et al., 2008). Also, the Finnish and Estonian languages exhibit differences in phonological, lexical, and grammatical features (Remes, 2015). Finnish is a predominantly agglutinative language, in which grammatical forms are built by adding suffixes to a word stem (Karlsson, 2008; Remes, 2015). The words are often rather long. The Estonian morphology has developed towards a more mixed system with agglutinative features, and the words tend to be shorter than the Finnish words (Remes, 2015).

The LENA system has been utilized in a few studies to investigate the language and sound environment in NICU settings, both in open bay units (Caskey et al., 2011, 2014; Caskey & Vohr, 2013; Oller et al., 2019; Pineda et al., 2017) and in single-family rooms (Chow & Shellhaas, 2016; Pineda et al., 2017). In an open bay NICU, the correlation between LENA measures of adult word count from 5-minute segments from five recordings was $r = 0.93$ (Caskey et al., 2014). Due to the small number of studies completed so far, more validity information from different NICU settings is needed (see also Wang et al., 2017). Factors such as NICU facilities, parental presence, or interaction may influence the language environment (Best et al., 2018) and may thus also influence the data obtained in different studies. Open bay units may contain more overlapping talk and noise (Rand & Lahav, 2014), factors that may influence the LENA estimates (Canault et al., 2016; Xu et al., 2008). Further, single-family rooms are associated with lower sound levels (Philbin, 2017; Pineda et al., 2017) and increased parental presence (Kainiemi et al., 2021) than open bay units.

1.2.3 Parent-infant closeness

Parent-infant closeness in the NICU can be described as emotional and physical closeness, and both aspects are essential for the well-being of the preterm infant and the parents (Flacking et al., 2012). Close physical contact is considered an essential factor in establishing the parent-infant relationship and emotional connection (Flacking et al., 2012). Physical closeness factors in the NICU include parental presence, participation and holding of the infant, and parent-infant skin-to-skin contact (Flacking et al., 2012; Raiskila et al., 2017). A large body of evidence describes the significance of parental presence and involvement in the NICU (Pineda et al., 2018; Reynolds et al., 2013; Vohr, 2019). Skin-to-skin contact (kangaroo care), in which the infant is laid without clothes on the parent's bare chest, is an established and evidence-based practice, found to be beneficial for both the infant and the parents (Gonya et al., 2017; Moore et al., 2016).

Preterm birth is stressful for the parents. Mothers and fathers of preterm children report higher rates of psychological and parenting stress during the first two years after the birth of the child, compared with parents of full-term children (Treyvaud, 2013). A large body of research emphasizes the significance of early support for parents of preterm children (DeMaster et al., 2019; Latva et al., 2008; Muller-Nix et al., 2004; Treyvaud et al., 2009; Treyvaud et al., 2019). Studies especially emphasize the importance of supporting mothers who experience stress (Muller-Nix et al., 2004) or negative emotions (Latva et al., 2008) linked to the birth of their preterm infant. Best practice guidelines to support parents in the NICU include family-centered care, psychosocial support for parents, and early intervention programs focusing on the parent-infant relationship (Treyvaud et al., 2019).

Preterm birth also influences early parent-infant interaction, as the neonatal intensive care may limit the opportunities for interaction (DeMaster et al., 2019).

A systematic review on the mother-preterm infant relationship revealed that preterm birth does not necessarily constitute an elevated risk for preterm infants to establish an insecure attachment to their mothers, compared with full-term infants (Korja et al., 2012). Nonetheless, the review noted some differences in the early interaction between mothers and preterm infants, compared with the interaction in full-term groups (Korja et al., 2012). Mothers of preterm infants were described to be less sensitive and more controlling in their interaction with the infant than mothers of full-term children, which might be related to stress or early separation (Korja et al., 2012). However, a meta-analysis noted remarkable inconsistencies between different studies and did not find significant differences in the sensitivity or responsiveness between mothers of preterm and full-term children (Bilgin & Wolke, 2015). Further, the infant's condition or capacity may also influence and form the development of the parent-infant interaction (Rowe & Weisleder, 2020). The preterm infant's characteristics or health, such as immaturity, may influence how the parent can engage the infant in early reciprocal interaction (Korja et al., 2012; Landry et al., 1997). Preterm infants tend to be more passive and less attentive than full-term infants, which in turn might influence the interactive strategies of the mothers (Korja et al., 2012).

A sensitive and less controlling parenting style is shown to be positively associated with language development, especially in high-risk preterm children (Landry et al., 1997). In a Finnish prospective longitudinal study (Stolt, Korja, et al., 2014), the findings revealed different connections between mother-child interaction and language development in full-term and preterm groups. In the preterm group, mother-child interaction, especially at 6 months, was linked to the children's language performance at 24 months, emphasizing the importance of early mother-child interaction for language outcome (Stolt, Korja, et al., 2014).

Parent-infant closeness in the NICU is supported by care cultures and facilities developed to favor family-centered care and parental presence (Flacking et al., 2012). When planning and building new NICU facilities, there has been a shift from open bay units to single-family rooms (Flacking et al., 2012; Lester et al., 2011). Lester et al. (2011) list factors that presumably are positively affected by implementing single-family room care, including family-centered care, family factors, and medical practices (Lester et al., 2011). Family factors include psychological support, such as preventing parental stress and depression (Lester et al., 2011) and support for parenting behavior, such as parent-infant closeness, parental privacy and staying overnight (Flacking et al., 2012). Family and parent factors are described as mediating factors that are likely to contribute to optimizing neurobehavioral outcomes of preterm infants (Lester et al., 2011).

Systematic reviews and meta-analyses have found considerable support for single-family room care (van Veenendaal et al., 2019; van Veenendaal et al., 2020), including more parental involvement and skin-to-skin care (van Veenendaal et al., 2020). Nonetheless, more knowledge is needed on the long-term effects of single-family room care on developmental outcomes. One study has reported positive associations between single-family room care in the NICU and language scores of very preterm children at 18–24 months of age (Vohr et al., 2017). Still, a systematic review and meta-analysis did not detect differences in the long-term neurodevelopment outcomes between extremely preterm infants cared for in single family rooms or open bay units (van Veenendaal et al., 2019).

In the NICU of the Turku University Hospital, from which the data of the present study mainly have been collected, the implementation of the Close Collaboration with Parents intervention increased both the duration of parental presence and the mother-infant skin-to-skin contact (He et al., 2021; Toivonen et al., 2020). The Close Collaboration with Parents intervention was developed to promote the skills of the NICU staff to communicate and collaborate with parents to support parental involvement, the parent-infant relationship and the infant's development (Ahlqvist-Björkroth et al., 2017). After the Close Collaboration with Parents intervention, the NICU shifted from shared family rooms to single-family rooms (Kainiemi et al., 2021). The shift further increased the duration of parental presence, but not the duration of parent-infant skin-to-skin contact (Kainiemi et al., 2021). The authors discuss that the findings might be related to the already implemented family-centered care culture, established before the shift to single-family rooms. Thus, the new single-family room architecture did not further increase parent-infant skin-to-skin contact.

1.3 Early lexical abilities of preterm children

1.3.1 Lexical processing

Lexical processing can be described as the ability to interpret and identify spoken words and match them with the correct referent (Fernald et al., 2008; Marchman & Fernald, 2013). Speech perception development starts during the pregnancy (Moon, 2017) and is formed by early auditory experience (Curtin & Archer, 2015; Curtin & Hufnagle, 2009). A newborn infant can already differentiate between speech and non-speech sounds (Curtin & Archer, 2015; Curtin & Hufnagle, 2009). Further, during the first six months of life, the infant can discriminate both native and non-native speech sound contrasts (Curtin & Archer, 2015; Curtin & Hufnagle, 2009). However, from the second part of the first year of life, speech perception is reorganized towards language-specific discrimination, also described as perceptual narrowing (Curtin & Archer, 2015; Curtin & Hufnagle, 2009). This discrimination is influenced by sensitivity to crucial contrasts and regularities of the native language (Curtin & Hufnagle, 2009). Between 6 and 8 months of age, the child learns to segment the continuous auditory input into separate word units (Curtin & Archer, 2015; Curtin & Hufnagle, 2009). By approximately the end of the first year of life, the child can identify single familiar words in fluent speech (Curtin & Archer, 2015; Curtin & Hufnagle, 2009).

The second year of life is an active phase in the development of lexical processing and the child can react more rapidly to spoken words in the environment (Fernald et al., 2006). Concurrently, the processing speed accelerates and the processing accuracy increases (Fernald et al., 1998). From approximately 18 months of age, children can identify words and combine them with the corresponding images based on hearing only the initial phonemes of the word (Fernald et al., 2001). Further, lexical processing is suggested to be related to factors such as overall cognitive processing (Fernald et al., 2006), as well as attention, auditory memory and integration of auditory and visual perception (Fernald & Marchman, 2012; Fernald et al., 2001; Marchman & Fernald, 2013).

The influence of preterm birth on attention, memory, and processing abilities is complex. Several studies show that preterm children exhibit poorer early processing skills than their full-term peers, and that early processing is connected to later language or cognitive performance. In a study examining links between early processing and developmental outcomes, preterm children at 6 and 9 months showed poorer processing skills than full-term children, and the processing skills were associated with later cognitive and language scores (Ortiz-Mantilla et al., 2008). Another study revealed poorer performance in information processing by preterm children at 7 months of age than of their full-term peers (Rose et al., 2005). Further, processing speed was found to be related to memory skills, which in turn were connected to cognitive outcome at 2 and 3 years of age (Rose et al., 2005). Also, preterm children at 4 years of age exhibited weaker speech-sound discrimination than full-term controls, and the sound discrimination skills were associated with naming abilities (Jansson-Verkasalo et al., 2003). At age 5, preterm children also showed weaker performance in attention, working memory and processing speed than full-term controls (Potharst et al., 2013). A review on the neuropsychological development of preterm children (Sansavini, Guarini, & Caselli, 2011) concluded that preterm children show atypical trajectories in a range of neuropsychological abilities related to attention, memory and language processing. However, the individual neuropsychological profiles of the preterm children show a broad variation. Mild neuropsychological impairments across several domains are more frequent than severe cognitive or perceptual disabilities (Sansavini, Guarini, & Caselli, 2011).

Early lexical processing can be assessed by utilizing the looking-while-listening procedure developed by Fernald and colleagues (Fernald et al., 1998), which is considered an easily administered, valid and reliable method (Fernald et al., 2008). During the assessment, the child's eye movements are continuously measured while the child watches images and listens to phrases containing a target word referring to one of the images (Fernald et al., 2008). Further, eye tracking technology has been utilized to automatically measure the child's eye movements during the procedure (Donnelly & Kidd, 2020).

Traditional assessment methods evaluate the child's understanding of a target word after the child has heard the word. However, in everyday situations, understanding occurs simultaneously as words and sentences are continuously processed. Thus, it is important to assess processing skills during the listening moment, as implemented in the looking-while-listening paradigm, and not just after the event (Fernald et al., 2006; Marchman & Fernald, 2013). Accordingly, the looking-while-listening task can be considered comparable to an everyday situation when a child hears a word that is quickly required to be identified based on the available visual clues (Loi et al., 2017). Furthermore, the child's early receptive skills may be more challenging for the caregivers to estimate than the expressive skills (Feldman et al., 2000; Marchman & Fernald, 2013). Thus, the processing assessment may contribute to identify developing skills of the child that might be challenging to detect in regular daily situations (Fernald et al., 2006) and, accordingly, to document in parent report form methods (Marchman & Fernald, 2013), which are widely used instruments to measure early lexical development.

Primary variables of the looking-while-listening procedure are *reaction time* (speed), the time when the child looks from the distracter image to the target image, and *correct looking time* (accuracy), the proportion of time looking at the target image out of the total looking time (Fernald et al., 2006). Reaction time measures the speed of interpreting visual stimuli explicitly based on language input, rather than the speed of general visual orientation (Fernald et al., 2006). Because reaction time measures speed and correct looking time measures the proportion of time looking at the target image, the variables measure different aspects of lexical processing. In full-term children, reaction time has been shown to decrease significantly with age and correct looking time to increase significantly with age (Fernald et al., 2006).

In the looking-while-listening procedure, the data are analyzed from a selected time window, measured from the onset of the target word. The lower cut off point of the time window is usually 200 milliseconds (ms) from the target word onset, while the upper cut off point can slightly vary from study to study (Fernald et al., 2008). In studies measuring reaction time, the time window has ranged between 200 and 2300 ms from target word onset (Egger et al., 2020). When measuring accuracy, a specific time window of interest can be utilized (Fernald et al., 2008). Some studies on young infants have separately analyzed lexical processing data from an early (300–1800 ms) and a late (1800–3300 ms) time window (Lany et al., 2018). Further, time windows have been prolonged in processing tasks with different types of target words, for instance with adjective-noun target phrases (Fernald et al., 2010) and verbs (Valleau et al., 2018), to permit the child time to process the sentences.

In preterm children, the looking-while-listening paradigm has been used in only a few studies to compare the early processing skills of preterm and full-term children during the second year of life (Loi et al., 2017; Marchman et al., 2019; Ramon-Casas et al., 2013). Findings from some of those studies show that preterm children exhibited slower or less accurate processing, compared with full-term peers (Marchman et al., 2019; Ramon-Casas et al., 2013). Nonetheless, in another study, the processing efficiency of very preterm children at 18 months was comparable to the performance in the full-term group, when corrected age was applied (Loi et al., 2017). Because the number of studies on lexical processing of preterm children is still limited, more research-based information is necessary to fully comprehend the processing skills in this group of at-risk children.

1.3.2 Lexical development

The child's early lexicon is part of core language skills (Bornstein et al., 2016). The lexicon consists of receptive lexical skills, the words the child understands, and expressive lexical skills, the words the child produces (Stolt et al., 2008). Receptive and expressive lexical skills exhibit different trajectories during the second year of life (e.g. Clark, 2015; Fenson et al., 1994; Lyytinen, 1999). After the onset of word understanding by the end of the first year (Fenson et al., 1994), the child's receptive lexicon grows rapidly during the first part of the second year of life (e.g. Lyytinen, 1999; Stolt et al., 2008). The acquisition of the expressive lexicon is initially slow. At 12 months, the child typically produces only a few words, but the number of produced words grows rapidly between 15 and 18 months (e.g. Fenson et al., 1994; Lyytinen, 1999; Stolt et al., 2008). Individual variation in early lexical skills is broad, and broader in receptive skills than in expressive skills (e.g. Stolt et al., 2008). The child's early lexical skills constitute the base for later lexical and grammar development, and the predictive value of early lexical skills is especially strong in groups at risk for weak language skills (Stolt, 2019).

During the second year of life, preterm children show slower lexical development than their full-term peers. In a Finnish longitudinal study, the receptive lexicon of preterm children born between 23 and 34 gestational weeks was smaller at 12 and 15 months, compared with the lexicon of their full-term peers (Stolt et al., 2009). However, at this age, no significant differences were found between the preterm and the full-term group in the size of the expressive lexicon (Stolt et al., 2009). Weak language processing skills may contribute to the slower receptive lexical acquisition of preterm children (Stolt et al., 2009).

Further, at 2 years, weak language skills were found in 16%–18%, and at 5 years of age, in 20%–27% of the preterm children, compared with 8%–10% in the control group (Stolt, Matomaki, et al., 2014). In an Italian longitudinal study, 20% of preterm children showed delayed expressive lexical development at 2 years (Sansavini, Guarini, Savini, et al., 2011). Moreover, studies report stronger associations between different language domains in preterm children during the second year of life than in the full-term group, such as associations between the receptive and expressive lexicon (Sansavini, Guarini, Savini, et al., 2011).

Early lexical development of preterm children has been shown to predict later language outcomes. In a Finnish longitudinal study on preterm children, receptive lexical skills from 12 months showed a predictive value for language skills at 2 years (Stolt et al., 2009; Stolt, Makila, et al., 2014). Further, early vocalizations were associated with language performance at 2 years (Stolt et al., 2012). In an Italian longitudinal study, both receptive and expressive lexical development of preterm children at 12 and 18 months predicted expressive words at 2 years (Sansavini, Guarini, Savini, et al., 2011). Furthermore, preterm children's receptive language abilities at 2 years of age have been reported to predict language outcomes at 5 years (Stolt et al., 2016). Early receptive language skills can be regarded as important factors for preterm children's later language outcome, which might be explained by the fact that receptive language development incorporates all areas of language acquisition, including understanding of grammatical structures (Stolt et al., 2016).

Multiple studies emphasize the importance of early identification of weak language skills in the at-risk group of preterm children (Nguyen et al., 2018; Sansavini et al., 2010; Stolt et al., 2009; Vohr, 2014). However, accurate and sensitive instruments are required to assess early language development. Formal clinical language assessment of young children is challenging and influenced by diverse factors related to the assessment situation, the child, or the proficiency of the clinician (Fenson, 2007; Fenson et al., 2000; Law & Roy, 2008). Validated and normed parent report form instruments, where parents mark, for instance, the words the child understands and produces or the child's communication abilities on checklists, are widely used instruments for screening early lexical, language and communication skills (Feldman et al., 2005; Fenson, 2007; Fenson et al., 2000; Law & Roy, 2008; Wetherby et al., 2002). Parents are found to provide mainly correct information (Law & Roy, 2008); also, for children at 12–24 months of age, the validity was established by a concurrent face-to-face evaluation (Wetherby et al., 2002). The features of the instrument also enhance the reliability and validity, because the parents are asked to report only the current performance of their child, and the items are presented on structured checklists with appropriate alternatives (Fenson, 2007).

The short form version of the MacArthur Communicative Development Inventories (Fenson et al., 2000); Finnish version (FinCDI-SF; Stolt & Vehkavuori, 2018) and the Communication and Symbolic Behavior Scales, Developmental Profile, Infant-Toddler Checklist (Wetherby et al., 2002); Finnish version (FinCSBS-ITC; Laakso et al., 2011) are two different parent report form screening instruments developed for young children. Both tools are shown to provide valid information on different aspects of early language development during the second year of life (Laakso et al., 2011; Stolt & Vehkavuori, 2018). According to the validation study on the FinCDI-SF, the method is a valid instrument especially for assessing lexical development at 18 months of age (Stolt & Vehkavuori, 2018). The validation study of the FinCSBS-ITC demonstrated that the Symbolic Composite (understanding and object use) was most reliable at 12–18 months, and the Speech Composite (sound and word production) was most usable from 15 months of age (Laakso et al., 2011).

More information on the usability of the screening instruments in at-risk populations is needed (Vehkavuori & Stolt, 2018). Studies on the use of screening methods with preterm children during the second year of life are scarce. To my knowledge, the short form version of the MacArthur Communicative Development Inventories has been used only in one study (the Italian version) evaluating the lexical development of very preterm children between 12 and 24 months (Sansavini, Guarini, Savini, et al., 2011). Additionally, the Communication and Symbolic Behavior Scales, Developmental Profile, Infant-Toddler Checklist has been used in a study investigating the early language and communication development of preterm children at 24 months (Sanchez et al., 2019) and specifically to screen for autism spectrum disorders in preterm children at 24 months (Beranova et al., 2017; Dudova et al., 2014).

1.3.3 Associations between lexical processing and lexical development

Connections between speech perception and lexical development are reported from an early age. Tsao and colleagues (Tsao et al., 2004) found that speech perception at 6 months of age, measured with a vowel sound discrimination task, was associated with receptive and expressive lexical development at 13, 16, and 24 months of age. At a later age, several studies describe how processing skills during the second year of life, measured with looking-while-listening tasks, are connected to prior lexical growth, and language and cognitive outcomes. In a study by Donnelly and Kidd (2020) processing efficiency between 18 and 24 months was associated with prior lexicon. Further, processing efficiency at 25 months has been linked to lexical growth during the second year of life (Fernald et al., 2006). A study investigating the predicted value of early processing, lexical processing speed, and accuracy at 18 months predicted lexical development of both typically developing children and children defined as late talkers from 18 months to 30 months (Fernald & Marchman, 2012). In another longitudinal study, processing speed at 19 months was linked to syntactic and lexical development up to 36 months (Peter et al., 2019), although the links between speed and lexicon were found only in children with smaller lexicons. Thus, Peter et al. (2019) discussed that processing speed can be more crucial for children with challenges in word learning than for children with larger lexicons.

Furthermore, connections between early processing skills and later cognitive skills have been reported, as processing speed at 25 months was linked to both language and cognitive skills at 8 years of age (Marchman & Fernald, 2008).

Even if it is increasingly evident that lexical processing and lexical development are interrelated (Fernald & Marchman, 2012; Fernald et al., 2006; Loi et al., 2017; Marchman et al., 2019; Marchman et al., 2018; Peter et al., 2019), the theoretical aspects of the causality are not yet fully known (Fernald et al., 2006; Peter et al., 2019). Authors discuss whether strong lexical processing skills facilitate word learning or whether a large lexicon facilitates lexical processing (Fernald et al., 2006; Peter et al., 2019). Marchman and Fernald (2013) describe a model of cascading connections, where efficient processing enables the child to identify words quickly, which in turn facilitates the learning of new words. Faster processing may also be related to factors such as generally stronger language skills or richer language experience (Fernald et al., 2006). On the other hand, faster lexical processing may also facilitate the child's utilization of the words spoken in the environment (Fernald et al., 2006).

