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A large, light green stylized sunburst or fan-like graphic on the left side of the cover, composed of multiple curved segments radiating from a central point.

**PARENT-STAFF AND
PARENT-INFANT
COMMUNICATION –
IMPLICATIONS ON CHILD
DEVELOPMENT**

Anette Aija



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PARENT-STAFF AND PARENT-INFANT COMMUNICATION – IMPLICATIONS ON CHILD DEVELOPMENT

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The originality of this publication has been checked in accordance with the University of Turku quality assurance system using the Turnitin OriginalityCheck service.

ISBN 978-952-02-0247-7 (PRINT)
ISBN 978-952-02-0248-4 (PDF)
ISSN 0355-9483 (Print)
ISSN 2343-3213 (Online)
Painosalama, Turku, Finland 2025

To Hans and Oskar

UNIVERSITY OF TURKU

Faculty of Medicine

Department of Clinical Medicine

Pediatrics

ANETTE AIJA: PARENT-STAFF AND PARENT-INFANT

COMMUNICATION – IMPLICATIONS ON CHILD DEVELOPMENT

Doctoral Dissertation, 134 pp.

Doctoral Programme in Clinical Research

August 2025

ABSTRACT

After a preterm birth, the optimal growth environment in utero is replaced by a completely different, often rather stressful environment in the neonatal intensive care unit (NICU), which could potentially be harmful to the preterm infant's neurodevelopment. Developmentally supportive family-centered care could ameliorate these harmful effects. Specific family-centered care interventions in the NICU have shown promising results on preterm infants' short- and long-term outcomes, although inconsistencies exist.

This thesis aimed to evaluate: Firstly, how parents were integrated into the decision-making process during medical rounds in the NICU. Secondly, how early parental speech exposure in the NICU environment affects preterm infants' attention and social-cognitive development at seven months of corrected age. Thirdly, how early parental speech exposure and parent-infant communication in the NICU affect an infant's language development at one and two years of corrected age.

The results of this thesis indicate that parents have an important role in communicating with the staff and with their preterm infant, as a part of the developmental care team. The parents' presence and participation vary between and within countries, highlighting the impact of the unit's care culture. Exposure to the parents' speech during neonatal care is associated with the infant's early social-cognitive development. Early parent-infant communication and parental speech in the NICU are potentially beneficial to the infant's language development, while a high total amount of adult words could resemble noise exposure and have a negative impact on a child's development. This thesis has shown that including parents in the decision-making process, promoting parent-infant communication, and exposure to the parents' speech during neonatal care could improve the NICU environment and infant outcomes.

KEYWORDS: Preterm infant, NICU, family-centered care, development

TURUN YLIOPISTO

Lääketieteellinen tiedekunta

Kliininen laitos

Lastentautioppi

ANETTE AIJA: Vanhemman-henkilökunnan ja vanhemman-lapsen välinen läheisyys – vaikutus keskoslapsen kehitykseen

Väitöskirja, 134 s.

Turun Kliininen Tohtoriohjelma

Elokuu 2025

TIIVISTELMÄ

Ennenaikaisen synnytyksen jälkeen kohdun optimaalinen kasvuympäristö korvautuu vastasyntyneiden teho-osastolla, joka on täysin erilainen ja usein varsin stressaava ympäristö. Tämä saattaa olla haitallista keskosien kehitykselle. Kehitystä tukeva perhekeskeinen hoitokulttuuri voisi vähentää näitä haitallisia vaikutuksia. Tietyillä vastasyntyneiden teho-osastoilla perhekeskeisiä hoitokäytäntöjä toteutetuilla interventioilla on saavutettu lupaavia tuloksia keskokosten kehityksen suhteen, vaikka tieto onkin edelleen puutteellista.

Tämän väitöskirjan tarkoituksena oli arvioida ensinnäkin, kuinka vanhemmat otettiin mukaan päätöksentekoprosessiin vastasyntyneiden teho-osaston lääkärinkiertojen aikana. Toiseksi analysoitiin, kuinka varhainen altistus vanhempien puheelle keskola-ympäristössä vaikuttaa keskokosten huomiokykyyn ja sosiaaliseen ja kognitiiviseen kehitykseen seitsemän kuukauden korjatussa iässä. Kolmanneksi selvitettiin, kuinka varhainen altistus vanhempien puheelle ja vanhemman ja lapsen välinen viestintä keskolassa vaikuttavat lapsen kielen kehitykseen yhden ja kahden vuoden korjatussa iässä.

Tässä väitöskirjassa esitetyt tulokset osoittavat, että vanhempien kommunikoinnilla henkilökunnan ja lapsensa kanssa on tärkeä rooli lapsen kehityksen tukemisessa. Vanhempien läsnäolo ja osallistuminen sairaalahoitoon vaihtelevat maiden välillä ja sisällä, mikä korostaa yksikön hoitokulttuurin merkitystä. Altistuminen vanhempien puheelle vastasyntyneiden tehohoidon aikana vaikuttaa lapsen varhaiseen sosiaalkognitiiviseen kehitykseen. Varhainen vanhemman ja lapsen välinen kommunikaatio ja vanhempien puheen kuuleminen teho-osastolla voivat olla eduksi lapsen kielen kehitykselle, kun taas suuri kokonaismäärä aikuisten sanoja saattaa muistuttaa meluallistusta ja vaikuttaa negatiivisesti lapsen kehitykseen. Tämä väitöskirja osoittaa, että vanhempien mukaan ottaminen päätöksentekoprosessiin, vanhempien ja lasten välisen kommunikoinnin edistäminen ja vanhempien puheelle altistuminen vastasyntyneiden teho-osastolla voivat parantaa keskola-ympäristöä ja edistää lapsen kehitystä.

AVAINSANAT: keskonen, vastasyntyneiden teho-osasto, perhekeskeinen hoitokulttuuri, kehitys

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Abbreviations

APPLE	Auditory environment by Parents of Preterm infant; Language development and Eye-movements
BPD	Bronchopulmonary dysplasia
CPAP	Continuous positive airway pressure
CTC	Conversational turns count
CVC	Child vocalizations count
FCC	Family-centered care
FICare	Family-Integrated Care
FNI	Family Nurture Intervention
GW	Gestational weeks
IVH	Intraventricular hemorrhage
KMC	Kangaroo Mother Care
LENA	Language Environment Analysis
MCDI	MacArthur-Bates Communicative Development Inventory
MITP	Mother-Infant Transaction Program
NEC	Necrotizing Enterocolitis
NICU	Neonatal Intensive Care unit
NIDCAP	The Newborn Individualized Developmental Care and Assessment Program
NIV-NAVA	Non-invasive neurally adjusted ventilatory assist
PICU	Pediatric intensive care unit
PMA	Postmenstrual age
PVL	Periventricular leukomalacia
RDLS	Reynell Developmental Language Scales third edition
ROP	Retinopathy of prematurity
SCENE	Separation and Closeness Experiences in Neonatal Environment Study
SD	Standard deviation
SENSE	Supporting and Enhancing NICU Sensory Experiences
SFR	Single-Family Room
SSC	Skin-to-skin Contact

List of Original Publications

This dissertation is based on the following original publications, which are referred to in the text by their Roman numerals:

- I Aija A, Toome L, Axelin A, Raiskila S, Lehtonen L. Parents' presence and participation in medical rounds in 11 European neonatal units. *Early Human Development*, 2019; 130: 10-16.
- II Aija A, Leppänen J, Aarnos L, Hyvönen M, Ståhlberg-Forsén E, Ahlqvist-Björkroth S, Stolt S, Toome L, Lehtonen L. Exposure to the parents' speech is positively associated with preterm infant's face preference. *Pediatric Research*, 2024; 96: 1803–1811.
- III Aija A, Ståhlberg-Forsén E, Toome L, Aarnos L, Ahlqvist-Björkroth S, Stolt S, Lehtonen L. Parents' speech in the NICU and language development of very preterm children at 12 and 24 months. *Journal of Pediatrics: Clinical Practice*, 2025; 17: 200156.