A few studies have investigated the specific associations between early lexical processing and concurrent or later lexical development in preterm children. Studies utilizing the looking-while-listening paradigm have demonstrated that processing speed and accuracy of preterm children at 18 months significantly predicted concurrent language skills (Loi et al., 2017). Furthermore, the processing speed of preterm children at 18 months predicted expressive lexical development at 30 months (Marchman et al., 2019), receptive lexical development at 36 months (Marchman et al., 2016), and language development at 4.5 years (Marchman et al., 2018). Also, a study evaluating the processing skills of preterm children revealed that processing reaction time was a stronger predictor than medical complications of later expressive lexical development (Marchman et al., 2019). However, to my knowledge, the links between lexical processing at 18 months and preterm children's prior lexical development have not yet been described.

Marchman et al. (2022) have compared the associations between early language processing, expressive language, and non-verbal outcomes in full-term and preterm children. Findings revealed similar associations between processing skills at 18 months and language skills at 4.5 years of age in both full-term and preterm children, indicating comparable mechanisms and long-term connections between processing and language outcomes in both groups (Marchman et al., 2022). However, the associations between processing reaction time and later non-verbal skills were stronger in the preterm group, suggesting that especially processing speed in preterm children may be associated with more diverse skills and neuropsychological processes than in full-term children (Marchman et al., 2022).

In conclusion, more information on early lexical processing and development of preterm children is warranted. To my knowledge, the looking-while-listening paradigm has not previously been adapted to investigate the lexical processing of Finnish-acquiring children. Furthermore, links between preterm children's lexical processing at 18 months and lexical growth during the first part of the second year have not been widely investigated.

1.4 Associations between language environment and parent-infant closeness in the neonatal intensive care unit, and language development of preterm children

A body of research describes the positive short-term benefits of parental talk in the NICU for preterm infants (Filippa, 2017; Filippa et al., 2013; Saliba et al., 2018; Saliba et al., 2020; Williamson & McGrath, 2019). One systematic review (Filippa et al., 2017) identified positive effects of maternal talk in supporting the infant's oxygenation and decreasing cardiorespiratory events. Hearing nonmaternal voices in the NICU has also been reported to provide short-term and medium-term benefits for preterm infants, such as an increase in saturation and stability in heart rate (Saliba et al., 2018). However, another systematic review reported discrepancies in findings on the effects of maternal voice or talk in the NICU on the preterm children's physiological state (Provenzi et al., 2018). The authors discuss that the inconsistencies between findings might be related to different infant characteristics or procedures in different studies.

Different properties of adult talk might be important during different stages of language acquisition (Rowe & Weisleder, 2020). Both maternal and paternal infant-directed talk in the NICU are linked to higher alertness of the infant, but might also have a calming effect and support the development of responsiveness (Saliba et al., 2020). Further, studies on the NICU language environment underline that preterm infants benefit from synchronous sensitive talk, adapted to the infant's responses (Caskey et al., 2014; DeMaster et al., 2019; Kuhn et al., 2017; Rand & Lahav, 2014; Saliba et al., 2020). The preterm infants might perceive simultaneous asynchronous adult talk as background noise, which might not be beneficial for the child's language processing skills (Rand & Lahav, 2014). Also, because parental talk might raise the alertness of the infant, studies suggest that parental talk in the NICU should be sensitively adapted to the infant's responses (Saliba et al., 2020).

The associations between language environment and language development during the first years of life have been widely investigated. A recent review on language acquisition in a social context describes how language development is influenced by the everyday input of caregiver talk (Rowe & Weisleder, 2020).

The connections between language nutrition, defined as quantity- and quality-rich adult talk to children in an interactive context (Head Zauche et al., 2017), and early language development have been thoroughly examined (e.g. Head Zauche et al., 2017; Zauche et al., 2016). Yet, the differences between the effects of infant-directed and overheard adult-directed talk, or the quantity and quality of adult talk, are not fully established (Rowe & Weisleder, 2020). An integrative review revealed positive links between both the quality and quantity of adult talk and interaction, and children's language outcomes during the first 3 years of life (Zauche et al., 2016).

Other studies have described the importance of mainly quality aspects of adult talk, such as interactive talk or conversational turn-taking, for language outcomes (e.g. Donnelly & Kidd, 2021; Gilkerson et al., 2018; Romeo et al., 2018; Rowe, 2012; Wang et al., 2020; Weisleder & Fernald, 2013; Zauche et al., 2016). Studies utilizing the LENA automated estimates have also examined the associations between adult word and conversational turn counts, and language outcomes. A meta-analysis from studies on children below 4 years of age revealed stronger associations between conversational turn count values and the children's language outcome than between adult word count values and language outcome (Wang et al., 2020). In a study by Gilkerson et al. (2018) LENA-estimated conversational turn count at 18–24 months of age explained 14%–27% of the variance in cognitive and language scores 10 years later.

The long-term associations between parental (Filippa, 2017) or adult talk (Saliba et al., 2018) in the NICU on the later development of preterm children have not been widely studied. To my knowledge, only one study (Caskey et al., 2011, 2014) has investigated the associations between adult talk in the NICU and preterm children's later language development. The findings from an open-bay NICU demonstrated that LENA-provided adult word count values near the infant at 32 gestational weeks of age were positively associated with language scores at 18 months (Caskey et al., 2014). So far, a consensus has not been reached regarding the most beneficial amount or type of NICU language input for long-term developmental outcomes of preterm children (Best et al., 2018; Filippa et al., 2017). Also, more knowledge on the effects of hospital staff talk in the NICU is needed (Pineda et al., 2014; Saliba et al., 2018). Additionally, a review article by Cheong et al. (2020) pointed out that the long-term neurodevelopment of preterm children is also likely to be influenced by the environmental factors the child experiences after the NICU care period.

To my knowledge, the potential connections between the language environment in the NICU and later lexical processing skills of preterm children have not been reported. Also, the findings from studies conducted at later age points differ. In a study on preterm children, the LENA-provided adult word count value at 16 months was a significant predictor of the child's processing accuracy at 18 months (Adams et al., 2018). Studies on full-term children have found positive associations between infant-directed talk at 19 months and lexical processing at 24 months (Weisleder & Fernald, 2013) and stronger associations between the number of conversational turns and neural language processing at 4–6 years, than between adult words and processing (Romeo et al., 2018).

Parent-infant closeness and parental involvement in the NICU are shown to provide emotional, physical and developmental short- and long-term benefits for the preterm infant (e.g. Flacking et al., 2012; Gonya et al., 2017; Pineda et al., 2018; Reynolds et al., 2013; Vohr, 2019; Yrjölä et al., 2022). However, the links between parent-infant closeness in the NICU and preterm children's language outcomes have not been broadly investigated. Findings from one study indicated that extremely preterm infants who received more hours of skin-to-skin care from both mothers and fathers in the NICU scored higher on communication scores at 6 and 12 months, although the results were not statistically significant (Gonya et al., 2017). Another study reported a positive association between maternal involvement in the NICU and higher language and cognitive performance in preterm children at 18 months (Lester et al., 2016). Of the different involvement variables kangaroo care (skin-to-skin contact), breastfeeding, bottle feeding, and maternal care (including holding), kangaroo care exhibited the strongest positive associations with language and communication scores (Lester et al., 2016).

The specific effects of father-infant closeness and paternal involvement in the NICU are less studied than the maternal involvement effects. Studies have mainly focused on the effects of father-infant skin-to-skin contact, and the findings demonstrate positive physiological effects for the preterm infants comparable to mother-infant closeness (Filippa et al., 2021). Also, general long-term effects of paternal NICU involvement have been described, such as the positive impact of the father's involvement on parental bonding (Filippa et al., 2021) and on the well-being of the mother and the child (Treyvaud, 2013; Yogman & Garfield, 2016).

In summary, more information on the potential long-term associations between language environment and parent-infant closeness in the NICU, and preterm children's later language development is warranted. Additionally, to my knowledge, potential connections between NICU language environment and parent-infant closeness, and later lexical processing skills of preterm children have not been explored.

2 AIMS

The general focus of the present dissertation was to gain knowledge on the role of early language environment on very preterm children's lexical abilities during the second year of life. The dissertation had two main aims. The first main aim was methodological, to study the validity and usability of new methods in evaluating language environment and lexical processing of very preterm children (Studies I–II). Firstly, the dissertation examined the validity of the Language Environment Analysis (LENA) system in the NICU (Study I). Because it is important to study the validity of the LENA system in different language and NICU contexts, the study investigated the validity of the LENA system in the NICUs of both Turku University Hospital, Finland and Tallinn Children's Hospital, Estonia. Secondly, the dissertation evaluated the usability and provided validity information on an eye tracking-based lexical processing task to assess the lexical processing of very preterm children at 18 months of corrected age (the age was adjusted for degree of prematurity; Study II). The second main aim was clinical: to study the longitudinal associations between language environment and parent-infant closeness in the NICU, and lexical abilities of very preterm children at 15 and 18 months of corrected age (Study III). The specific aims of the original studies included in the dissertation are presented in Table 1. The specific research questions presented in the original studies are displayed in Table 2.

Table 1. The aims of the dissertation and the studies targeting them.

Aims	Study I	Study II	Study III
To examine the validity of the LENA system in the NICU.	x		
To examine the usability and provide validity information on an eye tracking based lexical processing task to assess lexical processing of very preterm children at 18 months of corrected age.		x	
To investigate the longitudinal associations between language environment, measured using the LENA system and parent-infant close contact in the NICU, and lexical abilities (lexical processing, lexical development) of very preterm children at 15 and 18 months of corrected age.			x

LENA = Language Environment Analysis; NICU = neonatal intensive care unit

This dissertation is part of the Auditory environment by Parents of Preterm infants; Language development and Eye movements (APPLE) research project (APPLE Study, 2021) conducted at Turku University Hospital, Finland, and Tallinn Children's Hospital, Estonia. Principal investigators of the research project are Professor Liisa Lehtonen and Associate Professor Suvi Stolt. The

Ethics Committees of the Hospital District of Southwest Finland and the University of Tartu have approved the study protocol. The families received written and verbal information about the study before signed consent was obtained.

Table 2. The research questions of the original studies.

Study	Research questions
I	1. How accurately does the LENA system identify segments of female and male adult, segments of key child (the infant with the recording processor) and silence in the Finnish and Estonian NICU environments?
	2. How valid is the information provided by the LENA system regarding female word count, male word count, adult word count, child vocalization count, conversational turns and duration of silence?
II	1. Is there an association between lexical processing abilities (reaction time, correct looking time) of very preterm children measured at 18 months of corrected age, and receptive and/or expressive lexical development measured at 12, 15 and 18 months of corrected age?
	2. How much do lexical processing abilities at 18 months of corrected age explain of the variance in receptive/expressive lexical development at the same age when the effect of gender is taken into consideration?
III	1. Is there an association between language environment and/or parent-infant close contact (parental skin-to-skin contact and holding), when measured in the NICU, and very preterm children's lexical development at 15 and 18 months of corrected age?
	2. Is there an association between NICU language environment and/or parent-infant close contact (parental skin-to-skin contact and holding), and very preterm children's lexical processing at 18 months of corrected age?
	3. To what extent does NICU language environment and/or parent-infant close contact (parental skin-to-skin contact and holding) explain the variation in very preterm children's lexical development at 18 months of corrected age?

LENA = Language Environment Analysis; NICU = neonatal intensive care unit

3 PARTICIPANTS AND METHODS

The participants in the study were very preterm born (<32 gestational weeks) infants, recruited to the longitudinal APPLE research project (APPLE Study, 2021) in the NICUs of Turku University Hospital and Tallinn Children's Hospital. The research project consists of two studies: APPLE I, in which the very preterm children's development has been followed during the first year of life, and APPLE II, in which the development has been followed during the second year of life.

The APPLE I Turku recruitments were conducted from February 2017–December 2020, and the Tallinn recruitments from March 2017–March 2018. From a total of 332 (Turku 212; Tallinn 120) very preterm children born in the two NICUs in question during the recruitment period, 176 infants were invited to the project. The recruitments were conducted by members of the APPLE research group. A research nurse and an MD PhD student conducted most of the recruitments, but the author also actively participated in the recruitments. Each invited family was approached in the NICU when the infant's medical condition was stable. A total of 156 infants were excluded due to medical reasons (life-threatening medical conditions, significant congenital anomalies or syndromes, n = 9), death (n = 18), transfer to other hospitals (n = 44), and other reasons (license and technical problems, social reasons, multiple gestation with more than two fetuses, the language of the family other than Finnish or Estonian, n = 85). Of the 176 invited infants, the parents of 60 infants declined to participate in the project. The final group of participants enrolled in the APPLE I study included 116 infants (63 infants from Turku and 53 infants from Tallinn). Further, parents of 51 infants from the APPLE I study in Turku consented to participate in the APPLE II study.

In the present dissertation, the participants in Study I were very preterm infants recruited to the APPLE I study in the Turku University Hospital and the Tallinn Children's Hospital, and from monolingual Finnish or Estonian-speaking families (total n = 116). At the time Study I was performed, data from 29 infants from Turku and 41 infants from Tallinn were available (data collected March 2017–June 2018). From those infants, a sample of 7 infants from the NICU in Turku and 7 infants from the NICU in Tallinn (a total of 14, 20% of recruited participants) were randomly selected as participants in Study I. Because the variables analyzed included the number of vocalizations from the infant with the recording device, twins were excluded to ensure that only the vocalizations from the index child were counted.

In Studies II-III of the present dissertation, the participants were very preterm children from Finnish-speaking families (≥60% Finnish spoken at home) recruited to the APPLE II study and born in the Turku University Hospital (total *n* = 51). The collected data included measures of language environment and parent-infant closeness in the NICU and lexical ability measures from 12, 15, and 18 months of corrected age. Because the methods used to assess lexical abilities were developed for Finnish-acquiring children, only children from the Turku unit were included in Study II-III.

Study II included data from 25 very preterm children from the Turku University Hospital. Lexical *processing* data were collected from 25 children at 18 months of corrected age. During the data collection period (August 2018–June 2021), a total of 38 children were eligible, but lexical processing data could not be obtained from 13 children. The reasons for the lost processing data were: inability to participate in the processing assessment due to COVID-19 epidemic restrictions (*n* = 6), inability to participate in the assessment due to the family's long distance from the hospital (*n* = 2), inability of the child to focus on the task (*n* = 2), inability to reach the family (*n* = 1), diagnosed developmental impairment of the child (*n* = 1) and technical problems (*n* = 1). Further, lexical *developmental* data were collected at 12 months (*n* = 22), 15 months (*n* = 22), and 18 months of corrected age (*n* = 23).

The sample of Study III included data from a total of 43 very preterm children born in the Turku University Hospital. These data were collected longitudinally in the NICU and at 15 and 18 months of corrected age. Data could be collected as follows: from the NICU *n* = 43, at 15 months of corrected age *n* = 36, at 18 months of corrected age *n* = 29 (lexical processing) and *n* = 38 (lexical development). During the data collection period (April 2017–March 2022), a total of 48 children were eligible, but data could not be obtained from 5 children. The reasons for the lost data were language environment data from the NICU was missing due to technical problems (*n* = 1) and lexical ability data could not be obtained (*n* = 4).

The background characteristics of the participants in the original studies are presented in Table 3.

Table 3. Background characteristics of the participants. Percentages are calculated from the total number of participants.

Participant characteristic	Study I (*N* = 14)		Study II (*N* = 25)		Study III (*N* = 43)	
	M(SD)	Min.–Max.	M (SD)	Min.–Max.	M (SD)	Min.–Max.
Gestational age at birth	27 (2)	23–31	28 (2)	23–31	28 (2)	23–31
Birth weight (gram)	1045 (358)	520–1640	1222 (431)	470–1860	1099 (408)	470–1860
	n	%	n	%	n	%
Gender: male	7	50	12	48	24	56
Children developing as twins	0	0	6	24	14	33
Small for gestational age (-2 SD)	4	29	3	12	6	14
Bronchopulmonary dysplasia (36 w)	7	50	9	36	19	44
ROP [1], stage 3, 4 or 5	0	0	0	0	1	2
IVH [2], grade III or IV	0	0	0	0	0	0
Respiratory support on recording day [3]						
Invasive ventilation	1	7	3	12	6	14
Invasive ventilation/CPAP [4]	3	21	4	16	7	16
High-flow nasal cannula	2	14	6	24	11	26
High-flow nasal cannula/CPAP [4]	1	7	1	4	2	5
None	7	50	11	44	16	37
Warmth regulation on recording day [3]						
Incubator	1	7	0	0	0	0
Warming mattress	9	64	8	32	10	23
None	4	29	17	68	32	74
Single-family room on recording day[5]	7	50	24	96	39	91
Need for hearing aids at 12 months	0	0	0	0	0	0
Developmental impairment at 12 months [6]			0	0	1	2
Visual impairment at 12 months [6]			0	0	1	2
Mother's education [7]						
Basic, high school	8	57	7	28	10	23
Lower university, higher university	6	43	17	68	32	74
Father's education [8]						
Basic, high school	9	64	16	64	24	56
Lower university, higher university	5	36	7	28	15	35

[1] Retinopathy of prematurity, infants born <30 gestational weeks of age
[2] Intraventricular hemorrhage
[3] Data missing from 1 child in Study III
[4] Continuous positive airway pressure
[5] Single-family room with one infant or twins
[6] Reported by the parents of Study II–III, data missing for 1 child in Study II and 2 children in Study III.
[7] Data missing for 1 parent in Study II–III
[8] Data missing for 2 parents in Study II and 4 parents in Study III

3.1 Methods

3.1.1 The Language Environment Analysis system validation and data collection in the neonatal intensive care unit

Study I examined the validity of the LENA (LENA®, Boulder, Colorado) system in the Finnish and Estonian language contexts and the Turku and Tallinn NICU settings. The natural language and sound environment of the very preterm infants in the NICU were measured with the LENA system for 16 hours at the age of 32–33 gestational weeks (32 weeks, 0 days—33 weeks, 6 days). During the recording, the processor was kept close (approximately 10–30 cm) to the infant's head during all daily activities.

The LENA system consists of a digital processor that captures the child's natural language and sound environment and of software that provides speech algorithm-based automatic analyzes of the measured values. In the automatic analyses of the recorded audio information, the LENA system first classifies the data into non-speaker or speaker segments and then labels the segment based on its acoustic features (Gilkerson & Richards, 2020; Xu et al., 2008). The speaker labels are female adult, male adult, key child (the child with the processor), and other child. Additionally, the LENA system categorizes speaker labels into near and far classes (Xu et al., 2008). The non-speaker labels are television/electronics, noise, overlap, and silence.

Based on the speaker labels, the LENA system estimates the number of adult words, female and male words, child vocalizations, and conversational turns (Gilkerson & Richards, 2020). Adult word counts and female and male word counts include the number of words spoken to or near the child. The LENA system excludes unclear or overlapping speech from the word counts. The child vocalization count includes vowel-like sounds, squeals, and growls surrounded by more than 300 milliseconds of silence or sounds that are not the infant's vocalization. The LENA system does not include cries or vegetative sounds in the child vocalization count. Further, LENA-estimated conversational turns are the child's responses to adult speech or an adult's responses to child vocalizations within 5 seconds (Gilkerson & Richards, 2020). However, the LENA software does not differentiate infant-directed speech from overheard speech (Gilkerson & Richards, 2020; Gilkerson et al., 2017). Silence is defined as a segment of ≥800 ms with sparse or no acoustic information or with an acoustical energy of 32 dB or less (Gilkerson & Richards, 2020).

To obtain an extensive overview of the tool's validity, both of the LENA-provided measures, labels and counts, were investigated in the validation procedure. The agreements between the LENA and human coder-provided values were compared. For each of the 14 participants in Study I, two 5-minute segments from the LENA recording, containing the 10% highest measure of adult word count when a parent was present, were selected for analysis. Accordingly, the total amount of analyzed data was 140 minutes. A two-part procedure, based on information from previous research (Caskey et al., 2011, 2014; Caskey & Vohr, 2013), was developed to evaluate the validity of the LENA-provided measures. Information received from the LENA Foundation was also utilized (e.g. LENA Foundation, 2015, 2019). The analyses were conducted with the transcriber software (Barras et al., 2001).

The validation procedure consisted of a part A and a part B. Part A investigated the agreements between LENA-provided and human coder-provided labels for female adult, male adult, key child, and silence. Near/far classes of the speaker labels were combined to obtain a comprehensive picture of the validity. From the non-speaker labels, only the silence label was analyzed. The human coder listened to the segments recorded by the LENA system and noted, based on the human ear, if the LENA-provided labels were correct or not. The agreement between the LENA labels and human coders was analyzed by calculating agreement percentages.

Part B investigated the agreements between LENA and human coder-provided values for adult word, female word, male word, child vocalization and conversational turn counts. In addition, the validity of the silence estimate was investigated. The human coder first transcribed the speech recorded by the LENA system, implementing the same definitions for the values as the LENA provided definitions (Gilkerson et al., 2008; Gilkerson & Richards, 2008; Gilkerson et al., 2017; Xu et al., 2008). Then, the human coder manually counted the numbers of adult words, female and male words, vocalizations, and conversational turns included in the 5-minute segment that was analyzed. Additionally, the duration of silence was manually measured with a digital stopwatch. All ≥1 s measured segments of no sound or with very faint background sound were included in the human estimate of silence. Finally, the human coder values were compared with the LENA-provided estimates.