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1 Introduction

Advances in neonatal care have enhanced the survival of premature and critically ill infants. While the incidence of certain long-term neurodevelopmental issues (i.e., cerebral palsy) has decreased, difficulties in cognitive and language abilities remain unchanged (Morgan et al. 2022; McGowan et al. 2022; O'Reilly et al. 2020; Twilhaar et al. 2018; Vohr 2016). The need to improve long-term neurodevelopmental outcomes has led to a focus on improving developmental care within the neonatal intensive care unit (NICU), targeting the period of earliest brain plasticity, and therefore modifying the possible epigenetic changes (Provenzi et al. 2018). Emphasizing a developmentally supportive physical and social NICU environment is vital for preterm infants and their families, as infants are still developing the ability to achieve balanced neurobehavioral organization and engage meaningfully with their caregivers (Lehtonen & White 2020). Physical and emotional closeness between the preterm infant and the parent in the NICU is shown to be beneficial for both the infant and the parent (Flacking et al. 2012). Parents themselves have described that support from the staff (culture) and the opportunities offered by the unit (environment) play a crucial role in parent-infant closeness and thereby facilitate parent-infant bonding (Väliaho et al. 2023).

Even though many NICUs worldwide have abandoned visiting restrictions and include parents in the preterm infant's care, there are still wide variations between units in different European countries (Greisen et al. 2009; Raiskila et al. 2016), in parental presence (van Veenendaal et al. 2022) and in the quality of the family-centered care (Raiskila et al. 2016). The parents' participation in medical rounds and shared decision-making seems to be the most difficult aspect to change in the daily routines of neonatal care, as the parents' participation in medical rounds is the most persistent restriction across units (Greisen et al. 2009).

Many family-centered developmental care interventions have reported beneficial effects on preterm infants' short- and long-term outcomes (Als et al. 2004; Boundy et al. 2016; Welch et al. 2017; van Veenendaal et al. 2019; Pineda et al. 2020; Itoshima et al. 2024). There is a paucity of studies about the effectiveness of sensory exposures in the NICU environment, as studies are controversial (Aita et al. 2021). There are studies indicating that parental speech exposure has a positive effect on

infants' language development (Caskey et al. 2014; McGowan et al. 2024), but there are also negative examples of adult speech exposure in the NICU that could have effects similar to noise (Ståhlberg-Forsén et al. 2022). The association between early NICU sensory experiences and infants' long-term neurodevelopmental outcomes has not yet been determined.

The first aim of this thesis was to evaluate how parents were integrated into the decision-making process during medical rounds. Secondly, we aimed to assess the impact of early parental speech exposure in the NICU environment on the preterm infants' attention at seven months of corrected age, as well as language development at one and two years of corrected age. We showed that parental speech exposure in the NICU environment is beneficial to the infants' social-cognitive development and supports their language development. Therefore, the care culture in a NICU plays an important role in involving the parents in neonatal care, highlighting the need for specialized implementation programs.

2 Review of the Literature

2.1 Fetal brain development in utero in the physiological environment

Fetal brain development in utero is a complex process that begins early in pregnancy and continues throughout gestation. The development of the nervous system starts at 2–3 gestational weeks (GW) with neurulation, the process during which neuroectodermal cells formulate the neural tube (Borsani et al. 2019; Gressens et al. 2020). In addition to structural development, intrauterine brain development consists of four phases: neurogenesis, neuronal migration, synaptogenesis, and myelination (Borsani et al. 2019). Neurons are the information processing cells in the human brain and their production is largely completed by midgestation (Borsani et al. 2019; Stiles and Jernigan 2010). The neurons then proceed to migrate to different brain areas to make connections with other neurons and form important pathways (Stiles and Jernigan 2010). Essential neural pathways (i.e., thalamocortical and corticothalamic pathways), which are crucial for sensory, cognitive, and motor functions, begin to form in the second trimester and are completed by GW 26 (Stiles and Jernigan 2010). Myelination is the formation of myelin sheaths around the axons of neurons, and it starts in the cerebral hemispheres around term age and is largely completed by early childhood (Gressens et al. 2020).

This genetically programmed complex process – synaptogenesis and myelination – continues postnatally until late adolescence and supposedly throughout the individual’s lifespan (Stiles and Jernigan 2010). Importantly, fetal life and early childhood up to two to three years of life (Borsani et al. 2019) are the most critical periods when brain development is susceptible to various factors. In addition to genetics, it is affected by environmental input, and disruptions can significantly impact neural outcomes (Stiles and Jernigan 2010; Gressens et al. 2020).

2.1.1 Sensory functions

Vision, hearing, smell, and taste are the senses that develop well before birth. They are modified by in-utero stimuli, and they mature rapidly prior to term age and during

the first year of life (Clark-Gambelunghe and Clark 2015). For example, the anatomical development of the outer and middle ear starts early on, at GW 5–6 (Kuhn et al. 2017). The development of the inner ear starts even earlier, is followed step-by-step maturation by the neuronal migration, synaptogenesis, and formulation of the pre- and postsynaptic circuits in the primary auditory cortex and is sufficiently mature by GW 20–25, enabling the fetus to start detecting sounds (Borsani et al. 2019; Kuhn et al. 2017; Hall 2000). Auditory development continues throughout the third trimester of the pregnancy, during which the fetal sensory systems become more functional and integrated (Borsani et al. 2019; Hall 2000) so that the fetus can react to environmental stimuli. Auditory pathways continue to mature postnatally.

A fetus's attraction to the mother's sensory stimuli marks the initial stage of attachment and bonding. This process begins during the last trimester of pregnancy, as the auditory and olfactory systems become functional, enabling the fetus to recognize and familiarize itself with the mother's voice and scent (Sullivan et al. 2011; Clark-Gambelunghe and Clark 2015; Trevarthen 2017; Borsani et al. 2019). Maternal voice is one of the most prominent characteristics of the prenatal sensory environment, and it has been shown that a fetus responds to the mother's voice with cardiac and motor activity (Moon 2017). Throughout gestation, the fetus learns the mother's voice and smell, and term-born newborns are intuitively capable of crawling to the breast of their mother and sucking from the breast within the first hour of life (Widström et al. 2020). Infants' attraction to the smell of their mother could be indicative of prenatal olfactory learning (Varendi et al. 1996; Bloomfield et al. 2017). Fetuses can also develop music and speech memory traces during the fetal period, which also shape autonomic and neuronal responses to these stimuli in the neonatal period (Partanen et al. 2013; Movalled et al. 2023).

Therefore, the appropriate physiological environment for early human brain development is in utero, where the fetus can move around in warm amniotic fluid, be in a flexed position, and sense the mother's movements, her circadian rhythm, her smell, her voice, and other sounds, while being protected from loud noise and light (White 2011; Parga et al. 2018; Lehtonen & White 2020; Craighero 2024).

2.1.2 Epigenetics and plasticity

Epigenetics explains how our experiences and environmental factors shape gene activity; it focuses on variations in gene expression rather than changes in the gene sequence (Champagne 2010). Epigenetic modifications include DNA methylation, histone modification, and the activation or silencing of genes associated with non-coding RNAs, without altering the genotype (Gialeli et al. 2023). There is evidence of epigenetics also correlating with NICU-related stress and preterm infant development (Provenzi et al. 2018).

There is a growing body of evidence in animal and human studies that illustrates the potential plasticity of these epigenetic mechanisms (Gudsnuk & Champagne 2011; Provenzi et al. 2018; Casavant et al. 2019; Gialeli et al. 2023). This shows that different interventions that moderate the quality of the early environment – minimizing the separation and enhancing postnatal parent-infant interactions – could ameliorate the negative effects of preterm birth on the neurodevelopmental outcomes (Champagne 2010; Gudsnuk & Champagne 2011; Flacking et al. 2012). Preterm infants have a limited capacity to cope with stressful stimuli that are often unavoidable in the NICU. Enabling a caring physical and emotional environment in the NICU for preterm infants could help minimize stress and, therefore, modify the potential plasticity of the epigenetic mechanisms, e.g., by reversing DNA methylation (Montirosso & Provenzi 2017).

The quality of hospital care plays a significant role in the long-term developmental outcomes of preterm infants. Factors such as medical procedures, medications, nutrition, the physical and social environment, and routine infant care can either support or harm brain development. One principle that is often applied in the absence of research data is that the experiences provided in the NICU should aim to replicate the physiological conditions of the in-utero environment (Lehtonen & White 2020).

2.1.3 Preterm birth

After a preterm birth, the optimal growth environment in utero is replaced by a completely different environment in the NICU. Stressful stimuli include the busy and brightly illuminated NICU environment, a wide range of nosocomial odors, painful medical procedures, early separation, and lack of biological stimuli from the mother (Kuhn et al. 2011; Milgrom et al. 2010; Vázquez et al. 2000). Preterm infants have been shown to be exposed to five times less adult speech than fetuses (Monson et al. 2023), and they are more exposed to noise (Best et al. 2018).

The World Health Organization defines preterm birth as a birth before 37 GW. Preterm births are then further classified into extremely preterm (<28 GW), very preterm (28 to <32 GW), and moderate to late preterm births (32 to <37 GW). Across countries, the prevalence of preterm birth ranges from 4–16% of live births (World Health Organization 2023). In 2010, preterm birth rates were the lowest in Northern European countries and the highest in sub-Saharan Africa, Southeastern Asia, and South Asia regions (Blencowe et al. 2012).

Depending on their gestational age, preterm infants are born at varying developmental stages, as described above, resulting in significant differences in the maturity of their nervous systems and their sensory functions (Lehtonen & White 2020). Therefore, preterm infants have an increased risk for different

neurodevelopmental and cognitive impairments (Pierrat et al. 2021), including attention-deficit/hyperactivity disorder (Franz et al. 2018), autism spectrum disorders (Pinto-Martin et al. 2011; Lampi et al. 2012; Agrawal et al. 2018), visual attention dysfunction (Kooiker et al. 2019; Burstein et al. 2021), socio-emotional difficulties (Montagna & Nosarti 2016; Mathewson et al. 2017), academic difficulties (McBryde et al. 2020), and delays in language development (van Noort-van der Spek et al. 2012). Some of these difficulties are present in up to 50–70% of extremely prematurely born infants (Linsell et al. 2019).

2.2 The parents' presence and participation in neonatal care

Historically, more than 40 years ago, the parents' presence and participation in infant hospital care was rigorously restricted, and mainly healthcare professionals were responsible of the care and the decision-making (Franck & O'Brien 2019). Research on animals has greatly enhanced our understanding of human attachment. Offspring in animal models, and therefore newborn infants, are biologically pre-programmed to form attachments with their caregivers, an important process forming a foundation for the normal emotional and cognitive development of the child (Sullivan et al. 2011). Parent-infant separation can mediate various consequences in offspring phenotype and long-term neurodevelopmental outcomes (Flacking et al. 2012). A Finnish study group, Latva et al. (2004), showed that the absence of the mother from the NICU increased the risk for behavioral and emotional problems for the preterm infant. Even though visitation restrictions have been abandoned in the majority of NICUs, there are still variations between units and countries (Greisen et al. 2009; Raiskila et al. 2016).

Over the past 25 years, neonatal care worldwide has moved from medical-centered conventional care to developmentally supportive family-centered care (McGrath 2000; Dunn et al. 2006). The developmental care goal is to create a supportive, encouraging family-centered environment for the preterm infant and the family, by protecting sleep, minimizing sensory stress, and facilitating parent-infant bonding (Coughlin et al. 2009; Griffiths et al. 2019). Additionally, the goal is to recognize the physical, psychological, and emotional vulnerabilities of the high-risk infants to minimize complications associated with a preterm birth and hospital experience (Coughlin et al. 2009).

Family-centered care (FCC) and developmental care often overlap. FCC has been defined as a care model, a philosophy, a paradigm, a practice-theory (Mikkelsen & Frederiksen 2011), and as a set of principles to guide the delivery of healthcare by empowering and involving the family in care (Franck & O'Brien 2019). Although variations in definitions and inconsistencies in outcome measures exist (Shields et

al. 2012; Uniacke et al. 2018; Kocakabak et al. 2025), there are some fundamental aspects of this concept. FCC is characterized by professional support or a relationship between the healthcare professionals and the family, with the aim of providing support, respect, collaboration, involvement, participation, empowerment, and flexibility (Mikkelsen & Frederiksen 2011; Franck & O'Brien 2019). It is delivering care in a holistic manner to meet the developmental, physical, and psychosocial needs of infants and their families (Dunn et al. 2006).

2.3 Parental stress

In animal models, it has been shown that prenatal maternal stress affects early brain development through impaired negative feedback regulation of the hypothalamic-pituitary-adrenal axis and possible general susceptibility to psychopathology (Huizink et al. 2004). Maternal stress is a major risk factor affecting fetal development and increasing the likelihood of developmental disorders (Gudsnuk & Champagne 2011). A study by Laurent et al. (2016) that observed infant cortisol levels and mother-infant behavior in stress sessions, found that maternal sensitivity is also important to an infant's stress regulation. Maternal sensitive caregiving behavior and physical closeness has been shown to be essential for developing a secure attachment between the mother and the infant (Hane & Fox 2006; Flacking et al. 2012), whereas low levels of sensitivity increase the infant's fearfulness (Hane & Fox 2006). It is noteworthy that preterm infants cared for by depressed mothers demonstrated higher cortisol levels than preterm infants cared for by non-depressed mothers (Bugental et al. 2008).