Two principal coders, one coder in Turku and one coder in Tallinn, analyzed most of the samples (Turku: 93%, Tallinn: 86%). The rest of the samples were analyzed by trained independent coders. The author served as the principal coder in Turku and compiled the data from Turku and Tallinn. Interrater reliability was examined based on the double-scored data of 29% (4 samples) of the data. Krippendorff's alpha (Kalpha, **α**) values were calculated between the scorings (Hayes & Krippendorff, 2007). The interrater reliability values were as follows in part A; female adult $\alpha = 0.72$, male adult $\alpha = 0.15$, key child $\alpha = 0.98$, and silence $\alpha = 0.29$, and in part B; female word count $\alpha = 0.92$, male word count $\alpha = 0.94$, adult word count $\alpha = 0.78$, child vocalization count $\alpha = 0.77$, conversational turns $\alpha = 0.81$, and silence $\alpha = 0.94$.

Study III utilized the LENA-provided estimates of adult word, female and male word, conversational turn and child vocalization counts. The specific variables used in the original studies are displayed in Table 4.

Table 4. Methods and variables used in the original studies.

Method	Variables analyzed		
	Study I	Study II	Study III
LENA	Labels for female adult, male adult, key child, and silence Adult word, female and male word, child vocalization and conversational turn counts, duration of silence		Adult word, female and male word, child vocalization, and conversational turn counts
Parental closeness diaries	Parental presence		Maternal close contact Paternal close contact Parental close contact
Eye tracking-based lexical processing task		Reaction time and correct looking time.	Reaction time and correct looking time
FinCDI-SF		Receptive and expressive lexicon at 12, 15, and 18 months	Receptive and expressive lexicon at 15 and 18 months
FinCSBS-ITC		Symbolic and Speech Composites at 12, 15, and 18 months	Symbolic and Speech Composites at 15 and 18 months

LENA = The Language Environment Analysis system; variables include labels, counts and duration of silence

FinCDI-SF = Finnish short form version of the MacArthur Communicative Development Inventories; FinCSBS-ITC = the Finnish version of the Symbolic Behavior Scales, Developmental Profile, Infant–Toddler Checklist

3.1.2 Parent-infant closeness data collection in the neonatal intensive care unit

Parent-infant closeness data were collected through parental closeness diaries (Axelin et al., 2020; Raiskila et al., 2017). The diary is a data collection instrument developed to measure the duration of parent-infant NICU closeness for 14 days, from both parents individually and from the infant's perspective (Axelin et al., 2020). Using the diary, the parents report the following measures of parent-infant closeness: the duration of parental presence in the NICU unit, the duration of parent-infant skin-to-skin contact (the parent is holding the infant, dressed only in a diaper and possibly a cap, on the parent's bare chest) and the duration of parental holding (the dressed infant is kept in the parent's arms) (Axelin et al., 2020; Raiskila et al., 2017).

In the present study, the diaries were used to document parent-infant closeness in the NICUs for 14 consecutive days at 32–33 weeks of gestational age, including the day of the LENA recording. The diary was kept at the infant's bedside and both parents filled in daily data on the mother's and father's presence, skin-to-skin contact, and holding (Axelin et al., 2020; Raiskila et al., 2017).

Study I utilized the diaries to identify the times when at least one parent was present in the NICU, because only these periods were eligible for analysis. Study III utilized the diaries to measure the duration of parent-infant closeness in the NICU. The mother's skin-to-skin contact and holding values were added to form a mother's close contact variable (mother's skin-to-skin contact and holding) and the father's values formed a father's close contact variable (father's skin-to-skin contact and holding). Furthermore, both parents' close contact variables were summed to a compound parental close contact variable (mother's skin-to-skin contact and holding + father's skin-to-skin contact and holding). Mean values in minutes per day were used in the analyses. The specific variables used in the original studies are displayed in Table 4.

3.1.3 Methods used to assess lexical abilities of very preterm children: lexical processing and development

An eye tracking-based task to assess lexical processing

An eye tracking technology-based lexical processing task (Ståhlberg-Forsén, Leppänen & Stolt) was developed to assess the lexical processing skills of very preterm children at 18 months of corrected age. The task was conceptualized, developed, and modified by the author, Associate Professor Leppänen and Associate Professor Stolt. The author compiled the audio and video elements of the task and conducted all the assessments. Professor Leppänen conducted the analyses of the eye tracking data.

The task was based on the looking-while-listening procedure (Fernald et al., 2006; Fernald et al., 1998; Fernald et al., 2008; Loi et al., 2017; Marchman & Fernald, 2013) and modified to measure the lexical processing skills of Finnish-acquiring children. The target words in the present task were 11 Finnish words: *silmä, auto, kuppi, kukka, puu, kuu, avaimet, leijona, hyppää, nauraa* and *iso* (*eye, car, cup, flower, tree, moon, keys, lion, jump, laugh* and *big),* presented in short phrases ("*Where is the car, where is it?")* by a native Finnish speaker. The words were chosen based on the typical receptive lexical development of 18-month-old Finnish children (Stolt & Vehkavuori, 2018). The target words included 4 easy words (reported to be known by 80%–99%), 4 moderately difficult words (known by 60%–80%), and 3 difficult words (known by <60%) (Stolt & Vehkavuori, 2018). Of the target words, 8 were nouns, 2 verbs, and 1 adjective. Photo or digital color images of the target words were presented in pairs; each image 3 times as a target and 3 times as a distracter image. The noun target word pairs were unyoked. During the assessment, the child was watching the images on a computer screen while listening to the phrases. The child's eye movements were measured with the eye tracker Tobii X2-60, which uses image sensors and processing algorithms to register the participant's gaze points on the computer screen (Tobii Technology AB, 2014). A pilot study with 4 children was performed and the task was technically improved before the study phase. A read-out (a smiley face) showing the child's distance from the screen, based on the eye tracking output, was added to the design of the task to facilitate the detection of the correct position of the child.

The lexical processing assessments were performed at the hospital facility and began with an introduction. The child sat on the parent's lap watching a children's movie on the computer screen. The parent wore dark glasses to obstruct the eye tracker from registering the parent's eye movements. When the child's position was correct (distance approximately 60 cm and angle approximately 0 degrees), the assessment started with a 5-point eye tracker calibration. After the calibration, 2 practice trials were run before the onset of the actual trials. Before each trial, a fixation stimulus (a cat animation) was presented to standardize the child's gaze location at the center of the screen at the trial start. The trial started automatically when the child looked at the fixation stimulus or after a 1000 ms waiting period. The trial began with the images visible on the screen, and after two seconds, the sound stimulus was presented. The images were visible during the sound stimulus and approximately 1 second after. The test trials included 5 blocks, each block consisting of 6–7 trials exhibiting pairs of images. The pairs of images appeared in random order with the same target image only once in each block. Approximately 5-second-long video clips were shown before the first trial, between the blocks, and after the last trial, to sustain the child's motivation and attention. The procedure lasted approximately 10 minutes.

Two primary variables of the looking-while-listening paradigm, reaction time (speed) and correct looking time (accuracy) (Fernald et al., 2008), were used in the present study. The reaction time was the latency with which the child looked at the target image after the target word onset. Correct looking time was the mean proportion of time that the child looked at the target image out of the total looking time. Because reaction time measures speed and correct looking time measures accuracy, the variables were chosen to measure different aspects of lexical processing and, thus, to supplement one another.

The reaction time was measured within the 200–2800 ms time window from the target word onset. Trials, where the child's gaze point was on the target image already when the target word was presented, were excluded from the analyses, which is according to the principles of the looking-while-listening procedure (Fernald et al., 2008). The lower cut-off value of the time window was based on previous research (Fernald et al., 2008). The upper cut-off value was prolonged, due to the phonetic characteristics of the Finnish language and to the specific features of the target words used in the present task. The target words included vowel-initial words, three-syllable-long words, and words with diphthongs, words typical in the Finnish language (Karlsson, 1983). Moreover, the target words included 2 verbs and 1 adjective, which are part of a sentence context, and thus may require more verbal working memory capacity and longer processing time (Fernald et al., 2010).

The correct looking time value was measured from both distracter and target initial trials. Due to the characteristics of the target words, the upper cut-off value time window in the correct looking time analyses was also prolonged, as is done in studies with young children (Bergelson & Swingley, 2012; Fernald et al., 2010). Also, research based on a data bank of eye tracking data recommends the use of a longer time window to improve the reliability of the task (Zettersten et al., 2021). For Study II, which aimed to investigate associations between lexical processing and lexical development, the total time window was divided into early and late time windows. The objective was to study the child's looking behavior during the entire processing task and to detect individual differences between the very preterm children. The early time window captured 200–2800 ms and the late time window 2800–6400 ms from target word onset. An early and late time window has previously been used in studies with young children (Lany et al., 2018). Study III, which investigated the associations between language environment and parent-infant closeness, and lexical abilities, utilized the total time window. The total time window captured 200–6400 ms from the target word onset, thus, including both the early and late time windows. The specific variables used in the original studies are displayed in Table 4.

The eye tracking-based lexical processing task included 33 trials. Trials that contained missing data for a continuous period lasting over 250 ms were excluded. This criterion was established a priori to data analysis and based on previous research (Leppanen et al., 2015). In the present study, the maximum length of missing gaze data was prolonged from 200 to 250 ms to reduce data attrition. The data consisted of averaged information obtained from both eyes or of data from one valid eye.

Methods used to assess lexical development

At 12, 15, and 18 months of corrected age, information on the very preterm children's lexical development was collected using two different screening methods. The Finnish short form version (FinCDI-SF; Stolt & Vehkavuori, 2018) of the MacArthur Communicative Development Inventories (Fenson et al., 2000) is a parental report form instrument for screening early lexicon. The method is validated and normed for Finnish children (Stolt & Vehkavuori, 2018). The instrument consists of an infant form, for infants aged 9–18 months, and a toddler form, for children aged 18–24 months. Studies II and III utilized the infant form, providing information on receptive and expressive words from different lexical categories. The instrument is composed of a checklist of 89 words, where the parent marks the words the child understands or produces. The maximum score, for both expressive and receptive categories, is 89 points (one point for each word).

The Finnish version (FinCSBS-ITC; Laakso et al., 2011) of the Communication and Symbolic Behavior Scales, Developmental Profile, Infant-Toddler Checklist (Wetherby et al., 2002) is a screening method using parent reporting to measure prelinguistic communication and language development in children between 6 and 24 months of age. The method has been validated and normed for the Finnish population (Laakso et al., 2011). The instrument consists of Social, Symbolic, and Speech Composites, from which a total score is computed. The scores are given on a 3-, 4- or 5-point scale, describing the performance of the child. As Study II and Study III investigated the lexical development, only the Symbolic and the Speech Composites of the method were used. The Symbolic Composite includes 6 questions investigating the understanding of words and object use (maximum score of 17 points). The Speech Composite includes 5 questions related to sound and word production (maximum score of 14 points).

Both screening methods were mailed by the author to the families who filled in the methods at home, within two weeks from the corrected date. Study II utilized the methods collected at 12, 15, and 18 months and Study III the methods collected at 15 and 18 months of corrected age. The specific variables used in the original studies are displayed in Table 4.

3.2 Data analysis

Spearman's correlation coefficient values were used to analyze all associations. Study I investigated the associations between the LENA and human coder-provided estimates. Study II analyzed the associations between the very preterm children's lexical processing and lexical development, and Study III the associations between language environment and parent-infant closeness, and later lexical abilities. In Study I, Krippendorff´s Alpha (Hayes & Krippendorff, 2007) was also used to analyze the associations between LENA and human coder-provided estimates, and interrater reliability. Kalpha analyses are considered to give robust results for small data sets with any data distribution and missing data.

In Study II, four linear regression models were created to explore how much of the variance in lexical development at 18 months could be explained by lexical processing variables, together with background factors. Four regression models with expressive lexical development as dependent variables were selected, based on the preliminary correlation analyses. In the first two models, the dependent variable was FinCDI-SF expressive lexical development. In the first model, the independent variable was reaction time, and in the second model correct looking time. In the next two models, the dependent variable was FinCSBS-ITC speech development, and reaction time and correct looking time were independent variables. The independent variables were chosen based on preliminary correlation analyses. Based on the preliminary analyses, the late time window value was chosen to represent the correct looking time variable. Gender was selected as the independent background variable in all models. The preliminary analyses demonstrated that gender, of the available background factors, exhibited the strongest associations with the lexical measures.

In Study III, four linear regression models were formed to study how much NICU language environment and parent-infant close contact variables explained the lexical development variance at 18 months. FinCDI-SF receptive and expressive values and FinCSBS-ITC Symbolic and Speech Composite values were dependent variables. Conversational turn count and parental close contact (mother's skin-to-skin contact and holding + father's skin-to-skin contact and holding) were independent language environmental and parent-infant closeness variables in all four models, chosen based on the preliminary correlation analyses. Based on the preliminary analyses, gender was selected as the third independent variable. Of the background factors (gender, gestational age at birth, birth weight, maternal and paternal educational level), gender showed the strongest associations with the lexical values utilized as dependent variables in the regression models. Transformed conversational turn count values were used in the regression models due to data skewness.

Data analysis was conducted with SPSS versions 27 and 28 (IBM Corp.) and *p*-values below 0.05 were considered statistically significant. Kalpha 0.80 was considered a good reliability value, with a minimum of 0.60. The statistical analyses were performed by the author after consulting the Biostatistics unit of the University of Helsinki.

4 RESULTS

4.1 Validation of the Language Environment Analysis system

In part A of the validation process, the total number of female LENA labels noted in the samples analyzed was 1421. From those, the human coder coded 86% as correct, based on the human ear. The highest total agreement between LENA labels and human coders was found in female labels, of which the human coders in Turku coded 90% as correct and the coders in Tallinn 82% as correct. The agreement for key child, male, and silence was modest or fair. The samples included 263 key child labels, and the human coder coded 39% of those as correct. Table 5 displays the descriptive data from part A of the validation study.

The Kalpha values for the agreements between the LENA and human coder for the combined Turku and Tallinn samples were as follows: female labels $\alpha = 0.80$, male labels $\alpha = 0.28$, key child labels $\alpha = 0.25$ and silence labels $\alpha = 0.30$.

Table 5. Descriptive statistics of part A of the validation study. Agreement percentages, based on mean values, are displayed.

LENA label	Number of LENA-provided labels	Number of labels classified as correct by human coder	Agreement percentage
Total: Turku and Tallinn (*n* = 14)			
Female	1421	1247	86
Male	578	294	47
Key child	263	101	39
Silence [1]	467	216	42
Turku (*n* = 7)			
Female	824	740	90
Male	355	176	42
Key child	141	54	54
Silence [1]	191	42	72
Tallinn (*n* = 7)			
Female	597	507	82
Male	223	118	53
Key child	122	47	24
Silence [1]	276	74	22

LENA = Language Environment Analysis

[1] LENA labels for silence were missing for 3 children in Turku and 1 child in Tallinn

In part B of the validation process, in the total sample of children, the LENA-estimated mean value for female words was 609, and the respective value estimated by the human coder was 698. The LENA-estimated mean number of adult words was 799, and the human coder estimated number was 817. Further, the LENA-estimated mean value of child vocalizations was 14 and the corresponding human coder value based was 6. Significant positive associations between LENA and human coder estimates were found for the following total values: adult word counts (r = 0.95), female word (r = 0.91) and male word counts (r = 0.64), and duration of silence (r = 0.64). The results indicated that agreement between LENA and the human coder provided estimates for adult word, female word, and male word counts and the duration of silence was high. Furthermore, the associations between LENA and human-provided estimates for conversational turn counts nearly reached significance level in the Turku unit (r = 0.73) but were lower in the Tallinn unit (r = 0.23). Table 6 shows the descriptive data from part B of the validation study.

The Kalpha values for the agreement between LENA and human coder for the combined Turku and Tallinn samples were as follows: adult word count α = 0.92, female word count α = 0.88, male word count α = −0.33, conversational turns α = 0.25, child vocalization count α = 0.09 and silence α = −0.18.

Table 6. The descriptive statistics for part B of the validation study. The length of silence is presented in seconds. Agreements between LENA and human estimates are presented using Spearman correlation coefficients (*r*) and significance level (*p*).

LENA variable	LENA estimates		Human coder estimates			
	Mean (SD)	Min.–Max.	Mean (SD)	Min.–Max.	*r*	*p*
Total: Turku and Tallinn (*n* = 14)						
Adult word count	799 (381)	156–1331	817 (324)	224–1312	**0.95****	**<0.001**
Female word count	609 (374)	12–1249	698 (323)	110–1207	**0.91****	**<0.001**
Male word count	191 (254)	5–862	119 (323)	0–592	**0.64***	**0.02**
Conversational turn count	8 (9)	1–26	4 (4)	0–14	0.23	0.44
Child vocalization count	14 (20)	1–59	6 (5)	0–16	-0.03	0.91
Silence (s)	200 (110)	28–414	56 (39)	0–109	**0.64***	**0.01**
Turku (*n* = 7)						
Adult word count	978 (220)	708–1288	969 (241)	662–1312	**0.82***	**0.02**
Female word count	712 (272)	263–1105	812 (233)	484–1207	**0.79***	**0.04**
Male word count	266 (314)	12–862	157 (207)	0–592	**0.86***	**0.01**
Conversational turn count	7 (9)	1–26	4 (3)	0–7	0.73†	0.06
Child vocalization count	13 (21)	1–59	8 (4)	0–12	0.13	0.79
Silence (s)	133 (166)	28–185	41 (38)	0–109	0.61	0.15
Tallinn (*n* = 7)						
Adult word count	620 (438)	156–1331	665 (339)	224–1256	**0.96****	**<0.001**
Female word count	505 (452)	12–1249	584 (376)	110–1166	**1.00****	**<0.001**
Male word count	115 (166)	5–476	81 (146)	0–403	0.52	0.30
Conversational turn count	8 (9)	1–26	4 (5)	0–14	0.08	0.87
Child vocalization count	15 (21)	1–55	4 (5)	0–16	-0.10	0.83
Silence (s)	267 (106)	139–414	70 (37)	15–106	**0.86***	**0.01**

† $p<0.10$ *$p<0.05$, ** $p<0.01$, significant results are bolded

LENA = Language Environment Analysis

4.2 Lexical abilities of very preterm children, and associations between lexical processing and development

In terms of lexical processing at 18 months, the mean reaction time in the processing assessment was 1637 ms. The mean proportion of correct looking time for the early time window was 0.52 and for the late time window 0.48 respectively. For the total time window, the mean proportion of correct looking time was 0.50. The number of successful trials was the following: for reaction time mean 8; for correct looking time early time window 19 and late time window 13; and for the total time window 13, respectively. The total descriptive data from the lexical processing assessment conducted at 18 months of corrected age is presented in Table 7 (Study III, *n* = 29; data for the early and late windows not published in the original article). The descriptive lexical processing data for Study II is presented in the original article.

Table 7. Descriptive statistics for lexical processing values (*n* = 29) measured at 18 months of corrected age. Reaction time is displayed in milliseconds and correct looking time is in proportion of time.

Lexical processing variable	Mean (SD)	Min.–Max.
Reaction time	1037 (320)	306–1728
Correct looking time: ET	0.52 (0.14)	0.16–0.83
Correct looking time: LT	0.48 (0.13)	0.24–0.74
Correct looking time: TT	0.50 (0.11)	0.24–0.71

ET = Early time window; LT = Late time window; TT = total time window

Data for the early and late windows not published in the original article.

In terms of lexical development during the beginning of the second year of life, the results showed an increase in developmental skills from 12 months to 18 months, but broad variation at all measure points. The FinCDI-SF mean receptive values at 12,15 and 18 months were 20, 38, and 52 (normative mean values: 23, 48, and 67). The mean expressive values were 2, 8, and 20, respectively (normative values: 3, 9, and 26). The FinCSBS-ITC mean Symbolic Composite values at 12,15 and 18 months were 8, 12, and 14 (normative mean values: 10, 13, and 15). The mean Speech Composite values were 6, 8, and 10, respectively (normative values: 8, 9, and 11). Descriptive statistics for the data on lexical development between 12 and 18 months (Study III, data from 12 months not published in the original article) are presented in Table 8. The descriptive lexical development data for Study II is presented in the original article.

Table 8. Descriptive statistics for lexical development measures from the FinCDI-SF and the FinCSBS-ITC at 12, 15, and 18 months of corrected age.

Method	12 months		15 months		18 months	
	Mean (SD)	**Min.–Max.**	**Mean (SD)**	**Min.–Max.**	**Mean (SD)**	**Min.–Max.**
FinCDI-SF Lexical development						
Rec	20 (15)	2–66	38 (19)	1–78	52 (22)	3–88
Expr	2 (3)	0–12	8 (9)	0–31	20 (16)	0–60
FinCBCS-ITC Lexical development						
SyC	8 (2)	4–14	12 (3)	5–17	14 (2)	8–17
SpC	6 (2)	3–11	8 (3)	2–13	10 (3)	3–14

FinCDI-SF = the Finnish short form version of the MacArthur Communicative Development Inventories; Fin-CSBS-ITC = the Communication and Symbolic Behavior Scales, Developmental Profile, Infant-Toddler Checklist; Rec = Receptive lexical; Expr = Expressive lexical; SyC = Symbolic Composite (understanding of words, object use); SpC = Speech Composite (vocalizations, expressive words)

Note: data retrieved from language items varied between 35–39 cases.
Data from 12 months not published in the original article.

Regarding the associations between lexical processing reaction time at 18 months of age and lexical development at 12, 15 and 18 months of age, statistically significant and negative associations were found between reaction time and FinCSBS-ITC Speech Composite variables at 12 and 15 months (r-values = -0.45 and -0.51). Further, the association between reaction time and FinCSBS-ITC Speech Composite value at 18 months nearly reached the significance level (r = -0.43). The results indicated that the more slowly the child looked to the target image after the target word onset, the weaker the child's speech development.