After a preterm birth, psychological distress, trauma, and grief are frequent experiences for parents in the NICU. In a French survey, parents of preterm infants reported feeling more stress and fear in the NICU than the parents of term-born infants' (Dicky et al. 2021). Importantly, when these issues are overlooked, they can negatively impact parent-child bonding (DiBari & Rouse 2023). Physical closeness in the NICU ranges from being present in the unit to close skin-to-skin contact between the parent and the preterm infant. Emotional closeness represents feelings from strong positive affection to disconnection. Although physical and emotional closeness are tied, there may be times after preterm birth when the parents are physically close yet feel emotionally detached or are physically distant but still maintain a strong emotional connection with their infant (Flacking et al. 2012).

Family-centered medical rounds are one possible way to integrate parents in decision-making and enhance communication (Voos et al. 2011). The parents' participation in medical rounds and decision-making gives them the opportunity to feel empowered and involved in infant care (Harris 2014). Studies have confirmed that FCC practices and interventions are critical mediators in reducing parental stress

and enhancing confidence in the parental role (Kynø et al. 2013; Ahlqvist-Björkroth et al. 2019; Axelin et al. 2022; van Veenendaal et al. 2022; Franck et al. 2023; Loutfy et al. 2024).

2.4 Family-centered care interventions in the neonatal environment

As described previously, the NICU environment and preterm birth are stressful for both the infant and the parents. Neonatal care culture and the NICU environment should encourage parents to maintain physical and emotional closeness with their infant and foster sensitive parent-infant communication. Family-centered developmental care is a comprehensive approach to infant care that integrates principles from neurodevelopment, neurobehavior, parent-infant communication, parental participation, and favoring breastfeeding. These developmental care interventions can be used alone or combined into structured intervention programs (Klein et al. 2021). Neonatal care today has taken a step further by developing specific family-centered developmental care interventions to implement these practices more effectively, more conveniently, and more scientifically (Ahlqvist-Björkroth et al. 2024). Next, I will describe some widespread interventions and structurally conceptualized intervention programs (summarized in **Table 1**).

2.4.1 Kangaroo Mother Care

Historically, in 1978, Kangaroo Mother Care (KMC) was presented in Bogota, Colombia as a revolutionary care model due to the lack of staff and equipment, where mothers were sent home with their very preterm infants and instructed to care for their infant between the mother's breasts ("kangaroo care") and fed only mother's milk (Whitelaw & Sleath 1985). Nowadays, the parents' physical closeness with their infant – skin-to-skin contact (SSC), also called kangaroo care, is a widespread and routine care model in the NICUs and has several scientifically proven benefits for infant physiology and behavior (Boundy et al. 2016). World Health Organization defines KMC through four key components: early, continuous, and prolonged skin-to-skin contact, exclusive breastfeeding, early discharge, and regular follow-up at home (WHO 2003, 2023). KMC fulfills the essential needs of preterm infants by providing breastfeeding, warmth, sensorimotor and skin-to-skin stimulation, security, protection from infections, and affection (Schneider et al. 2012).

Table 1. Family-centered care interventions

	Founded	Focus	Main principles
Kangaroo Mother Care (KMC)	In 1978, Bogota, Colombia	Minimizing separation by keeping the mother and the baby together	<ul style="list-style-type: none"> - Early, continuous skin-to-skin contact - Exclusive breastfeeding - Early discharge - Providing warmth - Sensorimotor stimulation - Security - Protection from infections - Affection
The Newborn Individualized Developmental Care and Assessment Program (NIDCAP)	In 1970s Boston, USA	Observation of the infant's behavior according to the synactive theory	<ul style="list-style-type: none"> - Education and training to health care practitioners - Understanding the behavior of premature infants in constant interaction with the environment and sharing it with the parents - In neurodevelopmentally supportive, individual, family-centered framework
Family-Integrated Care (FICare)	In 2010s, Toronto, Canada	Educating the staff and parents in involving parents to the neonatal care	<ul style="list-style-type: none"> - Encouraging parental presence in the unit - Providing psychosocial support for the family, and creating a nurturing environment in the unit - Parents' active involvement in infant care as integral members of the healthcare team
Close Collaboration with Parents	In 2008 Turku, Finland	Educating the staff in involving parents to the neonatal care	<ul style="list-style-type: none"> - Educating neonatal health care team in supporting parents and parenting during early neonatal care - To strengthen partnerships and collaboration between the parents and NICU staff - Fostering shared responsibility - Open information exchange - Emotional support, negotiation - Participation in shared decision-making
Family Nurture Intervention (FNI)	In 2000s New York, USA	Calming sessions performed by mothers to improve mother-infant emotional closeness	<ul style="list-style-type: none"> - Performed by mothers, who receive guidance by trained nurses - Through calming sessions - To promote early mother-infant autonomic emotional closeness in the neonatal unit - To improve infant neurobehavior and the mother's well-being - Based on emotional connection and visceral/autonomic co-regulation between the mother and the infant - The calming sessions are used to build these nurturing interactions between the mother and the infant by using sensory systems (tactile, auditory, olfactory, visual, and kinesthetic)

<p>Supporting and Enhancing NICU Sensory Experiences (SENSE)</p>	<p>In 2010s St. Louis, USA</p>	<p>Educating the parents to support the developmental needs of their preterm infant by applying positive multisensory exposures</p>	<ul style="list-style-type: none"> - SENSE administrator educates and supervises families - Parents are the primary operators in this program - To optimize the NICU environment by helping parents support the developmental needs of their preterm infant by applying positive multisensory exposures each day during the NICU stay - The sensory experiences provided daily by the parents are tactile, auditory, olfactory, visual, and kinesthetic
<p>Mother-Infant Transaction Program (MITP)</p>	<p>In 1980s New York, USA</p>	<p>Educating parents to observe their infant and to respond sensitively to the infants' individual needs</p>	<ul style="list-style-type: none"> - To promote mother-infant interactions and thereby improve developmental outcomes for the preterm infant - Training parents to recognize and interpret infant cues and to respond sensitively to the infants' individual needs -The original MITP consists of one-to-one sessions in the NICU before discharge and home visits during the first three months after discharge - The training helps the parent to be able to calm an upset infant, therefore allowing the infant to develop self-regulation skills
<p>Single-Family Room (SFR)</p>	<p>In 1980s France</p>	<p>Enabling privacy for families</p>	<ul style="list-style-type: none"> - A private room equipped with the necessary medical tools for infant care and treatment while also providing facilities for the parents. - Enabling privacy for families, therefore adding an extra layer to implementing the FCC culture.
<p>Couplet Care</p>	<p>In 1990s Sweden</p>	<p>Minimizes separation by caring for the infant and the mother in the same room from the very beginning</p>	<p>An approach in neonatal care that provides care for the mother in the NICU throughout the hospital stay, coupling the infant's care with the postpartum care of the mother.</p>

2.4.2 The Newborn Individualized Developmental Care and Assessment Program (NIDCAP)

This program originates from the 1970s from Boston Children’s Hospital and Harvard Medical School, in the United States, and is based on synactive theory (Als 1982). Synactive theory describes infant behavior as the expression of ongoing interactions among autonomic, motor, state, attention-interaction, and self-regulation systems – each of which respond to environmental stimuli and mature through individualized, developmentally supportive care (Als 1982; Als & Gilkerson 1997; Westrup et al. 2000). NIDCAP provides education and specific training in developmental behavior observation to health care practitioners in a neurodevelopmentally supportive, individualized, and family-centered framework (Vittner et al. 2024).

2.4.3 Family-Integrated Care (FICare)

This program was developed in Mount Sinai Hospital in Toronto, Canada, in the early 2010s, following an example from Tallinn Children’s Hospital, Estonia, where the first “mother-infant unit” was opened in 1979 due to the shortage of nursing staff (Levin 1994; O’Brien et al. 2013). This care model contributes to the parents’ active involvement in infant care as integral members of the healthcare team (Moreno-Sanz et al. 2024). The program consists of four fundamental principles: educating and supporting the staff, educating the parents, encouraging parental presence in the unit, providing psychosocial support for the family, and creating a nurturing environment in the NICU (Moreno-Sanz et al. 2024). The program can be implemented flexibly depending on the needs of the family and the resources of the organization.

2.4.4 Close Collaboration with Parents

This program originates from Turku University Hospital, Finland, starting from 2008, and is based on developmental theories about early parenthood and parent-infant bonding (Ahlqvist-Björkroth et al. 2017). It is designed to coach neonatal staff – nurses and doctors – in supporting parents and parenting during early neonatal intensive care. This educational program aims to strengthen partnerships and collaboration between the parents and NICU staff, fostering shared responsibility, open information exchange, emotional support, negotiation, and participation in shared decision-making, thus changing the unit’s care culture (Axelin et al. 2018; Ahlqvist-Björkroth et al. 2024).

2.4.5 Family Nurture Intervention (FNI)

This program was designed in early 2000 by Professor Martha Welch in the United States, based on her earlier clinical work (Woodward et al. 2024). The goal of this intervention is to promote early mother-infant autonomic emotional closeness in the neonatal unit to improve infant neurobehavior and the mother's well-being through calming sessions combined with maternal emotional expression (Woodward et al. 2024). This intervention is performed by the mothers, who receive guidance from trained nurses (Woodward et al. 2024). The FNI program sees the biological birthing mother as an exceptionally important first physiological contact to establish a relationship with the newborn infant. This relationship has formed already in utero (through, i.e., hormonal, physiological and neurological changes, fetal movements, maternal voice) and fosters mother-infant attachment postnatally (Woodward et al. 2024). FNI is based on emotional connection and visceral/autonomic co-regulation between the mother and the infant (Welch 2016). The calming sessions are used to build these nurturing interactions between the mother and the infant by using sensory systems (i.e., using a cloth with the mother's smell, guiding the mother to speak and sing emotionally to their infants, touch through the port of the incubator, SSC or holding, eye-contact, taste, temperature, movements) (Welch 2016; Beebe et al. 2018).

2.4.6 Supporting and Enhancing NICU Sensory Experiences (SENSE)

This program was formulated in 2017, and the main aim of this intervention is to optimize the NICU environment by helping parents support the developmental needs of their preterm infant by applying positive multisensory exposures each day during the NICU stay (Pineda et al. 2024). The SENSE administrator educates and supervises families who provide the sensory exposures, and the parents are the primary operators in this program (Pineda et al. 2024). The sensory experiences provided daily by the parents are tactile (holding, SSC), auditory (reading, singing, speaking, music), olfactory (breast milk), visual (parent's face, protection from bright light), and kinesthetic (changing positions, including tummy time) (Pineda et al. 2024).

2.4.7 Mother-Infant Transaction Program (MITP)

This program was developed in the late 1980s at Columbia University in New York City and is designed to promote mother-infant interactions and thereby improve developmental outcomes for the preterm infant (Rauh et al. 1990). This program is based on training parents to recognize and interpret infant cues and to respond

sensitively to the infants' individual needs, thus minimizing the preterm infants' stress (Milgrom et al. 2013). The original MITP consists of one-to-one sessions in the NICU before discharge and home visits during the first three months after discharge (Newnham et al. 2009). Various versions of this program have been used in practice, e.g., carrying out the initial debriefing session and a varying number of one-to-one sessions in the NICU or at home (Ulvund 2022). Overall, the one-to-one sessions were designed to improve the quality of mother-infant interaction by guiding the mothers to be more sensitive and responsive to their infants' physiological and social cues. This sensitivity training includes homeostatic, motoric, distress, alert and playing behaviors, temperament, and care-taking routines (Newnham et al. 2009). Over time this emotional regulation training helps the parent to be able to calm an upset infant, therefore allowing the infant to develop self-regulation skills (Newnham et al. 2009).

2.4.8 Single-family rooms

The first NICU consisting only of private single-family rooms (SFR) was built in the 1980s in France to minimize nosocomial infections (White 2010). A SFR is a private room equipped with the necessary medical tools for infant care and treatment while also providing facilities for the parents. Parental presence in the neonatal units and SFRs has been promoted since the early 1990s (Lehtonen et al. 2020). Today, NICU design and SFRs are important cornerstones in enabling privacy for families, therefore adding an extra layer to implementing the FCC culture. Designing and planning optimal neonatal units plays a key role. In addition to utilizing efficient medical technology, the importance of creating the best care environment for infants, families, and caregivers is also highlighted (White 2011).

2.4.9 Couplet Care

The development of the Couplet Care approach begun in Sweden in the late 1990s (Klemming et al. 2021). This is an approach in neonatal care that provides care for the mother in the NICU throughout the hospital stay, coupling the infant's care with the postpartum care of the mother (Westrup 2015; Klemming et al. 2023). Over the years, it has become clear that engaging families in developmentally supportive care from the very beginning is very important (Westrup 2015). Almost half of the mothers need prolonged medical care after a preterm delivery (Westrup 2015) and therefore would be separated from their infant during the very important first days of attachment and bonding. This care approach minimizes separation by caring for the infant and the mother in the same room from the very beginning, for as long as the mother needs hospital care (Klemming et al. 2023; White 2024). The innovative

Couplet Care model has led neonatal care to a new phase where increasing numbers of couplet care NICUs are opened each year (White 2024).

There are additional family-based interventions, which are not discussed in this thesis, e.g., Creating Opportunities for Parent Empowerment, the Infant Health and Development Program (Roué et al. 2017). Although there are differences in the nature and framework of these interventions, there are still similarities in developmental support for the child and the family, and parenting education (Roué et al. 2017, Ahlqvist-Björkroth et al. 2024).

2.5 Early environment and preterm infant's outcomes

2.5.1 The effects of FCC interventions

The effects of FCC interventions are summarized in **Table 2**.