Regarding the associations between lexical processing correct looking time and lexical development, statistically significant and positive associations were found between correct looking time and FinCDI-SF expressive lexical development at 15 and 18 months, and with FinCSBS-ITC Symbolic Composite value at 12 months and Speech Composite value at 18 months (r-values varied between 0.43 and 0.58). Further, the association between correct looking time early time window values and FinCSBS-ITC Symbolic and Speech Composite values at 18 months nearly reached significance level (r = 0.37 and 0.42). The results indicate that the longer the child looked at the target image, the stronger the child's symbolic, speech or expressive lexical development. The associations between lexical processing values measured at 18 months and lexical developmental values measured at 12, 15, and 18 months are presented in Table 9.

Table 9. Correlations (Spearman's *r*-values) between lexical processing values measured at 18 months of corrected age and lexical developmental values from the FinCDI-SF and the FinCSBS-ITC at 12, 15 and 18 months of corrected age.

Lexical processing		**Fin-CDI-SF Lexical development**					
		12 months		**15 months**		**18 months**	
		Rec	Expr	Rec	Expr	Rec	Expr
RT [1]	*r*	-0.21	-0.15	-0.29	-0.29	-0.31	-0.29
	p	0.36	0.51	0.20	0.20	0.15	0.19
CLT ET	*r*	0.12	0.11	0.37†	**0.58****	0.34	**0.46***
	p	0.61	0.62	0.09	**0.00**	0.11	**0.03**
CLT LT [1]	*r*	0.18	0.14	0.17	0.25	0.28	**0.52***
	p	0.44	0.56	0.45	0.28	0.21	**0.01**
		FinCSBS-ITC Lexical development					
		SyC	SpC	SyC	SpC	SyC	SpC
RT [1]	*r*	-0.34	**-0.51***	-0.26	**-0.45***	-0.11	-0.43†
	p	0.14	**0.02**	0.29	**0.04**	0.63	0.05
CLT ET	*r*	**0.43***	0.26	0.42†	0.19	0.42†	0.37†
	p	**0.05**	0.27	0.07	0.39	0.05	0.09
CLT LT [1]	*r*	**0.52***	0.37	0.35	0.15	0.10	**0.45***
	p	**0.02**	0.10	0.15	0.52	0.67	**0.04**

† $p<0.10$ *$p<0.05$, ** $p<0.01$, significant results are bolded

RT = Reaction time; CLT = Correct looking time; ET = Early time window; LT = Late time window; FinCDI-SF = the Finnish short form version of the MacArthur Communicative Development Inventories; Fin-CSBS-ITC = the Communication and Symbolic Behavior Scales, Developmental Profile, Infant-Toddler Checklist; Rec = Receptive lexical; Expr = Expressive lexical; SyC = Symbolic Composite (understanding of words, object use); SpC = Speech Composite (vocalizations, expressive words)

[1] data from one case was missing.

Note: data retrieved from lexical items varied 19–23 cases.

The statistically significant linear regression models, with the lexical processing variables that best explained the variance in lexical development at 18 months, included expressive development as the dependent variable and lexical processing values (Model 1: reaction time, Model 2: correct looking time) and gender as explaining variables. Models 1–2 with FinCDI-SF expressive lexical development as dependent variables explained 24% and 40% of the variation in expressive development, respectively. Correct looking time was a significant explanatory variable. Models 3–4 with FinCSBS-ITC Speech Composite values as dependent variables explained 33% and 26% of the variance. As explanatory variables, reaction time and correct looking time nearly reached statistical significance. Gender was a significant explanatory factor in all four models. The models are presented in Table 10.

Table 10. Linear regression models with expressive values measured at 18 months of corrected age as dependent variables. Reaction time (RT), correct looking time (CLT, late time window), and gender were the independent variables.

Independent variable	B	95% CI	R^2 (adj R^2)	F	*p*
Model 1: FinCDI-SF Expressive lexical skills			0.31 (0.24)	4.22	**0.03***
RT	-0.02	-0.04–0.01			0.12
Gender	-17.08	-31.25–2.92			**0.02***
Model 2: FinCDI-SF Expressive lexical skills			0.46 (0.40)	8.01	**<0.01****
CLT	65.20	17.73–112.67			**0.01***
Gender	-17.55	-30.08– -5.03			**0.01***
Model 3: FinCSBS-ITC Speech Composite			0.40 (0.33)	5.98	**0.01***
RT	-0.00	-0.01–0.00			0.05†
Gender	-3.23	-5.47– -0.99			**0.01***
Model 4: FinCSBS-ITC Speech Composite			0.33 (0.26)	4.43	**0.03***
CLT	7.74	-0.92–16.39			0.08†
Gender	-2.72	-5.04– -0.40			**0.02***

† *p*<0.10 **p*<0.05, ** *p*<0.01, significant results are bolded

FinCDI-SF = the Finnish short form version of the Communicative Developmental Inventories; FinCSBS-ITC = the Finnish version of the Symbolic Behavior Scales, Developmental Profile, Infant-Toddler Checklist; Symbolic Composite = understanding of words, object use; Speech Composite = vocalizations, expressive words

4.3 Associations between language environment and parent-infant closeness in the neonatal intensive care unit, and lexical abilities of very preterm children

4.3.1 Descriptive data of language environment and parent-infant closeness

Based on the LENA estimates from the NICU, the mean adult word count value per hour was 700. The mean female word count value was 571, the mean male word count value was 140, and the mean number of conversational turns was 6. In the sample of 43 infants, the mean number of child vocalizations per hour was 23. However, the individual variation was broad. The data describing the language environment (Study III, n = 43) in the NICU are demonstrated in Table 11.

Table 11. Descriptive statistics (N = 43) derived from LENA used in the neonatal intensive care unit for 16 hours.

LENA values (rate/hour)	Mean (SD)	Min.–Max.
Adult word count	700 (420)	102–2320
Female word count	571 (335)	92–1501
Male word count	140 (161)	10–820
Conversational turn count	6 (7)	1–42
Child vocalization count	23 (20)	2–113

LENA = Language Environment Analysis

Based on the Parental Closeness diaries, the mothers spent 435 minutes per day in the NICU and the fathers 265 minutes per day, respectively (data not published in the original Study III). The mean value for mothers' close contact (skin-to-skin contact + holding) was 164 minutes/day and the mean value for fathers' close contact (skin-to-skin contact + holding) was 81 minutes/day. There was considerable individual variation in parental presence and close contact values. The data describing parental closeness values (Study III, n = 43) in the NICU are presented in Table 12.

Table 12. Descriptive statistics (*N* = 43) were derived from the parental closeness diaries used in the neonatal intensive care unit for 14 days.

Parental closeness values (minutes/day)	Mean (SD)	Min.–Max.
Maternal presence	435 (146)	225–822
Paternal presence	265 (177)	0–712
Parental presence	701 (299)	253–1532
Mother-infant close contact	159 (61)	26–369
Father-infant close contact	78 (63)	0–245
Parent-infant close contact	236 (102)	52–506

Note: Parental values are the sum variables of the mother's and father's mean values. Close contact values are the sum variables of mean skin-to-skin contact and holding measures.

Data on parental presence not published in the original article.

4.3.2 Associations between language environment, parent-infant closeness, and lexical abilities

Regarding values measured in the NICU and lexical processing skills at 18 months of age, the following statistically significant associations were detected. Adult and female word counts estimated by the LENA system in the NICU were significantly and negatively associated with lexical processing correct looking time values ($r = -0.38 - -0.40$). The higher the LENA estimated adult and female word count values near the child in the NICU, the less correct looking time the child showed in the processing task at 18 months. No significant associations were found between LENA values and the measured reaction time in the lexical processing task.

Regarding values measured in the NICU and lexical development between 12 and 18 months of age the following associations were found. Statistically significant associations were found between LENA-estimated conversational turns in the NICU and very preterm children's later lexical development (r = 0.42–0.46). The higher the conversational turn count value in the NICU, the stronger the receptive lexical development the child exhibited at 15 and 18 months (r = 0.42–0.46). Further, the higher the LENA-estimated child vocalization count value in the NICU, the stronger the receptive lexical skills the child showed at 15 and 18 months of corrected age (r = 0.42–0.57). No significant associations were found between adult word count in the NICU and later lexical development. The longitudinal associations between language environmental values measured in the NICU and lexical abilities measured during the second year of life (Study III) are presented in Table 13.

Table 13. Longitudinal associations (Spearman's *r*-values) between language environment measured in the neonatal intensive care unit, lexical processing values at 18 months of corrected age and lexical development values at 12, 15 and 18 months of corrected age.

LENA variable	**Lexical Processing**		**Lexical development FinCDI-SF**				**Lexical development FinCSBS-ITC**			
	18 months		**15 months**		**18 months**		**15 months**		**18 months**	
	RT	CLT	Rec	Expr	Rec	Expr	SyC	SpC	SyC	SpC
AWC	0.05	**-0.40***	-0.13	-0.20	-0.11	-0.13	0.05	-0.24	0.02	0.07
FWC	0.12	**-0.38***	-0.05	-0.13	-0.09	-0.07	0.13	-0.21	0.05	0.05
MWC	-0.34†	-0.20	-0.21	-0.16	0.01	0.07	-0.10	-0.07	-0.07	0.28†
CTC	0.25	-0.05	**0.42****	0.22	**0.46****	0.07	**0.44***	0.25	0.21	0.17
CVC	0.28	0.14	**0.49****	**0.42***	**0.57****	0.29†	**0.57****	0.30†	0.23	0.32†

† $p<0.10$ *$p<0.05$, ** $p<0.01$, significant results are bolded

LENA = Language Environment Analysis; FinCDI-SF = the Finnish short form version of the Communicative Developmental Inventories, FinCSBS-ITC = the Finnish version of the Symbolic Behavior Scales, Developmental Profile, Infant-Toddler Checklist; AWC = Adult word count, FWC = Female Word count, MWC = Male word count, CTC = Conversational turn count, CVC = Child vocalization count, RT = Reaction time, CLT = correct looking time (total time window); Rec = Receptive lexical; Expr = Expressive lexical; SyC = Symbolic Composite (understanding of words, object use); SpC = Speech Composite (vocalizations, expressive words)

Note: data retrieved from lexical ability measures varied 30–38 cases.

Regarding the parental closeness values documented in the NICU and lexical abilities between 12 and 18 months the following associations were detected. The father's presence in the NICU was statistically significantly and negatively associated with lexical processing reaction time (r = -0.40) at 18 months of age. The longer the father was present in the NICU, the faster the reaction time of the child in the processing task. Maternal presence was not significantly associated with lexical processing values. Further, no significant associations were found between the duration of parental presence documented in the NICU and very preterm children's later lexical development.

No statistically significant associations were found between maternal or paternal close contact and lexical processing values. However, maternal and paternal close contact values were significantly and positively associated with lexical developmental values at 15 and 18 months (r = 0.35–0.39). The longer the duration of parent-infant close contact in the NICU, the stronger the lexical skills the child showed at 15 and 18 months. Further, no statistically significant associations (r = -0.08–0.27) between language environment values and parental close contact values were found. The longitudinal associations between parent-infant closeness values measured in the NICU and lexical abilities measured during the second year of life are presented in Table 14 (Study III, data on associations between parental presence and lexical abilities were not presented in the original articles).

Table 14. Longitudinal associations (Spearman's *r*-values) between parent-infant closeness values from the neonatal intensive care unit, lexical processing values measured at 18 months of corrected age and lexical development values measured at 15 and 18 months of corrected age.

Closeness variable	**Lexical Processing**		**Lexical development FinCDI-SF**				**Lexical development FinCSBS-ITC**			
	18 months		**15 months**		**18 months**		**15 months**		**18 months**	
	RT	CLT	Rec	Expr	Rec	Expr	SyC	SpC	SyC	SpC
Maternal presence	-0.26	0.10	0.21	-0.03	0.14	-0.14	0.10	0.17	0.00	-0.09
Paternal presence	**-0.40***	0.23	0.23	0.01	0.06	-0.04	0.22	0.20	0.05	0.00
Parental presence	-0.36†	0.16	0.22	0.02	0.09	-0.11	0.15	0.20	-0.01	-0.07
Maternal close contact	-0.30	0.11	0.13	0.19	0.24	0.28†	-0.04	**0.36***	0.03	**0.38***
Paternal close contact	-0.32	0.26	0.29†	0.04	**0.35***	0.17	0.27	0.31†	0.15	0.31†
Parental close contact	-0.33†	0.18	0.23	0.14	**0.37***	0.28†	0.15	**0.37***	0.12	**0.39***

† $p<0.10$ *$p<0.05$, ** $p<0.01$, significant results are bolded

FinCDI-SF = the Finnish short form version of the Communicative Developmental Inventories; FinCSBS-ITC = the Finnish version of the Symbolic Behavior Scales, Developmental Profile, Infant-Toddler Checklist; RT = Reaction time; CLT = correct looking time (total time window); Rec = Receptive lexical; Expr = Expressive lexical; SyC = Symbolic Composite (understanding of words, object use); SpC = Speech Composite (vocalizations, expressive words)

Note: data retrieved from lexical ability measures varied 30–38 cases.

Data on parental presence not published in the original article.

The linear regression models with the environmental and parental close contact values that best explained the variance in lexical skills at 18 months contained receptive skills as dependent variables and conversational turns, parental close contact, and gender as independent variables. Models 1 and 3 were statistically significant. Model 1, with FinCDI-SF receptive lexical values as dependent variables, explained 34% of the lexical development variation at 18 months. CTC and gender were significant explanatory variables. Model 2, with FinCSBS-ITC Symbolic Composite values as dependent variables, explained 35% of the variation. CTC and gender were significant explanatory variables. The linear regression models are presented in Table 15.

Table 15. Linear regression models with lexical developmental values measured at 18 months as dependent variables. Conversational turn count, parental close contact, and gender were independent variables.

Independent variable	B	95% CI	R (adj R)	F	p
Model 1: FinCDI-SF Receptive lexical development			0.43 (0.34)	4.85	**0.01***
Conversational turn count	12.45	1.91,22.99			**0.02***
Parental close contact	0.04	-0.03, 0.12			0.25
Gender	-18.77	-35.48, -2.06			**0.03***
Model 2: FinCDI-SF Expressive lexical development			0.25 (0.13)	2.06	0.14
Conversational turn count	2.80	-6.40, 12.00			0.53
Parental close contact	0.02	-0.05, 0.08			0.57
Gender	-15.47	-30.04, -0.89			**0.04***
Model 3: FinCSBS-ITC Symbolic Composite			0.44 (0.35)	4.79	**0.01***
Conversational turn count	1.19	0.09, 2.30			**0.04***
Parental close contact	0.00	-0.01, 0.01			0.68
Gender	-2.33	-4.11, -0.56			**0.01***
Model 4: FinCSBS-ITC Speech Composite			0.35 (0.25)	3.28	0.05†
Conversational turn count	0.45	-0.96,1.86			0.51
Parental close contact	0.01	-0.00, 0.02			0.08†
Gender	-2.54	-4.80, 0.27			**0.03***

† *p* <0.10 **p* <0.05, ** *p* <0.01, significant results are bolded

FinCDI-SF = the Finnish short form version of the Communicative Developmental Inventories; FinCSBS-ITC = the Finnish version of the Symbolic Behavior Scales, Developmental Profile, Infant-Toddler Checklist; Symbolic Composite = understanding of words, object use; Speech Composite = vocalizations, expressive words.

5 DISCUSSION

The main focus of the present dissertation was to investigate the role of language environment in the NICU on the early lexical abilities of very preterm children. The first main aim was to study the validity and usability of new methods in evaluating language environment and lexical processing of very preterm children. The second main aim was to study the longitudinal associations between language environment and parent-infant closeness in the NICU, and early lexical abilities of very preterm children. The main findings demonstrated that the LENA system provided valid estimates of female labels, and adult and female word counts when compared to human coder estimates. Further, the findings imply that the eye tracking-based lexical processing task provides usable and valid information on preterm children's early processing skills. The very preterm children's lexical processing at 18 months was associated with expressive lexical development. The findings on the longitudinal associations between the NICU language environment and parent-infant closeness, and later lexical abilities revealed that conversational turn and child vocalization counts, and parent-infant close contact were significantly and positively associated with the later lexical development of very preterm children. A high measure of adult word count was negatively associated with lexical processing correct looking time at 18 months.

5.1 Discussion of the main findings

5.1.1 Validity of the Language Environment Analysis system in the neonatal intensive care unit

The findings from the validity study demonstrated high agreement for female labels and adult and female word counts in both the Finnish and Estonian language contexts. The LENA system has previously been investigated in only one study in the Finnish language setting, with children aged 6-12 months (Elo, 2016). Additionally, LENA has been utilized in the Estonian language setting in one study, with children aged 3–4 years (Tulviste & Tamm, 2021). The current findings are in line with the findings from the previous Finnish study (Elo, 2016), and also from studies in other non-English languages (Bruyneel et al., 2021; Canault et al., 2016; Gilkerson et al., 2015; Schwarz et al., 2017). The adult word count is a core function of the LENA system (Gilkerson & Richards, 2020) and is found to be relatively robust across different samples, including samples of different dialects and language contexts (Cristia et al., 2021). Thus, the present findings also verify the usability of the LENA-provided estimates for adult word count in the less-studied Finnish and Estonian language settings.

The present study provided novel information on the LENA estimates from two different NICU contexts. Use of the LENA system in the Finnish and Estonian NICU settings has not previously been reported. Both units have an emphasis on family centered care. At the time of the recordings, most infants in the Turku unit stayed in single-family rooms and most infants in the Tallinn unit stayed in rooms with two children or more. The sound and language environments in different NICUs may vary. Single-family rooms may induce lower sound levels (Philbin, 2017; Pineda et al., 2017) and increased parental presence (Kainiemi et al., 2021; van Veenendaal et al., 2020), while rooms with several infants may imply more overlapping talk and noise (Rand & Lahav, 2014). Still, in the present study, the validity results for female labels and adult and female word counts were mainly equivalent for both units. Thus, the findings confirm the validity and usability of the LENA system as an instrument to measure adult word count in the Finnish and Estonian NICU settings. Further, the results propose that the LENA-provided adult word count measure is valid in both single-family and open-bay NICU units.

The present findings demonstrated lower agreement between LENA- and human coder-provided male labels and word counts than for adult word count. The present finding is in line with findings from the previous study utilizing the LENA system in the Finnish language context (Elo, 2016). The findings also correspond to the findings from the in-depth evaluation of the LENA system measures (Cristia et al., 2021). The evaluation reported a weaker accuracy for male adult measures than for the adult word count measures, and a tendency of the LENA system to confuse female and male labels (Cristia et al., 2021). In the present sample, it is also possible that the LENA system could not differentiate between some male and female voices due to different language-specific features in the Finnish and Estonian languages, compared with the features of the normative American-English sample, such as the speakers' use of a falling intonation towards the end of the sentences (Karlsson, 2008) or a lower voice frequency of female speakers (Leino et al., 2008). The agreement for male labels and word counts might also have been influenced by the smaller quantity of male speech in the current sample. To conclude, the findings from the present and previous studies (Cristia et al., 2021; Elo, 2016) indicate that the LENA adult word count is a more reliable measure than the LENA female and male word counts.

The correlation coefficient value expressing the agreements between LENA and a human coder for the conversational turn count in the Turku NICU was rather high (r = 0.73). However, total agreement (Turku and Tallinn) for the conversational turn count was considerably lower (r = 0.23), which is in line with findings from previous studies (Bruyneel et al., 2021). The LENA-measured conversational turn count was originally based on adult speech and vocalizations of children from 2 months of age (Gilkerson et al., 2017), which may have influenced the present agreement. The infant's ability to communicate and participate in interaction develops within the social context of attentive and responsive caregivers (Gratier & Devouche, 2017). In the NICU, the preterm infant's active participation in social interaction is in the very early stages of development and how the caregiver responds to the infant's signals is essential (Gratier & Devouche, 2017). Studies report that caregivers respond to newborn infants' protophones as precursors to speech and interact with them in a conversational way (Yoo et al., 2018), already in the NICU (Oller et al., 2019). Consequently, in the NICU context, the conversational turn count implies that the adult interprets the preterm infant's protophones and responds to them accordingly.

It is also possible that the validity of the conversational turn count may vary in different NICU environments and samples, depending on room type, noise, overlapping talk or the medical status of the infants. In the present sample, the agreement for the conversational turn count was lower in the Tallinn unit than in the Turku unit. In Tallinn the infants stayed in rooms with two infants or more, which may elicit more overlapping talk and noise (Rand & Lahav, 2014). Conversational turn count values from the NICU are scarcely reported (Best et al., 2018). Generally, more validity information on the LENA conversation turn count estimate is still required (Cristia et al., 2020; Cristia et al., 2021). However, whether the accuracy of a LENA system automatic measure can be considered adequate for a specific study depends on the objective of the study (Cristia et al., 2021). Taking this into account, the current findings suggest that the LENA-provided estimate for conversational turns can be used to estimate early conversational turn-taking in the NICU setting. This is relevant, because caregivers are found to frequently interact with preterm infants in a conversational way in the NICU (Oller et al., 2019), and in this context, the caregivers' responses are important.