2.5.1.1 Kangaroo Mother Care

A meta-analysis by Boundy et al. (2016) showed that infants receiving kangaroo care, when compared to infants receiving conventional care, have a lower mortality, readmission rate, risk of infection and breathing rate, as well as a higher oxygen saturation, better temperature and blood glucose balance, and increased breastfeeding rate. A recent meta-analysis was in line with the results regarding lower mortality rates (Sivanandan & Sankar 2023). A randomized clinical trial from Sweden and Norway showed that even immediate SSC within the first 6 hours after birth in very preterm infants has beneficial effects on cardiorespiratory stability (Linnér et al. 2022), normal thermoregulation (Lode-Kolz et al. 2023), empowered parents' experience and early parent-infant bonding, including both mothers and fathers (Lilliesköld et al. 2022). A more recent multicenter randomized study from three Norwegian neonatal units, which compared immediate SSC with standard care in very preterm infants after delivery, found no difference between the groups in neurodevelopmental outcomes at two to three years of corrected age, as measured by the Bayley Scales of Infant Development (Kristoffersen et al. 2025). Although the same study demonstrated that breastfeeding rates at discharge were statistically significantly higher in the SCC group (Kristoffersen et al. 2025).

Schneider et al. reported that KMC influences the connectivity of cerebral pathways and therefore influences brain networks and synaptic efficacy up to 14–15 years of age (2012). A study that analyzed SSC and sleep patterns by electroencephalography found that SSC (one hour a day, four times a week, duration 8 weeks) accelerates brain maturation (more quiet sleep, longer sleep cycles,

increased respiratory regularity) in healthy preterm infants when compared with non-SSC control groups (Scher et al. 2009). However, the control group was not recruited contemporaneously and was recorded in different hospital settings, which might have influenced the results (Scher et al. 2009). A meta-analysis of randomized controlled trials that explored the effect of kangaroo mother care on physiological stress parameters of premature infants found no statistically significant difference between KMC and standard care groups in heart rate, oxygen saturation, and temperature control (Cristóbal Cañadas et al. 2022).

2.5.1.2 The Newborn Individualized Developmental Care and Assessment Program

A randomized controlled trial in three centers in the United States showed that preterm infants in a NIDCAP care group had a shorter duration of parenteral feeding, improved growth, a shorter length of stay in the hospital, reduction in parental stress, and enhanced appreciation of the infant (Als et al. 2003). A randomized trial that tested the neurodevelopmental effectiveness of the NIDCAP in preterm infants found that this early experience in the NICU enhances early brain functions, brain structure, and behavioral regulation (Als et al. 2004). Infants who received NIDCAP developmental care had improvement in Assessment of Preterm Infants' Behavior (APIB) scores (i.e., self-regulation, motor system functions, state stability, intensity), enhanced functional connectivity between brain regions, measured using electroencephalography, and a more mature brain structure, measured using magnetic resonance imaging at two weeks of corrected age (Als et al. 2004). A French single-center retrospective study comparing three time periods before and after implementing the NIDCAP program showed that by implementing the NIDCAP intervention in the NICU, there were fewer painful procedures and more parental presence, SCC was performed earlier, the duration of mechanical ventilation was shorter and weight gain at discharge was better (Klein et al. 2021). Additionally, the NIDCAP improved behavioral function at nine months of corrected age, measured using the Bayley Scales of Infant Development (Als et al. 1994), although, at two years of age, there were no difference in the Bayley scores of the NIDCAP group and the control group (Ariagno et al. 1997)

Although studies have shown positive results from implementing the NIDCAP program, other studies and meta-analyses claim that this approach seems to have no statistically significant effects in improving short- and long-term outcomes (Ariagno et al. 1997, Westrup et al. 2000, Ohlsson & Jacobs 2013). A meta-analysis of five randomized control trials showed improvement in neurodevelopmental outcomes at nine and 12 months, but not at two years of corrected age (Jacobs et al. 2002). A more recent meta-analysis with 11 trials and seven follow-up studies and altogether

627 preterm infants did not find any significant difference between the NIDCAP and control groups in short-term medical nor long-term neurodevelopmental outcomes (Ohlsson & Jacobs 2013). In a Swedish randomized clinical trial, no significant association was found in the duration of mechanical ventilation, nor in the growth or discharge timing of the NIDCAP group when compared to the control group (Westrup et al. 2000).

2.5.1.3 Family-Integrated Care

A randomized control trial in 26 NICUs from Canada, Australia, and New Zealand, including 895 preterm infants in the FICare group and 891 infants in the standard care group, reported that infants in the FICare group had better weight gain, a higher proportion of mothers breastfeeding more than six times a day at discharge and parents with lower mean stress scores (O'Brien et al. 2018). No difference was found in outcomes related to mortality, major morbidity, duration of oxygen therapy, or length of hospital stay (O'Brien et al. 2018).

Another randomized controlled trial from 11 NICUs in China, including 601 preterm infants, reported that the FICare group (six units), when compared to the standard care group (five units) had better weight gain velocity, a shorter duration of supplemental oxygen, fewer nosocomial infections, a shorter length of stay in the hospital and a higher breastfeeding rate at discharge (Hei et al. 2021).

A quasi-experimental study from the United States including 253 infants found that the FICare group had fewer nosocomial infections (Franck et al. 2022), and FICare was associated with fewer post-discharge depression symptoms among mothers who had higher NICU-related stress and participated actively in the infant care (Franck et al. 2023).

The long-term impacts of FICare were reported by Church et al. (2020), demonstrating that FICare infants had better self-regulation skills at 18–21 months of corrected age. Synnes et al. (2022) reported better motor scores in FICare infants, measured using the Bayley-III assessment tool at 18 months of corrected age, although they also reported that the FICare group infants had a higher incidence of intraventricular hemorrhage. There was no difference in the cognitive or language scores of the FICare group and the standard care group (Synnes et al. 2022). Moe et al. (2022) reported higher scores in the Ages and Stages Questionnaire's communication domain, indicating a protective effect of FICare against communication delays up to 24 months of corrected age; no other significant associations (in the motor, problem-solving, or social domains) were found. A retrospective study from Nantong, China, including 115 preterm infants in the FICare group and 100 preterm infants in the traditional care group, was able to show the benefits of FICare for preterm infants' later neurodevelopment and language

development at 6, 12, and 18 months of age (Liang et al. 2022). These two care groups were comparable in their maternal and neonatal background characteristics, even though this was a retrospective study without randomization between the study and control groups (Liang et al. 2022). They demonstrated early language milestone scores (related to expressive, receptive, and visual abilities) and development quotient scores (related to adaptability, motor and fine movement, language understanding function, and social contact) that were significantly higher from 6 to 18 months of age in the FICare group, where parents participated in their infant's care at least three hours a day, compared to the traditional care group, where the parents were able to visit the unit only twice a week (Liang et al. 2022).

2.5.1.4 Close Collaboration with Parents

Nationwide studies in Finnish hospitals that have implemented the educational program have shown that this intervention increased the parents' presence in the NICU and the amount of SSC (He et al. 2021), shortened the length of stay in the hospital, improved the infants' postnatal growth, and decreased the rehospitalization rate (Itoshima et al. 2024). Additionally, it was shown in a pre-post study covering 8 NICUs that the Close Collaboration with Parents intervention increased the overall quality of family-centered care, measured through interviews and the Bliss Audit Tool for the staff and parents, containing statements about different categories of FCC (Toivonen et al. 2020). Maternal depression scores measured using the Edinburgh Postnatal Depression Scale were significantly lower in the post-intervention cohort (Ahlqvist-Björkroth et al. 2019) and in the long term, up to two years after delivery (Ahlqvist-Björkroth et al. 2022). Interestingly, the fathers' and nurses' satisfaction with the overall quality of FCC increased after implementing the program (Toivonen et al. 2023). The mothers' satisfaction with the FCC quality was at a high level both before and after the intervention, without a difference between the two time periods (Toivonen et al. 2023).

2.5.1.5 Family Nurture Intervention

Randomized control trials evaluating the effectiveness of this intervention showed positive effects on the mother-infant relationship, maternal mental health, and infant short- and long-term neurodevelopmental outcomes (Woodward et al. 2024). More precisely, infants had lower heart rate in the FNI group (Ludwig et al. 2021), increased cerebral cortical electroencephalographic activity and greater regional independence at term (Welch et al. 2017), more positive mother-infant face-to-face engagement at four months of corrected age (Beebe et al. 2018), higher cognitive

and language scores and fewer attention problems at 18 months of corrected age (Welch et al. 2015), and less maternal depression and anxiety (Welch et al. 2016).

2.5.1.6 Supporting and Enhancing NICU Sensory Experiences

Only a few studies have been conducted about the efficacy of the SENSE program. It has been shown that infants who participated in the SENSE program had better neurobehavioral scores at term, measured using the NICU Network Neurobehavioral Scale (NNNS) and the Hammersmith Neonatal Neurological Evaluation (HNNE), and their parents reported more confidence (Pineda et al. 2020). Infants who participated in the SENSE program had better feeding outcomes, achieving faster full oral feeding (Patel et al. 2021). Additional research on the efficacy of this program is ongoing (Pineda et al. 2024).

2.5.1.7 Mother-Infant Transaction Program

A randomized controlled trial from Australia including 123 preterm infants <30 GW found that the MITP intervention promotes the mothers' sensitivity and responsiveness to infant cues, resulting in significantly lower stress in preterm infants during a bathing session at term age and higher scores in communication abilities at six months of corrected age, reported based on parental report measurement (Milgrom et al. 2013). There were no significant between-group differences in behavioral, cognitive, or executive functioning at two and 4.5 years of corrected age in the same study population (Milgrom et al. 2019).

Another randomized controlled trial from Norway, including 118 late preterm infants (30–36 GW), found that mothers in the intervention group had lower depression scores at one month after discharge, but no group differences were found in later parenting stress assessments at six and 12 months of corrected age (Ravn et al. 2012). The same study reported that more mothers were breastfeeding at nine months of corrected age in the intervention group than in the control group (Ravn et al. 2012). No favorable effects were found on maternal perception of infant temperament, as the study reported less smile and laughter at six and 12 months of corrected age in the intervention group (Ravn et al. 2012). Additionally, no significant differences between the intervention and standard care groups were found in infant communication skills, reported by mothers using Pictorial Infant Communication Scales method at 12 months of corrected age (Ravn et al. 2012).

Another randomized controlled study from Norway, including 148 preterm infants with birth weight <2000 g, reported that the infants in the intervention group, when compared to the standard care group, had no difference in cognitive, motor, and behavioral outcomes at two years of corrected age, but the parenting stress index

was reduced (Kaaresen et al. 2008). The same intervention group had fewer behavioral problems reported by the mothers at the corrected age of five years (Nordhov et al. 2012) and fewer attention problems and better academic performance, reported by their parents and teachers, at the age of 7 and 9 years (Landsem et al. 2015).

2.5.1.8 Single-family room

A meta-analysis including 4793 patients reported that compared to open bay units, a SFR decreased the incidence of sepsis and promoted breastfeeding outcomes, whereas neither differences in cognitive neurodevelopment nor effects on the length of stay, mortality, or other morbidity rates were found (van Veenendaal et al. 2019). However, it is important to mention that this meta-analysis included one study in the family room category where infants were treated in a private room (Pineda et al. 2014) with very little parental presence, and SFR criteria were not met in this study. The other studies in this analysis about neurodevelopmental outcomes (Lester et al. 2016, Vohr et al. 2017) favored the SFR unit (van Veenendaal et al. 2019). An international survey based on 10 neonatal networks, including 4662 infants, found benefits from SFR in relation to mortality, major morbidity, sepsis, bronchopulmonary dysplasia, and length of hospital stay (Lehtonen et al. 2020). A two-center prospective study from Norway comparing the SFR unit to an open-bay unit showed that SFR design increased parental presence, parent-infant closeness, involvement, and SSC (Tandberg et al. 2018) and decreased stress scores for both parents (Tandberg et al. 2019). A meta-analysis by van Veenendaal et al. (2020) was in line with these results by suggesting that SFR design increases parental presence, empowerment, and satisfaction with FCC, increases SSC, and reduces NICU-related stress.

2.5.1.9 Couplet Care

As this is a fairly recent care model, only a few studies have been completed to assess the effect of the intervention. A recent study that evaluated the effect of Couplet Care showed that this care model enables the start of the first SSC significantly earlier, even within two hours after birth, thereby accelerating the parent-infant closeness during the early moments of postnatal care (Itoshima et al. 2024). Additionally, a recent study showed that Couplet Care lowered maternal stress and improved breastfeeding outcomes (Doughty et al. 2024).

Table 2. Effects of family-centered care interventions

	Possible positive effects			No effect or conflicting results
	for infant		for parents	
	Meta-analysis, randomized controlled trials, nationwide studies	Clinical trials		
Kangaroo Mother Care (KMC)	<ul style="list-style-type: none"> - Lower mortality (Boundy et al. 2016, Sivanandan & Sankar 2023) - Lower readmission rate (Boundy et al. 2016) - Lower risk of infection (Boundy et al. 2016) - Lower breathing rate, higher oxygen saturation (Boundy et al. 2016) - Better temperature balance (Boundy et al. 2016) - Better blood glucose balance (Boundy et al. 2016) - Increased breastfeeding rate (Boundy et al. 2016, Kristoffersen et al. 2025) 	<ul style="list-style-type: none"> - Cardio-respiratory stability (Linnér et al. 2022) - Better thermo-regulation (Lode-Kolz et al. 2023) 	<ul style="list-style-type: none"> - More empowered (Lilliesköld et al. 2022) - Enhances early parent-infant bonding (Lilliesköld et al. 2022) 	<ul style="list-style-type: none"> - No statistically significant difference with standard care in oxygen saturation, heart rate or temperature control (Cristóbal Cañadas et al. 2022) - Accelerates brain maturation (more quiet sleep, longer sleep cycles)? Study compared different hospital settings, which may have influenced the results (Scher et al. 2009) - No difference compared with standard care in neurodevelopmental outcomes at two to three years of corrected age (Kristoffersen et al. 2025)
The Newborn Individualized Developmental Care and Assessment Program (NIDCAP)	<ul style="list-style-type: none"> - Shorter duration of parenteral feeding (Als et al. 2003) - Improved growth (Als et al. 2003) - Shorter length of stay (Als et al. 2003) - Enhances infant's early brain functions, brain structure, and behavioral regulation (Als et al. 2004) 	<ul style="list-style-type: none"> - Fewer painful procedures (Klein et al. 2021) - Shorter duration of mechanical ventilation (Klein et al. 2021) - Better weight gain at discharge (Klein et al. 2021) - Improved behavioral function at 9 months of corrected age (Als et al. 1994) 	<ul style="list-style-type: none"> - Reduction in parental stress (Als et al. 2003) - Enhanced appreciation of the infant (Als et al. 2003) - More parental presence (Klein et al. 2021) 	<ul style="list-style-type: none"> - No statistically significant effects in improving short- and long-term outcomes (Ariagno et al. 1997, Westrup et al. 2000, Ohlsson & Jacobs 2013) - Improvement in neurodevelopmental outcomes at nine and 12 months, but not at two years of corrected age (Jacobs et al. 2002) - No significant association was found in the duration of mechanical ventilation, nor in the growth or discharge timing of the NIDCAP group when compared to the control group (Westrup et al. 2000)