Agreement between LENA and a human coder for key child labels and child vocalization count was low. The LENA system was originally normed for children between 2 and 48 months of age (Gilkerson & Richards, 2008; Gilkerson & Richards, 2020; Gilkerson et al., 2017). Thus, the low agreement can be explained by the difference in the features of the very preterm infants' vocalizations and the vocalizations of the older children in the normative sample of the LENA system. The present agreement was also lower than in previous research in the Finnish language context, where the participants were 6–12 months old, and thus, within the normative scope of the LENA system (Elo, 2016). LENA has been found to accurately estimate vocalizations of children that are older than the children in the norming sample (Cristia et al., 2021). However, the automatic estimations of the very early child vocalizations in the NICU are likely to be more challenging than estimating the vocalizations of older children. Studies from the NICU have reported that preterm infants are already starting to vocalize by producing protophones, i.e., vocants, squeals, and growls, at 32 weeks of gestational age (Caskey et al., 2011; Oller et al., 2019). Thus, in the NICU context, the LENA measured child vocalization count implies differentiating the infant's protophones from vegetative sounds or cries. In the NICU, the medical condition or care of the infant, such as incubation care, may also influence the vocalizations and the validity of the LENA estimates. More information on the validity of the LENA estimates of child vocalizations of very preterm infants in the NICU is needed.

In the present study, both LENA- and human coder-estimated numbers of child vocalizations were lower than in a previous study conducted in the NICU (Oller et al., 2019). The differences might be explained by differences in the sample selection, as the present study included and the previous study (Oller et al., 2019) excluded samples when the infants were asleep. Furthermore, the presence of the parents and parental speech (Caskey et al., 2011; Caskey & Vohr, 2013) and the use of infant-directed speech (Oller et al., 2019) in the recorded NICU environment might influence the number of infant vocalizations. To be noted, it might also be challenging for the LENA system and for the human coder to differentiate very preterm infants' early vocalizations from vegetative sounds.

The agreements between LENA and human coder estimates for silence labels varied between the two different measures (labels and counts) investigated and between the Turku and Tallinn units. The primary objective of the LENA system is to measure the language environment (Gilkerson et al., 2017). The system was originally developed to ensure the identification and differentiation of child vocalizations and adult words to provide feedback on adult behavior (Gilkerson & Richards, 2020) and the validity of the LENA estimates of silence are not widely described. Further, the validity of the silence measure is difficult to investigate because the LENA automatic measurement of silence probably differs from the human perception and measurement. The LENA system can automatically measure a brief duration of silence or pauses during speech (Gilkerson & Richards, 2020), which are challenging for a human coder to manually measure. However, because silence, noise, and electronics are elements of interest in the NICU sound environment, it is relevant to further investigate the LENA non-speaker labels and estimates of silence in NICU settings.

In conclusion, based on the findings, the advantage of the LENA system in the NICU context can be described as functioning as a non-intrusive and valid method to automatically measure the number of adult words during day long recordings. Further, the method provides valuable information on very early adult-infant conversational turn taking, in this context especially on adults' responses and interaction with early protophones or signals of the preterm infants. The limitations of the method in this context include the lower validity of infant vocalizations especially. Furthermore, because the LENA system provides information on mainly quantity aspects of language environment, non-verbal interaction elements and comprehensive quality aspects of early adult-infant interaction cannot not be investigated with this method.

5.1.2 The eye tracking-based lexical processing task and its associations to lexical development

The present study provides novel information on the usability and validity of an eye tracking-based lexical processing task, adapted to assess the lexical processing of Finnish-acquiring very preterm children. The individual variation in performance was broad, which corresponds to information on processing skills at 18 months (Fernald et al., 2006). Furthermore, the children exhibited a slightly longer reaction time than in previous studies with mainly full-term children (Egger et al., 2020), which might be related to the sample of preterm children, the task, or the target words used.

The preterm children that exhibited more efficient lexical processing at 18 months also showed stronger symbolic development at 12 months, and stronger expressive lexical or speech development at 15 and 18 months. According to previous research, the associations between the processing measures and other language measures, assessed with traditional methods, are the most convincing evidence of the validity of the processing assessment (Marchman & Fernald, 2013). Thus, the associations found in the present study indicate that the task can be a useful and potentially valid method for measuring the lexical processing of Finnish-acquiring very preterm children at 18 months.

This study provided information on the associations between very preterm children's lexical processing and prior lexical development at an earlier age than in previous studies (Loi et al., 2017; Marchman et al., 2019; Ramon-Casas et al., 2013). The lexical processing correct looking time was linked to symbolic skills at 12 months, expressive lexical skills at 15 months, and expressive lexical and speech development at 18 months. Thus, the associations suggest that lexical processing at 18 months was related to early lexical growth during the first part of the second year of life. Research has shown that full-term children with faster lexical growth during the second year of life exhibit more efficient processing at 25 months (Fernald et al., 2006). The present findings confirm similar patterns of associations in very preterm children. Further, because the FinCSBS-ITC Speech Composite also measures vocalizations and babbling, the current findings indicate that very preterm children's vocalizations at 12 months can be linked to later lexical processing. This is in line with the findings from a study in which preterm born (born between 23 and 34 gestational weeks) children's babbling was linked to later language outcomes (Stolt et al., 2012). However, the present finding still needs to be verified in future research.

The present study investigated both the reaction time (speed) and correct looking time (accuracy) of lexical processing, while many previous studies (Marchman et al., 2016; Marchman et al., 2019; Marchman & Fernald, 2008; Marchman et al., 2018; Peter et al., 2019) have focused on processing reaction time. Using the two different variables made it possible to obtain a versatile picture of the Finnish-acquiring very preterm children's processing skills. The findings on connections between processing reaction time and prior or concurrent expressive skills are consistent with research on full-term children (Fernald et al., 2006; Peter et al., 2019). Moreover, the findings are also comparable to findings on links between preterm children's processing and concurrent language development (Loi et al., 2017). The present study provides additional information on associations between processing and lexical development in very preterm children, suggesting that both reaction time and correct looking time were associated with prelinguistic and expressive lexical development at 12, 15 and 18 months.

In the linear regression analyses correct looking time was more significant than reaction time for explaining the expressive lexical development of very preterm children at 18 months. The reaction time values were derived from fewer trials, which might have influenced the results. In the linear regression model, correct looking time and gender explained a substantial percentage of expressive skills at 18 months. The findings, together with findings from a limited number of previous studies (Loi et al., 2017; Marchman et al., 2016; Marchman et al., 2019; Marchman et al., 2022), highlight the relevance of assessing early processing skills in very preterm children and demonstrate the importance of lexical processing in explaining expressive lexical development at 18 months. Furthermore, gender was a significant explaining variable in the regression models. The finding is in line with findings from some studies that have reported lower language scores for preterm boys than for preterm girls (Månsson et al., 2015; Sanchez et al., 2019; Sansavini, Guarini, Savini, et al., 2011).

The target words in the present study differed from the words used in previous processing tasks. The words in the present task included nouns, verbs, and an adjective, while most studies (Loi et al., 2017; Marchman et al., 2019; Marchman et al., 2018) on preterm children's processing have used only nouns as target words. Verb acquisition is a more demanding process than noun acquisition, and a lexicon containing more verbs is a sign of maturity (Hirsh-Pasek et al., 2006). Also, the target words included 3 difficult nouns, reported to be known by less than 60% of Finnish typically 18-months-old children (Stolt & Vehkavuori, 2018). Further, the present target words included vowel-initial words, three-syllable-long words, and words with diphthongs- typical characteristics of Finnish words (Karlsson, 1983, 2008).

Due to the characteristics of the target words the participants might have needed a longer time to process the words. This was taken into consideration by using a wider total time window in the correct looking time analyses than in previous research (Fernald et al., 2006; Loi et al., 2017; Marchman et al., 2019). Further, the total time window was divided into early and late time windows. The associations between lexical processing correct looking time and lexical development were evident during both time windows. In a previous study with full-term children at 12 months, differences in processing skills between children with small and large lexicons were found mainly during the early time window (Lany et al., 2018). The differences between findings might be related to the characteristics and age of the very preterm participants in the present study, differences in the processing tasks used, or language-specific issues.

Finally, some features might have positively influenced the accuracy of the present eye tracking-based processing task. The task utilized a large number of trials and an extended time window. Because the use of a large number of trials may improve the accuracy (Fernald & Marchman, 2012) and the use of a long time window may improve the reliability of the task (Zettersten et al., 2021), these factors might have had a positive impact on the validity of the task. Also, the use of unyoked pairs in the trials might have reduced the impact of image salience, which also might have improved the validity of the task.

5.1.3 Associations between language environment and parent-infant close contact in the neonatal intensive care unit, and lexical abilities of very preterm children

One of the main findings of the present dissertation was the positive associations between adult-infant conversational turn-taking in the NICU and very preterm children's later receptive lexical development. The conversational turn count is counted based on both adult words and child vocalizations and is more likely to contain infant-directed speech than the adult word count (Gilkerson et al., 2018; Wang et al., 2020). The current findings support previous findings and recommendations for sensitive and interactive talk in the NICU (Caskey et al., 2014; DeMaster et al., 2019; Kuhn et al., 2017; Rand & Lahav, 2014; Saliba et al., 2020). The findings are in line with the findings from the study by Caskey et al. (2014), which also reported positive correlations between conversational turn count in the NICU and later language scores of very preterm infants. However, the previous study did not include the conversational turn count variable in further analyses. The present findings are also consistent with findings from research on full-term children that reported stronger links between LENA-estimated conversational turn count and child language outcome than between adult word count and language outcome (Gilkerson et al., 2018; Wang et al., 2020; Zimmerman et al., 2009). However, the present study describes conversational turn-taking between adults and preterm infants at 32–33 gestational weeks of age. Thus, the study provides information from a very young age, a vulnerable group, and a sensitive context. As the LENA system may have challenges in identifying NICU child vocalizations, the child vocalization count may include some vegetative sounds as part of the conversational turn count. Still, it is plausible that caregiver responses to any early signals or sounds of the preterm infant may have a beneficial impact and should be encouraged.

The conversational turn count was positively associated with receptive lexical development. The finding differs from previous findings (Caskey et al., 2014), where the NICU conversational turn count measure at 32 gestational weeks of age was positively associated with language and expressive communication scores at 18 months. Different methods and outcome measures might have contributed to the divergence in findings. The present study provides information specifically on connections to lexical development rather than to general language abilities. During the first part of the second year of life the growth of the receptive lexicon is rapid, while the expressive words are just emerging (Stolt et al., 2008), which may explain the current associations to receptive lexical skills. Further, the individual variation in receptive lexical development during the first part of the second year of life is broad (Stolt et al., 2008), which may also contribute to the strength of the associations. Importantly, the association between conversational turn count and receptive lexical development is a significant finding, because early receptive skills especially are found to predict later language development in preterm children (Stolt et al., 2009; Stolt et al., 2016).

A novel finding of the present dissertation demonstrated that a high measure of adult word count near the infant in the NICU was linked to less correct looking time in the lexical processing task at 18 months. The results might be related to the auditory sensitivity of the preterm infant, described in previous research (Adam-Darque et al., 2020; Kuhn et al., 2017; McMahon et al., 2012). Preterm infants in the NICU react differently to familiar and unfamiliar voices (Kuhn et al., 2017) and different types of talk (Saliba et al., 2020). Due to medical care procedures, very preterm infants may experience a considerable amount of overheard talk. The infant might perceive simultaneous overheard talk as background noise, which might hinder the infant from distinguishing meaningful talk and might not enhance specific speech and language processing skills (Rand & Lahav, 2014). To my knowledge, connections between NICU language environmental factors and later lexical processing skills of very preterm children have not previously been described. Previous studies have mainly reported associations between language environment and processing skills during the second year of life (Adams et al., 2018; Weisleder & Fernald, 2013) or later in childhood (Romeo et al., 2018). Importantly, the present study provides information from a very early critical developmental stage. Thus, the present findings might not be comparable to findings from studies on older children.

Interestingly, in the present study, the adult word count measured in the NICU and processing correct looking time measured at 18 months of age were significantly and negatively associated, while adult word count was not significantly associated with processing reaction time. Differences in the associations between the adult word count measure in preterm children's environment and the processing reaction time and correct looking time (accuracy) values were also noted in a previous study, performed at a later age (Adams et al., 2018). However, associations between adult word count and processing skills during the second year of life may not be comparable to the associations between adult word count measured in the NICU near the preterm infant at 32–33 gestational weeks of age and later processing skills.

The adult word count near the very preterm child in the NICU was not associated with later lexical development. This finding differs from the findings of the previous study, which reported a positive association between the adult word count in an open bay NICU and language scores of very preterm children at 18 months (Caskey et al., 2014). Discrepancies in results may be related to the NICU unit, the prevailing amount or type of adult talk, or methods used to measure language development. In previous research, the adult word count has been associated with parental NICU presence (Caskey et al., 2011; Pineda et al., 2017) and holding (Pineda et al., 2017), which suggests an interrelation between the parental presence or parent-infant closeness, and adult talk. Still, in the present study, neither the adult word count nor the conversational turn counts were associated with the duration of parental presence or parent-infant closeness. The finding may be explained by the fact that all adult words near the child were included in the adult word count measure in the present study, as it was not possible to reliably separate parental speech from hospital staff speech. Thus, the present audio sample contains words uttered by both parents and hospital staff and reflects the preterm infant's actual available language environment in the NICU.

The child vocalization count measured in the NICU was positively and significantly associated with the children's later receptive and expressive lexical development at 15 months and receptive lexical development at 18 months of age. The findings are in line with described links between child vocalization count at 32 gestational weeks' age in the NICU and communication scores at 18 months (Caskey et al., 2014). Also, in a Finnish longitudinal study, the onset of babbling in preterm born (born between 23 and 34 gestational weeks) children was associated with language outcomes at 2 years of age (Stolt et al., 2012). Further, the predictive value of early vocalizations for later language skills was higher in the preterm than in the full-term group (Stolt et al., 2012). However, the present study provides information on the associations between very preterm children's protophones, i.e., very early vocalizations, estimated by the LENA in the NICU and specifically later lexical development, which have not previously been reported. However, the relatively low agreement between LENA and human coder estimates of child vocalizations in the present study needs to be taken into consideration when interpreting the present finding.

Parent-infant close contact in the NICU was positively associated with later lexical development of the preterm children. The duration of parental presence was not associated with the lexical development. Thus, the present findings suggest that the mere parental presence in the NICU might not be sufficient to support lexical development, but the close physical contact might be the significant factor. Adding skin-to-skin contact and holding values to a sum variable of close contact might have contributed to providing a coherent picture of the parent-infant close contact, as skin-to-skin contact has been found to decrease and the holding of the infant to increase during the first month of the preterm infant's life (Raiskila et al., 2017). The findings are in line with research describing the importance of physical parent-infant contact in the NICU (Flacking et al., 2012), and add information on longitudinal background factors of lexical development during the second year of life. Also, in the study by Lester et al. (2016), mother-infant kangaroo care showed stronger associations with language outcomes than other maternal involvement variables. Further, parent-preterm infant close contact is also likely to support early parent-infant interaction, which has been shown to be associated with later language development (Stolt, Korja, et al., 2014). The current findings may also represent general factors of parent-infant interaction, which may have continuously influenced the lexical development of the child during the follow-up period of the present study. Importantly, skin-to-skin contact may also represent a general aspect of parental involvement, which is a positive factor in the neurodevelopmental outcome of preterm children (Lester et al., 2016).

Several aspects of the fathers' involvement in the NICU were linked to later lexical abilities of very preterm children. Firstly, father-infant close contact was significantly and positively associated with later receptive lexical development. Secondly, the association between male word count in the NICU and the very preterm children's speech development and faster lexical processing reaction time at 18 months nearly reached statistical significance. Thirdly, the duration of the father's presence in the NICU was significantly associated with a faster lexical processing reaction time of the child at 18 months. Thus, the present findings add novel and important longitudinal information to previous research (Filippa et al., 2021) on the benefits of fathers' involvement in the NICU. Further, the findings indicate the importance of the fathers' talk in the NICU, which verifies findings from previous research (Saliba et al., 2020). Because parent-infant closeness in the NICU may reflect involvement and sensitivity, the present findings may suggest that the child benefits from the support of two involved and sensitive parents, which might have contributed to the longitudinal positive associations between father-infant close contact and lexical development in the present study. This is in line with research describing the importance of involvement (Lester et al., 2016) and sensitivity (Landry et al., 1997) for language outcomes. Paternal involvement is also reported to support the parental relationship (Filippa et al., 2021) and positively impact the well-being of the mother and the child (Treyvaud, 2013; Yogman & Garfield, 2016).

In the present study, both language environmental and parent-infant closeness factors were associated with the later lexical abilities of the very preterm children. The study provides information from a NICU unit with family-centered care practices and single-family room architecture, and very preterm children's early lexical abilities. In the present sample, the mean values of both adult word and conversational turn counts were higher than in a previous study performed in an open bay NICU unit (Caskey et al., 2011), which might be related to NICU or parental involvement factors. Further, the values in the present study included talk from both parents and hospital staff. The lexical development of very preterm children is a complex process influenced by different coexisting factors. To be noted, the very preterm infants' gestational age at birth or birth weight were not statistically significantly associated with lexical developmental values, which might be related to the present sample of very preterm children.

5.2 Strengths and limitations

The strengths of the dissertation include the evaluation of new instruments for the preterm population, which was necessary to be able to investigate the language environment and the lexical processing of the very preterm children in the study. Firstly, the study provides novel validity information on the LENA system in the NICU environment by analyzing both labels and counts from two less-studied language contexts in two different countries. The study also provides information on the conversational turn count, which is a less-studied LENA variable from the NICU context (Best et al., 2018). The LENA system has limitations on its capabilities but can still be considered an established method for representative day long investigations of children's natural language environment. Secondly, the study brings novel firsthand knowledge on assessing lexical processing of Finnish-acquiring very preterm children at 18 months using an eye tracking technology-based lexical processing task, an adaptation not previously described. Using this method, associations between lexical processing and both prior and concurrent receptive and expressive lexical development were investigated. Thirdly, two different validated and normed screening methods were used to assess lexical and language development of very preterm children providing data from an early stage of lexical development.

The present study provides data, collected within the scope of everyday NICU practice, from the Turku University Hospital NICU, a unit with an emphasis on family-centered care in a single-family room architecture (Ahlqvist-Björkroth et al., 2017; He et al., 2021; Kainiemi et al., 2021). The present study concurrently investigated both the language environment and parent-infant closeness, which is a strength of the study. Further, the closeness variables included father-infant closeness, which is a significant but less-studied NICU factor (Filippa et al., 2021).

The study explored the associations between NICU language environment and later lexical processing of very preterm children, connections not previously described. Further, the study provides novel information on the longitudinal associations between language environment and parent-infant closeness and preterm children's later lexical development during a reasonably long follow-up period, which is also a strength of the study.

The following limitations related to the methods used or the data collected can be identified. In the LENA validation study, larger samples with a variety of speech would have provided more in-depth validity information. Still, the correlation coefficient values expressing the agreement were high, suggesting that the sample size was sufficient for the present purpose. Further, the present study investigated both labels and counts, which provided additional validity information. Multiple factors related to the infant, the parents, or hospital routines may have influenced the LENA recordings and, thus, the data obtained from the two different NICUs. As an example, the infants' gestational weeks of age or respiratory support at the recording day and during the period of parent-infant closeness documentation varied. Further, most of the recordings started early in the morning, but a few recordings started later. Because different care procedures or daily routines may elicit different types and amounts of adult talk, the slightly different recording times might potentially have had an impact on the results. The recorded LENA data included both parental and hospital staff talk, and therefore the specific effects of parental talk could not be explored.

In the eye tracking-based lexical processing task, not all trials supplied valid data. Some of the data attrition was related to the challenges of maintaining the young children's correct position and attention on the task while measuring the eye movements. Further, because the reaction time values were analyzed only from the distracter initial trials, these values were based on a smaller number of trials than the correct looking time values. On the other hand, the considerable number of trials that need to be discarded is a well-known limitation of the looking-while-listening paradigm (Egger et al., 2020). Also, it is important to note that the instruments utilized to assess lexical development were screening tools and were not intended to offer a comprehensive or detailed assessment of the very preterm child's vocabulary.

Other potential limits are related to the sample and the follow-up period. Even if a considerable group of very preterm children could be followed during the follow-up period, the sample sizes in the studies are relatively small. Data could not be gathered from all the participants at all collection points or with all methods, which might have impacted the results. The study did not have a control group of full-term children. However, the participants' lexical development could be evaluated based on the norms of the validated screening methods, as the preterm children's lexical developmental values were compared to the normative values of the methods. Nevertheless, a comparison group of full-term children would have provided additional information. Finally, the study provides information on the longitudinal associations between the NICU measures and very preterm children's lexical abilities only up to 18 months of corrected age. The findings need to be confirmed in future research with larger samples and at a later age.

5.3 Clinical implications

The validity information retrieved from the present study, together with information from previous research (Caskey et al., 2011, 2014; Caskey & Vohr, 2013), indicate that the LENA system is a useful instrument to investigate adult talk in different NICU settings. The present findings show that the LENA system can also be reliable in the Finnish and Estonian languages and NICU settings. The LENA-provided information can be applied in the NICU context when investigating the type or the amount of adult talk, providing information and feedback to parents, and evaluating intervention programs or changes in the environment. Investigating and striving to modify environmental factors to optimize the outcome of at-risk infants is following the International Classification of Functioning, Disability and Health framework, an established model to describe factors influencing health-related outcomes (World Health Organization, 2007).

The present study provides information on new methods of assessing the emerging lexical abilities of very preterm children. The eye tracking-based lexical processing tasks have the potential to contribute to finding the individuals who need early follow-up and support for language development. Further, the task can provide additional information on emerging early receptive skills and thus complement other lexical measures. Lexical processing skills are more critical for children with small vocabularies (Peter et al., 2019) or difficulties in word learning (Lany, 2018), which is relevant in the at-risk group of very preterm children. The eye tracking-based task may be especially useful and potentially important in assessing the early lexical processing of children with challenges in participating in clinical testing situations, due to motor or social interaction challenges (see Loi et al., 2017; Valleau et al., 2018), impairments that are also frequent in preterm children (Dudova et al., 2014; Ritchie et al., 2015; Sanchez et al., 2019; Sansavini, Guarini, & Caselli, 2011). However, the psychometric quality of the task needs to be thoroughly examined before it can be used in a clinical context.

The findings from the present dissertation demonstrated the potential of the screening methods to provide information on the lexical development of very preterm children during the first part of the second year of life. The two methods evaluated different features of early lexical and language development and showed partly different associations to lexical processing skills, language environment, and parent-infant close contact. Thus, the methods may complement each other in clinical use. Nonetheless, the predictive value of the screening methods in this specific population needs to be further evaluated. Further, the findings highlight the relevance of assessing both lexical processing and lexical developmental skills during the second year of life in this at-risk group of children. Deficits in both lexical processing and development are likely to influence the daily functioning of the child (Marchman & Fernald, 2013), and weak processing skills will probably burden both understanding and communication.

As a novel and clinically relevant finding, the results indicate that a large number of adult words near the infant might not support later lexical processing. Medical procedures are frequently needed in the NICU, but the present findings suggest that protective strategies could possibly include considering the amount and the duration of adult-directed discussions in the infant's absolute proximity. The new-born preterm infant is auditorily sensitive (Adam-Darque et al., 2020; Kuhn et al., 2017; McMahon et al., 2012). Regulating simultaneous adult-directed talk near the infant might aid the infant in distinguishing meaningful parental or caregiver talk, which are significant factors for auditory development (Graven & Browne, 2008). Importantly, the recordings of the present study contained both parental and hospital staff talk, which might have influenced the current results.

The findings suggest that adult-child conversational turn-taking is beneficial for the lexical development of very preterm children, which is clinically applicable when instructing parents and NICU staff on how to communicate with the infant and when planning NICU guidelines or intervention procedures. The findings of the present study support current recommendations for interactive sensitive talk (Caskey et al., 2014; DeMaster et al., 2019; Kuhn et al., 2017; Rand & Lahav, 2014; Saliba et al., 2020), as also being advantageous for very preterm children's lexical development. Caregivers of children at risk for language impairments benefit from guidance on how to use sensitive and enriching infant-directed speech to support the language development of their children (Bang et al., 2020). Thus, neonatal nurses have an important role in describing and demonstrating the importance of early interaction (Romeo et al., 2022), encouraging parents to engage in interactive talk with their preterm infant and also sensitively communicating with the infant when the parents cannot be present in the NICU (Newnam & Muñoz, 2021). As early parental experiences in the NICU may shape later parenting (Lester et al., 2016), early parental experiences from parent-infant interaction may shape later parental interaction styles.

The present findings add clinically applicable information on the longitudinal associations between parent-infant close contact in the NICU and the child's later lexical development. The findings emphasize the importance of both parents' close contact with the infant in addition to being present in the NICU. Because it can be more difficult for fathers than for mothers to engage in skin-to-skin contact with the preterm infant (He et al., 2021), the fathers may need additional support and information on the benefits of paternal engagement, which might contribute to increased father-infant close contact and involvement. Furthermore, gender was the most significant background factor for explaining receptive lexical development. Thus, in addition to underlining the significance of involving fathers, the findings also highlight the significance of supporting the early lexical development of boys.

Because the findings from the present study imply that both adult-infant conversational turn-taking and parent-infant close contact are beneficial for the child's lexical development, the findings support strategies that combine factors of both parent-infant communication and closeness to a multimodal experience (Filippa, 2017; Filippa & Kuhn, 2017; Philbin, 2017). In the present study, adult-infant conversational turn-taking was positively associated with especially receptive lexical skills measured with the FinCDI-SF at 18 months, while parent-infant close contact was associated with both receptive lexical and speech skills measured with both screening methods at 18 months. Thus, theoretically, supporting both adult-infant conversational turn-taking and parent-infant close contact to form a multimodal whole could potentially enhance both the receptive and expressive development of very preterm children. However, if the medical condition of the infant does not permit skin-to-skin care or holding, the caregiver can still sensitively engage in verbal interaction with the infant (see Provenzi et al., 2018).

5.4 Future perspectives

For future clinical use, the eye tracking-based lexical processing task needs to be further developed and the sensitivity and reliability properties in samples of both full-term and preterm children evaluated. For an in-depth evaluation of the validity of the task, the effects of different target words need to be explored and trial-level results need to be examined. Additionally, more information on the causal relationships between lexical processing and different aspects of lexical and language development is necessary.

This study generates new topics that need to be investigated thoroughly, such as the effects of the language environment in the NICU on later lexical processing, which is an understudied subject. Because new-born preterm infants are auditory sensitive during the period of NICU care (Adam-Darque et al., 2020; Kuhn et al., 2017; McMahon et al., 2012), and exhibit an elevated risk for later processing (Marchman et al., 2019; Ramon-Casas et al., 2013) and language (Barre et al., 2011; van Noort-van der Spek et al., 2012; Vohr, 2014) difficulties, this is a highly relevant research area.

The present findings indicate that preterm children benefit from adult-infant conversational turn-taking and sensitive interactive adult talk in the NICU. Already available strategies developed to support early parent-infant communication can potentially be adapted in this very early stage of communication and language acquisition. Speech and language pathologists may have a significant role as a part of the multi-professional team of neonatal therapists and the preterm infant's family in targeting parent-infant interaction and communication in the NICU. A study conducted in a US unit reported that the intervention provided by the speech and language pathologists in the NICU typically focuses on oral feeding and oral motor development, but also includes team and parent involvement (Ross et al., 2017). Future research could investigate the optimal timing and features, and possible effects, of intervention programs commencing in the NICU (see Gilkerson et al., 2017; Mayne et al., 2022; Ross et al., 2017; Vohr, 2014) and the role of speech and language pathologists in supporting very early parent-preterm infant interaction and communication.

In the present study, both parental talk and hospital staff talk were included in the language environmental measurements. Future research could investigate the specific associations between parental speech and language outcomes. Furthermore, the language environmental and lexical development measurements could be repeated at a later age point to gather information on the long-term stability of the associations between language environment and lexical development in preterm children. In future research, it will also be important to verify the current findings on the associations between language environment and parent-infant close contact, and very preterm children's lexical abilities in larger samples.

6 CONCLUSIONS

The focus of the present dissertation was to investigate the role of language environment on later lexical abilities of very preterm children. The first main aim was to investigate the validity of the LENA system in the NICU and to study the lexical processing of preterm children. The second main aim was to investigate the longitudinal associations between language environment and parent-infant closeness in the NICU, and very preterm children's lexical abilities during the second year of life. The main findings show that the LENA system provides valid information from the NICU, especially on adult word count. More validity information, especially on the child vocalization count, is needed. The findings also suggest that the eye tracking based lexical processing task, modified for Finnish-acquiring children, is a promising method to provide useful information on very preterm children's lexical processing at 18 months of corrected age. Nonetheless, the task needs to be further developed and evaluated. Further, the findings suggest that very preterm children's lexical processing at 18 months was linked to prelinguistic and expressive lexical development.

The main findings also revealed that a large number of adult words spoken near the infant in the NICU was negatively associated with lexical processing accuracy at 18 months. Further, adult-infant conversational turn-taking and parent-infant close contact in the NICU were positively associated with later lexical abilities of very preterm children. The findings also underline the importance of both mother-infant and father-infant close contact in the NICU. The associations might be connected to general factors of parent-infant interaction or closeness, which are already evident in the NICU and continuously affect the lexical development of the children after discharge from the NICU and during the follow-up period. Still, the findings indicate that significant features can be detected and supported already in the NICU. The early language development of very preterm children is influenced by multiple factors. The present dissertation highlights the connections between NICU language environment and parent-infant close contact at 32–33 gestational weeks of age and later lexical abilities of very preterm children.

To summarize, adult-child conversational turn-taking and parent-infant close contact in the NICU can be recommended as beneficial for the very preterm child's later lexical development. Further, the findings imply that the amount of overheard adult-directed talk near the infant in the NICU should be considered. Future research is needed to verify the findings and to further explore the associations between NICU environment and closeness factors and language outcome in larger samples of preterm children and at a later age.

REFERENCES

Adam-Darque, A., Pittet, M. P., Grouiller, F., Rihs, T. A., Leuchter, R. H., Lazeyras, F., Michel, C. M., & Hüppi, P. S. (2020). Neural Correlates of Voice Perception in Newborns and the Influence of Preterm Birth. *Cerebral Cortex*, *30*(11), 5717-5730. https://doi.org/10.1093/cercor/bhaa144

Adams, K. A., Marchman, V. A., Loi, E. C., Ashland, M. D., Fernald, A., & Feldman, H. M. (2018). Caregiver Talk and Medical Risk as Predictors of Language Outcomes in Full Term and Preterm Toddlers. *Child Development*, *89*(5), 1674-1690. https://doi.org/10.1111/cdev.12818

Ahlqvist-Björkroth, S., Boukydis, Z., Axelin, A. M., & Lehtonen, L. (2017). Close Collaboration with Parents™ intervention to improve parents' psychological well-being and child development: Description of the intervention and study protocol. *Behavioural brain research*, *325*(Pt B), 303-310. https://doi.org/10.1016/j.bbr.2016.10.020

APPLE Study. (2021). *APPLE Research*. https://sites.utu.fi/apple/en/research-group/

Axelin, A., Raiskila, S., & Lehtonen, L. (2020). The Development of Data Collection Tools to Measure Parent–Infant Closeness and Family-Centered Care in NICUs. *Worldviews on Evidence-Based Nursing*, *17*(6), 448-456. https://doi.org/https://doi.org/10.1111/wvn.12475

Bang, J. Y., Adiao, A. S., Marchman, V. A., & Feldman, H. M. (2020). Language nutrition for language health in children with disorders: a scoping review. *Pediatric Research*, *87*(2), 300-308. https://doi.org/10.1038/s41390-019-0551-0

Barras, C., Geoffrois, E., Wu, Z., & Liberman, M. (2001). Transcriber: Development and use of a tool for assisting speech corpora production. *Speech Communication*, *33*(1), 5–22. https://doi.org/https://doi.org/10.1016/S0167-6393(00)00067-4

Barre, N., Morgan, A., Doyle, L. W., & Anderson, P. J. (2011). Language abilities in children who were very preterm and/or very low birth weight: a meta-analysis. *The Journal of Pediatrics*, *158*(5), 766–774. https://doi.org/10.1016/j.jpeds.2010.10.032

Beranova, S., Stoklasa, J., Dudova, I., Markova, D., Kasparova, M., Zemankova, J., Urbanek, T., Talasek, T., Luukka, P., & Hrdlicka, M. (2017). A possible role of the Infant/Toddler Sensory Profile in screening for autism: a proof-of-concept study in the specific sample of prematurely born children with birth weights <1,500 g. *Neuropsychiatric disease and treatment*, *13*, 191-200. https://doi.org/10.2147/NDT.S123066

Bergelson, E., & Swingley, D. (2012). At 6–9 months, human infants know the meanings of many common nouns. *Proceedings of the National Academy of Sciences - PNAS*, *109*(9), 3253-3258. https://doi.org/10.1073/pnas.1113380109

Best, K., Bogossian, F., & New, K. (2018). Language Exposure of Preterm Infants in the Neonatal Unit: A Systematic Review. *Neonatology*, *114*(3), 261-276. https://doi.org/10.1159/000489600

Bilgin, A., & Wolke, D. (2015). Maternal Sensitivity in Parenting Preterm Children: A Meta-analysis. *Pediatrics (Evanston)*, *136*(1), e177-e193. https://doi.org/10.1542/peds.2014-3570

Bornstein, M. H., Hahn, C.-S., & Putnick, D. L. (2016). Stability of core language skill across the first decade of life in children at biological and social risk. *Journal of child psychology and psychiatry*, *57*(12), 1434-1443. https://doi.org/10.1111/jcpp.12632

Bredin-Oja, S. L., Fielding, H., Fleming, K. K., & Warren, S. F. (2018). Clinician vs. Machine: Estimating Vocalizations Rates in Young Children With Developmental Disorders. *American journal of speech-language pathology*, *27*(3), 1066-1072. https://doi.org/10.1044/2018_AJSLP-17-0016

Bruyneel, E., Demurie, E., Boterberg, S., Warreyn, P., & Roeyers, H. (2021). Validation of the Language ENvironment Analysis (LENA) system for Dutch. *Journal of Child Language*, *48*(4), 765-791. https://doi.org/10.1017/S0305000920000525

Canault, M., Le Normand, M. T., Foudil, S., Loundon, N., & Thai-Van, H. (2016). Reliability of the Language ENvironment Analysis system (LENA) in European French. *Behavior Research Methods*, *48*(3), 1109–1124. https://doi.org/10.3758/s13428-015-0634-8

Caskey, M., Stephens, B., Tucker, R., & Vohr, B. (2011). Importance of parent talk on the development of preterm infant vocalizations. *Pediatrics*, *128*(5), 910–916. https://doi.org/10.1542/peds.2011-0609

Caskey, M., Stephens, B., Tucker, R., & Vohr, B. (2014). Adult talk in the NICU with preterm infants and developmental outcomes. *Pediatrics*, *133*(3), e578–584. https://doi.org/10.1542/peds.2013-0104

Caskey, M., & Vohr, B. (2013). Assessing language and language environment of high-risk infants and children: a new approach. *Acta Paediatrica*, *102*(5), 451–461. https://doi.org/10.1111/apa.12195

Cattani, A., Bonifacio, S., Fertz, M., Iverson, J., Zocconi, E., & Caselli, C. (2009). Communicative and linguistic development in preterm children: a longitudinal study from 12 to 24 months. *International journal of language & communication disorders*, 1-17. https://doi.org/10.1080/13682820902818870

Cheong, J. L. Y., Burnett, A. C., Treyvaud, K., & Spittle, A. J. (2020). Early environment and long-term outcomes of preterm infants. *Journal of Neural Transmission*, *127*(1), 1-8. https://doi.org/10.1007/s00702-019-02121-w

Chow, V. Y., & Shellhaas, R. A. (2016). Acoustic environment profile of the neonatal intensive care unit: High ambient noise and limited language exposure. *Journal of Neonatal Nursing*, *22*(4), 159-162. https://doi.org/10.1016/j.jnn.2016.03.003

Clark, E. V. (2015). Lexical meaning. In E. Bavin & L. R. Naigles (Eds.), *The Cambridge Handbook of Child Language* (pp. 351-368). Cambridge University Press.

Cristia, A., Bulgarelli, F., & Bergelson, E. (2020). Accuracy of the Language Environment Analysis System Segmentation and Metrics: A Systematic Review. *Journal of Speech, Language, and Hearing Research*, *63*(4), 1093-1105. https://doi.org/10.1044/2020_JSLHR-19-00017

Cristia, A., Lavechin, M., Scaff, C., Soderstrom, M., Rowland, C., Räsänen, O., Bunce, J., & Bergelson, E. (2021). A thorough evaluation of the Language Environment Analysis (LENA) system. *Behavior Research Methods*, *53*(2), 467-486. https://doi.org/10.3758/s13428-020-01393-5

Curtin, S., & Archer, S. L. (2015). Speech perception. In E. L. Bavin & L. R. Naigles (Eds.), *The Cambridge Handbook of Child Language* (pp. 137-158). Cambridge University Press.

Curtin, S., & Hufnagle, D. (2009). Speech perception. In E. Bavin (Ed.), *The Cambridge handbook of child language* (pp. 107-124). Cambride University Press.

DeMaster, D., Bick, J., Johnson, U., Montroy, J. J., Landry, S., & Duncan, A. F. (2019). Nurturing the preterm infant brain: leveraging neuroplasticity to improve neurobehavioral outcomes. *Pediatric Research*, *85*(2), 166–175. https://doi.org/10.1038/s41390-018-0203-9

Donnelly, S., & Kidd, E. (2020). Individual differences in lexical processing efficiency and vocabulary in toddlers: A longitudinal investigation. *Journal of experimental child psychology*, *192*, 104781. https://doi.org/10.1016/j.jecp.2019.104781

Donnelly, S., & Kidd, E. (2021). The Longitudinal Relationship Between Conversational Turn-Taking and Vocabulary Growth in Early Language Development. *Child Development*, *92*(2), 609-625. https://doi.org/10.1111/cdev.13511

Dudova, I., Markova, D., Kasparova, M., Zemankova, J., Beranova, S., Urbanek, T., & Hrdlicka, M. (2014). Comparison of three screening tests for autism in preterm children with birth weights less than 1,500 grams. *Neuropsychiatric disease and treatment*, *10*, 2201-2208. https://doi.org/10.2147/NDT.S72921

Egger, J., Rowland, C. F., & Bergmann, C. (2020). Improving the robustness of infant lexical processing speed measures. *Behavior Research Methods*, *52*(5), 2188-2201. https://doi.org/10.3758/s13428-020-01385-5

Elo, H. (2016). *Acquiring Language as a Twin : Twin children´s early health, social environment and emerging language skills* [Doctoral dissertation, University of Tampere]. Tampere University Press. http://urn.fi/URN:ISBN:978-952-03-0296-2

Feldman, H. M., Dale, P. S., Campbell, T. F., Colborn, D. K., Kurs-Lasky, M., Rockette, H. E., & Paradise, J. L. (2005). Concurrent and predictive validity of parent reports of child language at ages 2 and 3 years. *Child Development*, *76*(4), 856-868. https://doi.org/10.1111/j.1467-8624.2005.00882.x

Feldman, H. M., Dollaghan, C. A., Feldman, H. M., Dollaghan, C. A., Campbell, T. F., Kurs-Lasky, M., Janosky, J. E., & Paradise, J. L. (2000). Measurement properties of the MacArthur communicative development inventories at ages one and two years. *Child Development*, *71*(2), 310-322. https://doi.org/10.1111/1467-8624.00146

Fenson, L. (2007). *MacArthur-Bates Communicative Development Inventories : user's guide and technical manual* (2nd ed.). Paul H. Brookes Pub. Co.

Fenson, L., Dale, P., Reznick, J., Bates, E., Thal, D., & Pethick, S. (1994). Variability in Early Communicative Development. In *Mongraphs of the Society for Research in Child Development* (Vol. 242).

Fenson, L., Pethick, S., Renda, C., Cox, J. L., Dale, P. S., & Reznick, J. S. (2000). Short-form versions of the MacArthur Communicative Development Inventories. *Applied Psycholinguistics*, *21*(1), 95-116. https://doi.org/10.1017/S0142716400001053

Fernald, A., & Marchman, V. A. (2012). Individual differences in lexical processing at 18 months predict vocabulary growth in typically developing and late-talking toddlers. *Child Development*, *83*(1), 203-222. https://doi.org/10.1111/j.1467-8624.2011.01692.x

Fernald, A., Perfors, A., & Marchman, V. A. (2006). Picking up speed in understanding: Speech processing efficiency and vocabulary growth across the 2nd year. *Developmental psychology*, *42*(1), 98-116. https://doi.org/10.1037/0012-1649.42.1.98

Fernald, A., Pinto, J. P., Swingley, D., Weinberg, A., & McRoberts, G. W. (1998). Rapid Gains in Speed of Verbal Processing by Infants in the 2nd Year. *Psychological Science*, *9*(3), 228-231. https://doi.org/10.1111/1467-9280.00044

Fernald, A., Swingley, D., & Pinto, J. P. (2001). When half a word is enough: infants can recognize spoken words using partial phonetic information. *Child Development*, *72*(4), 1003-1015. https://doi.org/10.1111/1467-8624.00331

Fernald, A., Thorpe, K., & Marchman, V. A. (2010). Blue car, red car: Developing efficiency in online interpretation of adjective-noun phrases. *Cognitive Psychology*, *60*(3), 190-217. https://doi.org/10.1016/j.cogpsych.2009.12.002

Fernald, A., Zangl, R., Portillo, A. L., & Marchman, V. A. (2008). Looking while listening: Using eye movements to monitor spoken language. In I. A. Sekerina, E. M. Fernandez, & H. Clahsen (Eds.), *Developmental psycholinqustics: On-line methods in children's language processing* (pp. 97-135). John Benjamins.

Filippa, M. (2017). Early Vocal Contact: Direct Talking and Singing to Preterm Infants in the NICU. In M. Filippa, P. Kuhn, & B. Westrup (Eds.), *Early Vocal Contact and Preterm Infant Brain Development : Bridging the Gaps Between Research and Practice* (pp. 133-150). Springer International Publishing. https://doi.org/10.1007/978-3-319-65077-7_8

Filippa, M., Devouche, E., Arioni, C., Imberty, M., & Gratier, M. (2013). Live maternal speech and singing have beneficial effects on hospitalized preterm infants. *Acta Paediatrica*, *102*(10), 1017-1020. https://doi.org/10.1111/apa.12356

Filippa, M., & Kuhn, P. (2017). Support of Language and Communication Development as a Rationale for Early Maternal Vocal Contact with Preterm Infants. In M. Filippa, P. Kuhn, & B. Westrup (Eds.), *Early Vocal Contact and Preterm Infant Brain Development : Bridging the Gaps Between Research and Practice* (pp. 165-182). Springer International Publishing. https://doi.org/10.1007/978-3-319-65077-7_10

Filippa, M., Panza, C., Ferrari, F., Frassoldati, R., Kuhn, P., Balduzzi, S., & D'Amico, R. (2017). Systematic review of maternal voice interventions demonstrates increased stability in preterm infants. *Acta Paediatrica*, *106*(8), 1220-1229. https://doi.org/10.1111/apa.13832

Filippa, M., Saliba, S., Esseily, R., Gratier, M., Grandjean, D., & Kuhn, P. (2021). Systematic review shows the benefits of involving the fathers of preterm infants in early interventions in neonatal intensive care units. *Acta Paediatrica*, *110*(9), 2509-2520. https://doi.org/10.1111/apa.15961

Flacking, R., Lehtonen, L., Thomson, G., Axelin, A., Ahlqvist, S., Moran, V. H., Ewald, U., Dykes, F., Separation, & Closeness Experiences in the Neonatal Environment, g. (2012). Closeness and separation in neonatal intensive care. *Acta Paediatrica*, *101*(10), 1032–1037. https://doi.org/10.1111/j.1651-2227.2012.02787.x

Foster-Cohen, S., Edgin, J. O., Champion, P. R., & Woodward, L. J. (2007). Early delayed language development in very preterm infants: evidence from the MacArthur-Bates CDI. *Journal of Child Language*, *34*(3), 655-675. https://doi.org/10.1017/s0305000907008070

Foster-Cohen, S. H., Friesen, M. D., Champion, P. R., & Woodward, L. J. (2010). High Prevalence/Low Severity Language Delay in Preschool Children Born Very Preterm. *Journal of developmental and behavioral pediatrics*, *31*(8), 658-667. https://doi.org/10.1097/DBP.0b013e3181e5ab7e

Ganek, H., & Eriks-Brophy, A. (2018a). A Concise Protocol for the Validation of Language ENvironment Analysis (LENA) Conversational Turn Counts in Vietnamese. *Communication Disorders Quarterly*, *39*(2), 371–380. https://doi.org/10.1177/1525740117705094

Ganek, H., & Eriks-Brophy, A. (2018b). Language ENvironment analysis (LENA) system investigation of day long recordings in children: A literature review. *Journal of Communication Disorders*, *72*, 77–85. https://doi.org/10.1016/j.jcomdis.2017.12.005

Gayraud, F., & Kern, S. (2007). Influence of preterm birth on early lexical and grammatical acquisition. *First Language*, *27*(2), 159-173. https://doi.org/10.1177/0142723706075790

Gilkerson, J., Coulter, K. K., & Richards, J. A. (2008). *Transcriptional Analyses of the LENA Natural Language Corpus (Technical report LTR-06-2).* LENA Foundation.

Gilkerson, J., & Richards, A. J. (2008). *The LENA Natural Language study (Technical report LTR-02-02).* LENA Foundation.

Gilkerson, J., & Richards, A. J. (2020). *A Guide to Understanding the Design and Purpose of the LENA® System (Technical Report LTR-12).* LENA Foundation.

Gilkerson, J., Richards, J. A., Warren, S. F., Montgomery, J. K., Greenwood, C. R., Kimbrough Oller, D., Hansen, J. H. L., & Paul, T. D. (2017). Mapping the Early Language Environment Using All-Day Recordings and Automated Analysis. *American journal of speech-language pathology*, *26*(2), 248–265. https://doi.org/10.1044/2016_AJSLP-15-0169

Gilkerson, J., Richards, J. A., Warren, S. F., Oller, D. K., Russo, R., & Vohr, B. (2018). Language Experience in the Second Year of Life Predicts Language Outcomes in Late Childhood. *Pediatrics (Evanston)*, *142*(4). https://doi.org/10.1542/peds.2017-4276

Gilkerson, J., Zhang, Y., Xu, D., Richards, J. A., Xu, X., Jiang, F., Harnsberger, J., & Topping, K. (2015). Evaluating language environment analysis system performance for Chinese: a pilot study in Shanghai. *Journal of Speech, Language, and Hearing Research*, *58*(2), 445–452. https://doi.org/10.1044/2015_JSLHR-L-14-0014

Gonya, J., Ray, W. C., Rumpf, R. W., & Brock, G. (2017). Investigating skin-to-skin care patterns with extremely preterm infants in the NICU and their effect on early cognitive and communication performance: a retrospective cohort study. *BMJ Open*, *7*(3), e012985. https://doi.org/10.1136/bmjopen-2016-012985

Gratier, M., & Devouche, E. (2017). The Development of Infant Participation in Communication. In M. Filippa, P. Kuhn, & B. Westrup (Eds.), *Early Vocal Contact and Preterm Infant Brain Development : Bridging the Gaps Between Research and Practice* (pp. 55-69). Springer International Publishing. https://doi.org/10.1007/978-3-319-65077-7_4

Graven, S. N., & Browne, J. V. (2008). Auditory Development in the Fetus and Infant. *Newborn and infant nursing reviews*, *8*(4), 187-193. https://doi.org/10.1053/j.nainr.2008.10.010

Hayes, A. F., & Krippendorff, K. (2007). Answering the Call for a Standard Reliability Measure for Coding Data. *Communication Methods and Measures*, *1*(1), 77–89. https://doi.org/10.1080/19312450709336664

He, F. B., Axelin, A., Ahlqvist-Bjorkroth, S., Raiskila, S., Loyttyniemi, E., & Lehtonen, L. (2021). Effectiveness of the Close Collaboration with Parents intervention on parent-infant closeness in NICU. *BMC Pediatrics*, *21*(1), 28. https://doi.org/10.1186/s12887-020-02474-2

Head Zauche, L., Darcy Mahoney, A. E., Thul, T. A., Zauche, M. S., Weldon, A. B., & Stapel-Wax, J. L. (2017). The Power of Language Nutrition for Children's Brain Development, Health, and Future Academic Achievement. *Journal of Pediatric Health Care*, *31*(4), 493-503. https://doi.org/10.1016/j.pedhc.2017.01.007

Hirsh-Pasek, K., Michnick Golinkoff, R., & Golinkoff, R. M. (2006). *Action Meets Word : How Children Learn Verbs*. Oxford University Press, Incorporated.

Jansson-Verkasalo, E., Čeponien≐, R., Valkama, M., Vainionpää, L., Laitakari, K., Alku, P., Suominen, K., & Näätänen, R. (2003). Deficient speech-sound processing, as shown by the electrophysiologic brain mismatch negativity response, and naming ability in prematurely born children. *Neuroscience letters*, *348*(1), 5-8. https://doi.org/10.1016/S0304-3940(03)00641-4

Kainiemi, E., Hongisto, P., Lehtonen, L., Pape, B., & Axelin, A. (2021). Effects of single family room architecture on parent–infant closeness and family centered care in neonatal environments—a single-center pre–post study. *Journal of Perinatology*, *41*(9), 2244-2251. https://doi.org/10.1038/s41372-021-01137-z

Karlsson, F. (1983). *Suomen kielen äänne- ja muotorakenne*. Werner Söderström.

Karlsson, F. (2008). *Finnish. An Essential Grammar.* Routledge.

Kisilevsky, B. S., Hains, S. M., Brown, C. A., Lee, C. T., Cowperthwaite, B., Stutzman, S. S., Swansburg, M. L., Lee, K., Xie, X., Huang, H., Ye, H. H., Zhang, K., & Wang, Z. (2009). Fetal sensitivity to properties of maternal speech and language. *Infant behavior & development*, *32*(1), 59-71. https://doi.org/10.1016/j.infbeh.2008.10.002

Kiuru, S., Heino, A., & Gissler, M. (2022). *Perinataalitilasto–synnyttäjät, synnytykset ja vastasyntyneet 2021* (41/2022). Finnish institute for health and welfare. https://

www.julkari.fi/bitstream/handle/10024/145615/Perinataalitilasto%202021.pdf?sequence=5&isAllowed=y

Korja, R., Latva, R., & Lehtonen, L. (2012). The effects of preterm birth on mother-infant interaction and attachment during the infant's first two years. *Acta Obstetricia et Gynecologica Scandinavia*, *91*(2), 164-173. https://doi.org/10.1111/j.1600-0412.2011.01304.x

Kuhn, P., Dufour, A., & Zores, C. (2017). The Auditory Sensitivity of Preterm Infants Toward Their Atypical Auditory Environment in the NICU and Their Attraction to Human Voices. In M. Filippa, P. Kuhn, & B. Westrup (Eds.), *Early Vocal Contact and Preterm Infant Brain Development : Bridging the Gaps Between Research and Practice* (pp. 113-130). Springer International Publishing. https://doi.org/10.1007/978-3-319-65077-7_7

Laakso, M.-L., Eklund, K. M., & Poikkeus, A.-M. (2011). *Esikko-lapsen esikielellisen kommunikaation ja kielen ensikartoitus (The infant-toddler checklist of children's prelinqustic communication and language).* Niilo Mäki Instituutti.

Landry, S. H., Smith, K. E., Miller-Loncar, C. L., & Swank, P. R. (1997). Predicting Cognitive-Language and Social Growth Curves from Early Maternal Behaviors in Children at Varying Degrees of Biological Risk. *Developmental psychology*, *33*(6), 1040-1053. https://doi.org/10.1037//0012-1649.33.6.1040

Lany, J. (2018). Lexical-processing efficiency leverages novel word learning in infants and toddlers. *Developmental Science*, *21*(3), e12569. https://doi.org/10.1111/desc.12569

Lany, J., Giglio, M., & Oswald, M. (2018). Infants' Lexical Processing Efficiency is Related to Vocabulary Size by One Year of Age. *Infancy*, *23*(3), 342-366. https://doi.org/10.1111/infa.12228

Latva, R., Korja, R., Salmelin, R. K., Lehtonen, L., & Tamminen, T. (2008). How is maternal recollection of the birth experience related to the behavioral and emotional outcome of preterm infants? *Early Human Development*, *84*(9), 587-594. https://doi.org/10.1016/j.earlhumdev.2008.02.002

Law, J., & Roy, P. (2008). Parental Report of Infant Language Skills: A Review of the Development and Application of the Communicative Development Inventories. *Child & Adolescent Mental Health*, *13*(4), 198-206. https://doi.org/10.1111/j.1475-3588.2008.00503.x

Leino, T., Laukkanen, A.-M., Ilomäki, I., & Mäki, E. (2008). Assessment of Vocal Capacity of Finnish University Students. *Folia phoniatrica et logopaedica*, *60*(4), 199-209. https://doi.org/10.1159/000133651

LENA Foundation. (2015). *User Guide LENA Pro.* LENA Research Foundation.

LENA Foundation. (2019). *Tier 1 LENA Validation Guidelines [Unpublished work].*

Leppanen, J. M., Forssman, L., Kaatiala, J., Yrttiaho, S., & Wass, S. (2015). Widely applicable MATLAB routines for automated analysis of saccadic reaction times. *Behavior Research Methods*, *47*(2), 538-548. https://doi.org/10.3758/s13428-014-0473-z

Lester, B. M., Miller, R. J., Hawes, K., Salisbury, A., Bigsby, R., Sullivan, M. C., & Padbury, J. F. (2011). Infant Neurobehavioral Development. *Seminars in perinatology*, *35*(1), 8-19. https://doi.org/10.1053/j.semperi.2010.10.003

Lester, B. M., Salisbury, A. L., Hawes, K., Dansereau, L. M., Bigsby, R., Laptook, A., Taub, M., Lagasse, L. L., Vohr, B. R., & Padbury, J. F. (2016). 18-Month Follow-Up of Infants Cared for in a Single-Family Room Neonatal Intensive Care Unit. *The Journal of Pediatrics*, *177*, 84-89. https://doi.org/10.1016/j.jpeds.2016.06.069

Lewis, B. A., Singer, L. T., Fulton, S., Salvator, A., Short, E. J., Klein, N., & Baley, J. (2002). Speech and language outcomes of children with bronchopulmonary dysplasia. *Journal of Communication Disorders*, *35*(5), 393-406. https://doi.org/10.1016/S0021-9924(02)00085-0

Loi, E. C., Marchman, V. A., Fernald, A., & Feldman, H. M. (2017). Using Eye Movements to Assess Language Comprehension in Toddlers Born Preterm and Full Term. *The Journal of pediatrics*, *180*, 124-129. https://doi.org/10.1016/j.jpeds.2016.10.004

Lyytinen, P. (1999). *Varhaisen kommunikaation ja kielen kehityksen arviointimenetelmä*. Jyväskylän yliopiston Lapsitutkimuskeskus ja Niilo Mäki instituutti.

Marchman, V., & Fernald, A. (2013). Variability in Real-Time Spoken Language Processing in Typically Developing and Late-Talking Toddlers. In L. Rescorla & P. Dale (Eds.), *Late talkers*. Paul H. Brooks Publishing Co.

Marchman, V. A., Adams, K. A., Loi, E. C., Fernald, A., & Feldman, H. M. (2016). Early language processing efficiency predicts later receptive vocabulary outcomes in children born preterm. *Child Neuropsychology*, *22*(6), 649-665. https://doi.org/10.1080/09297049.2015.1038987

Marchman, V. A., Ashland, M. D., Loi, E. C., Adams, K. A., Fernald, A., & Feldman, H. M. (2019). Predictors of early vocabulary growth in children born preterm and full term: A study of processing speed and medical complications. *Child Neuropsychology*, *25*(7), 943-963. https://doi.org/10.1080/09297049.2019.1569608

Marchman, V. A., Ashland, M. D., Loi, E. C., Munevar, M., Shannon, K. A., Fernald, A., & Feldman, H. M. (2022). Associations between early efficiency in language processing and language and cognitive outcomes in children born full term and preterm: similarities and differences. *Child Neuropsychology*, 1-20. https://doi.org/10.1080/09297049.2022.2138304

Marchman, V. A., & Fernald, A. (2008). Speed of word recognition and vocabulary knowledge in infancy predict cognitive and language outcomes in later childhood. *Developmental Science*, *11*(3), F9-16. https://doi.org/10.1111/j.1467-7687.2008.00671.x

Marchman, V. A., Loi, E. C., Adams, K. A., Ashland, M., Fernald, A., & Feldman, H. M. (2018). Speed of Language Comprehension at 18 Months Old Predicts School-Relevant Outcomes at 54 Months Old in Children Born Preterm. *Journal of Developmental & Behavioral Pediatrics*, *39*(3), 246-253. https://doi.org/10.1097/dbp.0000000000000541

Mayne, J., McGowan, E. C., Chiem, A., Nwanne, O., Tucker, R., & Vohr, B. R. (2022). Randomised controlled trial of maternal infant-directed reading among hospitalised preterm infants. *Acta Paediatrica*, *111*(10), 1921-1932. https://doi.org/10.1111/apa.16445

McMahon, E., Wintermark, P., & Lahav, A. (2012). Auditory brain development in premature infants: the importance of early experience: McMahon et al. *Annals of the New York Academy of Sciences*, *1252*(1), 17-24. https://doi.org/10.1111/j.1749-6632.2012.06445.x

Mikkola, K., Ritari, N., Tommiska, V., Salokorpi, T., Lehtonen, L., Tammela, O., Paakkonen, L., Olsen, P., Korkman, M., Fellman, V., & Finnish, E. C. S. G. (2005). Neurodevelopmental Outcome at 5 Years of Age of a National Cohort of Extremely Low Birth Weight Infants Who Were Born in 1996-1997. *Pediatrics (Evanston)*, *116*(6), 1391-1400. https://doi.org/10.1542/peds.2005-0171

Mikkola, K., Tommiska, V., Hovi, P., & Kajantie, E. (2009). From preterm birth to adulthood. *Duodecim (Helsinki, Finland : 1961)*, *125*(12), 1341-1347.

Moon, C. (2017). Prenatal Experience with the Maternal Voice. In M. Filippa, P. Kuhn, & B. Westrup (Eds.), *Early Vocal Contact and Preterm Infant Brain Development : Bridging the Gaps Between Research and Practice* (pp. 25-37). Springer International Publishing. https://doi.org/10.1007/978-3-319-65077-7_2

Moore, E. R., Bergman, N., Anderson, G. C., & Medley, N. (2016). Early skin-to-skin contact for mothers and their healthy newborn infants. *Cochrane database of systematic reviews*, *2016*(11). https://doi.org/10.1002/14651858.CD003519.pub4

Muller-Nix, C., Forcada-Guex, M., Pierrehumbert, B., Jaunin, L., Borghini, A., & Ansermet, F. (2004). Prematurity, maternal stress and mother–child interactions. *Early Human Development*, *79*(2), 145-158. https://doi.org/10.1016/j.earlhumdev.2004.05.002

Månsson, J., Fellman, V., & Stjernqvist, K. (2015). Extremely preterm birth affects boys more and socio-economic and neonatal variables pose sex-specific risks. *Acta Paediatrica*, *104*(5), 514-521. https://doi.org/10.1111/apa.12937

Newnam, K. M., & Muñoz, L. R. (2021). Purposeful Language Exposure by Neonatal Nurses and Caregivers in the NICU. *Advances in neonatal care*, *21*(5), 407-417. https://doi.org/10.1097/ANC.0000000000000833

Nguyen, T.-N.-N., Spencer-Smith, M., Haebich, K. M., Burnett, A., Scratch, S. E., Cheong, J. L. Y., Doyle, L. W., Wiley, J. F., & Anderson, P. J. (2018). Language Trajectories of Children Born Very Preterm and Full Term from Early to Late Childhood. *The Journal of Pediatrics*, *202*, 86-91.e81. https://doi.org/10.1016/j.jpeds.2018.06.036

Nguyen, T.-N.-N., Spencer-Smith, M., Pascoe, L., Treyvaud, K., Lee, K. J., Thompson, D. K., Cheong, J. L. Y., Doyle, L. W., & Anderson, P. J. (2019). Language Skills in Children Born Preterm (<30 Wks' Gestation) Throughout Childhood: Associations With Biological and Socioenvironmental Factors. *Journal of developmental and behavioral pediatrics*, *40*(9), 735-742. https://doi.org/10.1097/DBP.0000000000000742

Oller, D. K. (2000). *The emergence of the speech capacity*. Lawrence Erlbaum Associates.

Oller, D. K., Caskey, M., Yoo, H., Bene, E. R., Jhang, Y., Lee, C. C., Bowman, D. D., Long, H. L., Buder, E. H., & Vohr, B. (2019). Preterm and full term infant vocalization and the origin of language. *Scientific reports*, *9*(1), 14734. https://doi.org/10.1038/s41598-019-51352-0

Oller, D. K., Eilers, R. E., Neal, A. R., & Schwartz, H. K. (1999). Precursors to speech in infancy: The prediction of speech and language disorders. *Journal of Communication Disorders*, *32*(4), 223-245. https://doi.org/10.1016/S0021-9924(99)00013-1

Ortiz-Mantilla, S., Choudhury, N., Leevers, H., & Benasich, A. A. (2008). Understanding language and cognitive deficits in very low birth weight children. *Developmental Psychobiology*, *50*(2), 107-126. https://doi.org/10.1002/dev.20278

Pae, S., Yoon, H., Seol, A., Gilkerson, J., Richards, J. A., Ma, L., & Topping, K. (2016). Effects of feedback on parent–child language with infants and toddlers in Korea. *First Language*, *36*(6), 549-569. https://doi.org/10.1177/0142723716649273

Perez-Pereira, M. (2021). Prevalence of Language Delay among Healthy Preterm Children, Language Outcomes and Predictive Factors. *Children (Basel)*, *8*(4). https://doi.org/10.3390/children8040282

Perez-Pereira, M., Fernandez, P., Gomez-Taibo, M. L., & Resches, M. (2014). Language development of low risk preterm infants up to the age of 30 months. *Early Human Development*, *90*(10), 649-656. https://doi.org/10.1016/j.earlhumdev.2014.08.004

Peter, M. S., Durrant, S., Jessop, A., Bidgood, A., Pine, J. M., & Rowland, C. F. (2019). Does speed of processing or vocabulary size predict later language growth in toddlers? *Cognitive Psychology*, *115*, 101238. https://doi.org/10.1016/j.cogpsych.2019.101238

Philbin, M. K. (2017). The Sound Environments and Auditory Perceptions of the Fetus and Preterm Newborn. In M. Filippa, P. Kuhn, & B. Westrup (Eds.), *Early Vocal Contact and Preterm Infant Brain Development : Bridging the Gaps Between Research and Practice* (pp. 91-111). Springer International Publishing. https://doi.org/10.1007/978-3-319-65077-7_6

Pineda, R., Bender, J., Hall, B., Shabosky, L., Annecca, A., & Smith, J. (2018). Parent participation in the neonatal intensive care unit: Predictors and relationships to neurobehavior and developmental outcomes. *Early Human Development*, *117*, 32-38. https://doi.org/10.1016/j.earlhumdev.2017.12.008

Pineda, R., Durant, P., Mathur, A., Inder, T., Wallendorf, M., & Schlaggar, B. L. (2017). Auditory Exposure in the Neonatal Intensive Care Unit: Room Type and Other Predictors. *The Journal of Pediatrics*, *183*, 56-66 e53. https://doi.org/10.1016/j.jpeds.2016.12.072

Pineda, R. G., Neil, J., Dierker, D., Smyser, C. D., Wallendorf, M., Kidokoro, H., Reynolds, L. C., Walker, S., Rogers, C., Mathur, A. M., Van Essen, D. C., & Inder, T. (2014). Alterations in brain structure and neurodevelopmental outcome in preterm infants hospitalized in different neonatal intensive care unit environments. *J Pediatr*, *164*(1), 52-60 e52. https://doi.org/10.1016/j.jpeds.2013.08.047

Potharst, E. S., van Wassenaer-Leemhuis, A. G., Houtzager, B. A., Livesey, D., Kok, J. H., Last, B. F., & Oosterlaan, J. (2013). Perinatal risk factors for neurocognitive impairments in preschool children born very preterm. *Developmental medicine and child neurology*, *55*(2), 178-184. https://doi.org/10.1111/dmcn.12018

Provenzi, L., Broso, S., & Montirosso, R. (2018). Do mothers sound good? A systematic review of the effects of maternal voice exposure on preterm infants' development. *Neuroscience and biobehavioral reviews*, *88*, 42-50. https://doi.org/10.1016/j.neubiorev.2018.03.009

Putnick, D. L., Bornstein, M. H., Eryigit-Madzwamuse, S., & Wolke, D. (2017). Long-Term Stability of Language Performance in Very Preterm, Moderate-Late Preterm, and Term Children. *The Journal of Pediatrics*, *181*, 74-79 e73. https://doi.org/10.1016/j.jpeds.2016.09.006

Raiskila, S., Axelin, A., Toome, L., Caballero, S., Tandberg, B. S., Montirosso, R., Normann, E., Hallberg, B., Westrup, B., Ewald, U., & Lehtonen, L. (2017). Parents' presence and parent-infant closeness in 11 neonatal intensive care units in six European countries vary between and within the countries. *Acta Paediatrica*, *106*(6), 878–888. https://doi.org/10.1111/apa.13798

Ramon-Casas, M., Bosch, L., Iriondo, M., & Krauel, X. (2013). Word recognition and phonological representation in very low birth weight preterms. *Early Human Development*, *89*(1), 55-63. https://doi.org/10.1016/j.earlhumdev.2012.07.019

Rand, K., & Lahav, A. (2014). Impact of the NICU environment on language deprivation in preterm infants. *Acta Paediatrica*, *103*(3), 243-248. https://doi.org/10.1111/apa.12481

Remes, H. (2015). *Viron kielioppi*. Finn Lectura.

Reynolds, L. C., Duncan, M. M., Smith, G. C., Mathur, A., Neil, J., Inder, T., & Pineda, R. G. (2013). Parental presence and holding in the neonatal intensive care unit and associations with early neurobehavior. *Journal of Perinatology*, *33*(8), 636-641. https://doi.org/10.1038/jp.2013.4

Ritchie, K., Bora, S., & Woodward, L. J. (2015). Social development of children born very preterm: a systematic review. *Developmental medicine and child neurology*, *57*(10), 899-918. https://doi.org/10.1111/dmcn.12783

Romeo, R., Pezanowski, R., Merrill, K., Hargrave, S., & Hansen, A. (2022). Parent and staff perspectives on the benefits and barriers to communication with infants in the neonatal intensive care unit. *Journal of child health care*, 13674935221076216-13674935221076216. https://doi.org/10.1177/13674935221076216

Romeo, R. R., Leonard, J. A., Robinson, S. T., West, M. R., Mackey, A. P., Rowe, M. L., & Gabrieli, J. D. E. (2018). Beyond the 30-Million-Word Gap: Children's Conversational Exposure Is Associated With Language-Related Brain Function. *Psychological Science*, *29*(5), 700-710. https://doi.org/10.1177/0956797617742725

Rose, S. A., Feldman, J. F., Jankowski, J. J., & Van Rossem, R. (2005). Pathways from prematurity and infant abilities to later cognition. *Child Development*, *76*(6), 1172-1184. https://doi.org/10.1111/j.1467-8624.2005.00843.x

Ross, K., Heiny, E., Conner, S., Spener, P., & Pineda, R. (2017). Occupational therapy, physical therapy and speech-language pathology in the neonatal intensive care unit: Patterns of therapy usage in a level IV NICU. *Research in developmental disabilities*, *64*, 108-117. https://doi.org/10.1016/j.ridd.2017.03.009

Rowe, M. L. (2012). A longitudinal investigation of the role of quantity and quality of child-directed speech in vocabulary development. *Child Development*, *83*(5), 1762-1774. https://doi.org/10.1111/j.1467-8624.2012.01805.x

Rowe, M. L., & Snow, C. E. (2020). Analyzing input quality along three dimensions: interactive, linguistic, and conceptual. *Journal of Child Language*, *47*(1), 5-21. https://doi.org/10.1017/S0305000919000655

Rowe, M. L., & Weisleder, A. (2020). Language Development in Context. *Annual Review of Developmental Psychology*, *2*(1), 201-223. https://doi.org/10.1146/annurev-devpsych-042220-121816

Rudolph, J. M. (2017). Case History Risk Factors for Specific Language Impairment: A Systematic Review and Meta-Analysis. *American journal of speech-language pathology*, *26*(3), 991-1010. https://doi.org/10.1044/2016_AJSLP-15-0181

Saliba, S., Esseily, R., Filippa, M., Kuhn, P., & Gratier, M. (2018). Exposure to human voices has beneficial effects on preterm infants in the neonatal intensive care unit. *Acta Paediatrica*, *107*(7), 1122-1130. https://doi.org/10.1111/apa.14170

Saliba, S., Gratier, M., Filippa, M., Devouche, E., & Esseily, R. (2020). Fathers' and Mothers' Infant Directed Speech Influences Preterm Infant Behavioral State in the NICU. *Journal of Nonverbal Behavior*, *44*(4), 437-451. https://doi.org/10.1007/s10919-020-00335-1

Sanchez, K., Spittle, A. J., Cheong, J. L., Thompson, D. K., Doyle, L. W., Anderson, P. J., & Morgan, A. T. (2019). Language in 2-year-old children born preterm and term: a cohort study. *Archives of Disease in Childhood*, *104*(7), 647-652. https://doi.org/10.1136/archdischild-2018-315843

Sansavini, A., Bosch, L., Wolke, D., & Leemhuis, A. (2018). *European Standards of Care for Newborn Health: Communication, speech, and language*. https://www.efcni.org/wp-content/uploads/2018/11/2018_11_16_ESCNH_Report_final.pdf

Sansavini, A., Guarini, A., Alessandroni, R., Faldella, G., Giovanelli, G., & Salvioli, G. (2006). Early relations between lexical and grammatical development in very immature Italian preterms. *Journal of Child Language*, *33*(1), 199-216. https://doi.org/10.1017/S0305000905007208

Sansavini, A., Guarini, A., & Caselli, M. C. (2011). Preterm birth: neuropsychological profiles and atypical developmental pathways. *Developmental Disability Research Reviews*, *17*(2), 102-113. https://doi.org/10.1002/ddrr.1105

Sansavini, A., Guarini, A., Justice, L. M., Savini, S., Broccoli, S., Alessandroni, R., & Faldella, G. (2010). Does preterm birth increase a child's risk for language impairment? *Early Human Development*, *86*(12), 765-772. https://doi.org/10.1016/j.earlhumdev.2010.08.014

Sansavini, A., Guarini, A., Savini, S., Broccoli, S., Justice, L., Alessandroni, R., & Faldella, G. (2011). Longitudinal trajectories of gestural and linguistic abilities in very preterm infants in the second year of life. *Neuropsychologia*, *49*(13), 3677-3688. https://doi.org/10.1016/j.neuropsychologia.2011.09.023

Schwarz, I.-C., Botros, N., Lord, A., Marcusson, A., Tidelius, H., & Marklund, E. (2017). The LENA System Applied to Swedish: Reliability of the Adult Word Count Estimate. Proceedings Interspeech 2017, Stockholm, Sweden.

Shapiro-Mendoza, C. K., & Lackritz, E. M. (2012). Epidemiology of late and moderate preterm birth. *Seminars in fetal & neonatal medicine*, *17*(3), 120-125. https://doi.org/10.1016/j.siny.2012.01.007

Stolt, S. (2019). Early lexicon and the development that precedes it and the development follws-A developmental view to early lexicon. In A.Bar-On & D.Ravid (Eds.), *Handbook of Communication Disorders* (pp. 91-100). Walter de Gruyter Inc.

Stolt, S., Haataja, L., Lapinleimu, H., & Lehtonen, L. (2008). Early lexical development of Finnish children: A longitudinal study. *First Language*, *28*(3), 259-279. https://doi.org/10.1177/0142723708091051

Stolt, S., Haataja, L., Lapinleimu, H., & Lehtonen, L. (2009). The early lexical development and its predictive value to language skills at 2 years in very-low-birth-weight children. *Journal of Communication Disorders*, *42*(2), 107-123. https://doi.org/10.1016/j.jcomdis.2008.10.002

Stolt, S., Klippi, A., Launonen, K., Munck, P., Lehtonen, L., Lapinleimu, H., Haataja, L., & Pipari Study, G. (2007). Size and composition of the lexicon in prematurely born very-low-birth-weight and full-term Finnish children at two years of age. *Journal of Child Language*, *34*(2), 283-310. https://doi.org/10.1017/s0305000906007902

Stolt, S., Korja, R., Matomaki, J., Lapinleimu, H., Haataja, L., & Lehtonen, L. (2014). Early relations between language development and the quality of mother-child interaction in very-low-birth-weight children. *Early Human Development*, *90*(5), 219-225. https://doi.org/10.1016/j.earlhumdev.2014.02.007

Stolt, S., Lehtonen, L., Haataja, L., & Lapinleimu, H. (2012). Development and predictive value of early vocalizations in very-low-birth-weight children: a longitudinal study. *Clinical Linguistics & Phonetics*, *26*(5), 414-427. https://doi.org/10.3109/02699206.2011.648365

Stolt, S., Lind, A., Matomaki, J., Haataja, L., Lapinleimu, H., & Lehtonen, L. (2016). Do the early development of gestures and receptive and expressive language predict language skills at 5;0 in prematurely born very-low-birth-weight children? *Journal of Communication Disorders*, *61*, 16-28. https://doi.org/10.1016/j.jcomdis.2016.03.002

Stolt, S., Makila, A. M., Matomaki, J., Lehtonen, L., Lapinleimu, H., & Haataja, L. (2014). The development and predictive value of gestures in very-low-birth-weight children: a longitudinal study. *International Journal of Speech Language Pathology*, *16*(2), 121-131. https://doi.org/10.3109/17549507.2013.794861

Stolt, S., Matomaki, J., Lind, A., Lapinleimu, H., Haataja, L., & Lehtonen, L. (2014). The prevalence and predictive value of weak language skills in children with very low birth weight--a longitudinal study. *Acta Paediatrica*, *103*(6), 651-658. https://doi.org/10.1111/apa.12607

Stolt, S., & Vehkavuori, S. (2018). *Sanaseula. MacArthur-Bates Communicative Development Inventories, menetelmän suomalainen lyhyt versio (The Finnish* *short form version of the MacArthur-Bates Communicative Development Invetories).* Niilo Mäki Instituutti.

Tobii Technology AB. (2014). *User's Manual. Tobii X2-60 Eye Tracker.* https://www.tobiipro.com/siteassets/tobii-pro/user-manuals/tobii-pro-x2-60-eye-tracker-user-manual.pdf/?v=1.0.3

Toivonen, M., Lehtonen, L., Löyttyniemi, E., Ahlqvist-Björkroth, S., & Axelin, A. (2020). Close Collaboration with Parents intervention improves family-centered care in different neonatal unit contexts: a pre–post study. *Pediatric Research*, *88*(3), 421-428. https://doi.org/10.1038/s41390-020-0934-2

Treyvaud, K. (2013). Parent and family outcomes following very preterm or very low birth weight birth: A review. *Seminars in fetal & neonatal medicine*, *19*(2), 131-135. https://doi.org/10.1016/j.siny.2013.10.008

Treyvaud, K., Anderson, V. A., Howard, K., Bear, M., Hunt, R. W., Doyle, L. W., Inder, T. E., Woodward, L., & Anderson, P. J. (2009). Parenting Behavior Is Associated With the Early Neurobehavioral Development of Very Preterm Children. *Pediatrics*, *123*(2), 555-561. https://doi.org/10.1542/peds.2008-0477

Treyvaud, K., Spittle, A., Anderson, P. J., & O'Brien, K. (2019). A multilayered approach is needed in the NICU to support parents after the preterm birth of their infant. *Early Human Development*, *139*, 104838. https://doi.org/https://doi.org/10.1016/j.earlhumdev.2019.104838

Tsao, F.-M., Liu, H.-M., & Kuhl, P. K. (2004). Speech Perception in Infancy Predicts Language Development in the Second Year of Life: A Longitudinal Study. *Child Development*, *75*(4), 1067-1084. https://doi.org/10.1111/j.1467-8624.2004.00726.x

Tulviste, T., & Tamm, A. (2021). Is silence golden? A pilot study exploring associations between children's language environment and their language skills in Estonian-speaking families. *Journal of experimental child psychology*, *207*, 105096-105096. https://doi.org/10.1016/j.jecp.2021.105096

Valleau, M. J., Konishi, H., Golinkoff, R. M., Hirsh-Pasek, K., & Arunachalam, S. (2018). An Eye-Tracking Study of Receptive Verb Knowledge in Toddlers. *Journal of Speech, Language, and Hearing Research*, *61*(12), 2917-2933. https://doi.org/10.1044/2018_JSLHR-L-17-0363

van Noort-van der Spek, I. L., Franken, M. C., & Weisglas-Kuperus, N. (2012). Language functions in preterm-born children: a systematic review and meta-analysis. *Pediatrics*, *129*(4), 745–754. https://doi.org/10.1542/peds.2011-1728

van Veenendaal, N. R., Heideman, W. H., Limpens, J., van der Lee, J. H., van Goudoever, J. B., van Kempen, A. A. M. W., & van der Schoor, S. R. D. (2019). Hospitalising preterm infants in single family rooms versus open bay units: a systematic review and meta-analysis. *The lancet child & adolescent health*, *3*(3), 147-157. https://doi.org/10.1016/S2352-4642(18)30375-4

van Veenendaal, N. R., van Kempen, A. A. M. W., Franck, L. S., O'Brien, K., Limpens, J., van der Lee, J. H., van Goudoever, J. B., & van der Schoor, S. R. D. (2020). Hospitalising preterm infants in single family rooms versus open bay units: A systematic review and meta-analysis of impact on parents. *EClinicalMedicine*, *23*, 100388-100388. https://doi.org/10.1016/j.eclinm.2020.100388

Vehkavuori, S.-M., & Stolt, S. (2018). Screening language skills at 2;0. *Infant behavior & development*, *50*, 174-179. https://doi.org/10.1016/j.infbeh.2018.01.001

Voegtline, K. M., Costigan, K. A., Pater, H. A., & DiPietro, J. A. (2013). Near-term fetal response to maternal spoken voice. *Infant behavior & development*, *36*(4), 526–533. https://doi.org/10.1016/j.infbeh.2013.05.002

Vohr, B. (2010). Cognitive and functional outcomes of children born preterm. In C. Nosartri, R. M. Murray, & M. Hack (Eds.), *Neurodevelopmental Outcomes of Preterm Birth. From Childhood to Adult Life.* (pp. 141-163). Cambridge University Press.

Vohr, B. (2014). Speech and language outcomes of very preterm infants. *Semininaars in Fetal & Neonatal Medicine*, *19*(2), 78-83. https://doi.org/10.1016/j.siny.2013.10.007

Vohr, B., McGowan, E., McKinley, L., Tucker, R., Keszler, L., & Alksninis, B. (2017). Differential Effects of the Single-Family Room Neonatal Intensive Care Unit on 18- to 24-Month Bayley Scores of Preterm Infants. *The Journal of Pediatrics*, *185*, 42-48.e41. https://doi.org/10.1016/j.jpeds.2017.01.056

Vohr, B. R. (2019). The importance of parent presence and involvement in the single-family room and open-bay NICU. *Acta Paediatrica*, *108*(6), 986-988. https://doi.org/10.1111/apa.14783

Wachman, E. M., & Lahav, A. (2011). The effects of noise on preterm infants in the NICU. *Archives of Disease in Childhood. Fetal and Neonatal Edition*, *96*(4), F305-F309. https://doi.org/10.1136/adc.2009.182014

Wang, Y., Hartman, M., Aziz, N. A. A., Arora, S., Shi, L., & Tunison, E. (2017). A Systematic Review of the Use of LENA Technology. *American annals of the deaf (Washington, D.C. 1886)*, *162*(3), 295-311. https://doi.org/10.1353/aad.2017.0028

Wang, Y., Williams, R., Dilley, L., & Houston, D. M. (2020). A meta-analysis of the predictability of LENA automated measures for child language development. *Developmental Review*, *57*. https://doi.org/10.1016/j.dr.2020.100921

Weisleder, A., & Fernald, A. (2013). Talking to children matters: early language experience strengthens processing and builds vocabulary. *Psychological Science*, *24*(11), 2143-2152. https://doi.org/10.1177/0956797613488145

Wetherby, A. M., Allen, L., Cleary, J., Kublin, K., & Goldstein, H. (2002). Validity and Reliability of the Communication and Symbolic Behavior Scales Developmental Profile With Very Young Children. *Journal of Speech, Language & Hearing Research*, *45*(6), 1202. https://doi.org/10.1044/1092-4388(2002/097)

White, R. D. (2020). Recommended standards for newborn ICU design, 9th edition. *Journal of Perinatology*, *40*(Suppl 1), 2-4. https://doi.org/10.1038/s41372-020-0766-2

Williamson, S., & McGrath, J. M. (2019). What Are the Effects of the Maternal Voice on Preterm Infants in the NICU? *Advances in neonatal care*, *19*(4), 294-310. https://doi.org/10.1097/ANC.0000000000000578

Wolke, D., & Meyer, R. (1999). Cognitive status, language attainment, and prereading skills of 6-year-old very preterm children and their peers: the Bavarian Longitudinal Study. *Developmental medicine and child neurology*, *41*(2), 94-109. https://doi.org/10.1017/S0012162299000201

World Health Organization. (2007). *International Classification of Functioning, Disability and Health: Children and Youth version : ICF-CY* (978-92-4-154732-1). https://apps.who.int/iris/bitstream/handle/10665/43737/9789241547321_eng.pdf

World Health Organization. (2022). *Preterm birth*. https://www.who.int/news-room/fact-sheets/detail/preterm-birth

Xu, D., Yapanel, U., & Gray, S. (2009). *Reliability of the LENA Language Environment Analysis System in Young Children's Natural Home Environment (Technical report LTR-05-2)*. LENA Foundation.

Xu, D., Yapanel, U., Gray, S., Gilkerson, J., Richards, J., & Hansen, J. (2008). Signal Processing for Young Child Speech Language Development. The 1st workshop on child, computor and interaction, Chania, Crete, Greece.

Yaari, M., Mankuta, D., Harel-Gadassi, A., Friedlander, E., Bar-Oz, B., Eventov-Friedman, S., Maniv, N., Zucker, D., & Yirmiya, N. (2018). Early developmental trajectories of preterm infants. *Research in developmental disabilities*, *81*, 12-23. https://doi.org/10.1016/j.ridd.2017.10.018

Yogman, M., & Garfield, C. F. (2016). Fathers' Roles in the Care and Development of Their Children: The Role of Pediatricians. *Pediatrics*, *138*(1), 1-1. https://doi.org/10.1542/peds.2016-1128

Yoo, H., Bowman, D. A., & Oller, D. K. (2018). The Origin of Protoconversation: An Examination of Caregiver Responses to Cry and Speech-Like Vocalizations. *Frontiers in Psychology*, *9*, 1510-1510. https://doi.org/10.3389/fpsyg.2018.01510

Yrjölä, P., Myers, M. M., Welch, M. G., Stevenson, N. J., Tokariev, A., & Vanhatalo, S. (2022). Facilitating early parent-infant emotional connection improves cortical networks in preterm infants. *Science Translational Medicine*, *14*(664), eabq4786. https://doi.org/doi:10.1126/scitranslmed.abq4786

Zauche, L. H., Thul, T. A., Mahoney, A. E. D., & Stapel-Wax, J. L. (2016). Influence of language nutrition on children's language and cognitive development: An integrated review. *Early Childhood Research Quarterly*, *36*, 318-333. https://doi.org/10.1016/j.ecresq.2016.01.015

Zettersten, M., Bergey, C., Bhatt, N. S., Boyce, V., Braginsky, M., Carstensen, A., deMayo, B., Kachergis, G., Lewis, M., Long, B., MacDonald, K., Mankewitz, J., Meylan, S. C., Saleh, A. N., Schneider, R. M., Tsui, A., Uner, S., Xu, T. L., Yurovsky, D., & Frank, M. C. (2021). Peekbank: Exploring children's word recognition through an open, large-scale repository for developmental eye-tracking data. *PsyArXiv, preprint online*. https://doi.org/10.31234/osf.io/ep693

Zimmerman, F. J., Gilkerson, J., Richards, J. A., Christakis, D. A., Xu, D., Gray, S., & Yapanel, U. (2009). Teaching by Listening: The Importance of Adult-Child Conversations to Language Development. *Pediatrics*, *124*(1), 342-349. https://doi.org/10.1542/peds.2008-2267