<p>Family-Integrated Care (FICare)</p>	<ul style="list-style-type: none"> - Better weight gain (O'Brien et al. 2018, Hei et al. 2021) - Shorter duration of supplemental oxygen (Hei et al. 2021) - Fewer nosocomial infections (Hei et al. 2021, Franck et al. 2022) - Shorter length of stay in the hospital (Hei et al. 2021) - Higher breastfeeding rate at discharge (O'Brien et al. 2018, Hei et al. 2021) 	<ul style="list-style-type: none"> - Better self-regulation skills at 18–21 months of corrected age (Church et al. 2020) - Better motor scores at 18 months of corrected age (Synnes et al. 2022) - Fewer communication delays up to 24 months of corrected age (Moe et al. 2022) 	<ul style="list-style-type: none"> - Lower mean parent stress scores (O'Brien et al. 2018) - Fewer post-discharge depression symptoms among mothers (Franck et al. 2023) 	<ul style="list-style-type: none"> - No difference in mortality, major morbidity, duration of oxygen therapy, or length of hospital stay (O'Brien et al. 2018) - No difference in the cognitive or language scores (Synnes et al. 2022) - No significant associations in the motor, problem-solving, or social domains (Moe et al. 2022) - Benefits of FICare for preterm infants' later neurodevelopment and language development at 6, 12, and 18 months of age? Parental presence at least three hours a day vs only twice a week, might have influenced the results (Liang et al. 2022)
<p>Close Collaboration with Parents</p>	<ul style="list-style-type: none"> - Increased amount of SSC (He et al. 2021) - Shorter length of stay in the hospital (Itoshima et al. 2024) - Improved postnatal growth (Itoshima et al. 2024) - Decreased rehospitalization rate (Itoshima et al. 2024) 	<p>Increased the overall quality of family-centered care (Toivonen et al. 2020)</p>	<ul style="list-style-type: none"> - Lower maternal depression scores (Åhqvist-Björkroth et al. 2019, 2022) - Fathers' and nurses' increased satisfaction with the overall quality of FCC (Toivonen et al. 2023) - Increased parental presence (He et al. 2021) 	
<p>Family Nurture Intervention (FNI)</p>	<ul style="list-style-type: none"> - Lower heart rate (Ludwig et al. 2021) - Increased cerebral cortical electroencephalographic activity at term (Welch et al. 2017) - More positive mother-infant face-to-face engagement at four months of corrected age (Beebe et al. 2018) - Higher cognitive and language scores at 18 months of corrected age (Welch et al. 2015) - Fewer attention problems at 18 months of corrected age (Welch et al. 2015) 		<p>Less maternal depression and anxiety (Welch et al. 2016)</p>	

<p>Supporting and Enhancing NICU Sensory Experiences (SENSE)</p>		<ul style="list-style-type: none"> - Better neuro-behavioral scores at term (Pineda et al. 2020) - Faster full oral feeding (Patel et al. 2021) 	<p>More confidence (Pineda et al. 2020)</p>	
<p>Mother-Infant Transaction Program (MITP)</p>	<ul style="list-style-type: none"> - Lower stress in preterm infants during a bathing session at term age (Milgrom et al. 2013) - Higher scores in communication abilities at six months of corrected age (Milgrom et al. 2013) - Better breastfeeding rates at 9 months of corrected age (Ravn et al. 2012) - Fewer behavioral problems at five years of corrected age (Nordhov et al. 2012) - Fewer attention problems and better academic performance at the age of 7 and 9 years (Landsem et al. 2015) 		<ul style="list-style-type: none"> - Promotes the mothers' sensitivity and responsiveness to infant cues (Milgrom et al. 2013) - Mothers' lower depression scores at one month after discharge (Ravn et al. 2012) - Reduced parenting stress index at infant's age of two years of corrected age (Kaaresen et al. 2008) 	<ul style="list-style-type: none"> - No significant differences in behavioral, cognitive, or executive functioning at two and 4.5 years of corrected age (Milgrom et al. 2019) - No group differences in later parenting stress assessments at six and 12 months of corrected age (Ravn et al. 2012) - No favorable effects on maternal perception of infant temperament (Ravn et al. 2012) - No significant differences in infant communication skills at 12 months of corrected age (Ravn et al. 2012) - No significant difference in cognitive, motor, and behavioral outcomes at two years of corrected age (Kaaresen et al. 2008)
<p>Single-Family Room (SFR)</p>	<ul style="list-style-type: none"> - Decreased the incidence of sepsis (van Veenendaal et al. 2019, Lehtonen et al. 2020) - Better breastfeeding outcomes (van Veenendaal et al. 2019) - Reduced mortality (Lehtonen et al. 2020) - Reduced major morbidity (Lehtonen et al. 2020) - Reduced length of hospital stay (Lehtonen et al. 2020) 	<p>Better cognitive and language scores at 18–24 months of corrected age (Lester et al. 2016, Vohr et al. 2017)</p>	<ul style="list-style-type: none"> - Increased parental presence (Tandberg et al. 2018, Veenendaal et al. 2020) - Increased parent-infant closeness and SSC (Tandberg et al. 2018, Veenendaal et al. 2020) - Better parental involvement and empowerment (Tandberg et al. 2018, Veenendaal et al. 2020) - Decreased stress scores for both parents (Tandberg et al. 2019, Veenendaal et al. 2020) - Satisfaction with overall FCC (Veenendaal et al. 2020) 	
<p>Couplet Care</p>		<ul style="list-style-type: none"> - First SSC significantly earlier (Itoshima et al. 2024) - Better breast-feeding outcomes (Doughty et al. 2024) 	<p>Lower maternal stress (Doughty et al. 2024)</p>	

FCC – Family-Centered Care; SSC – Skin-to-Skin Contact; NICU – Neonatal Intensive Care Unit

2.5.2 Effects from sensory stimulation

As previously described, the early environment and parental closeness after preterm birth play a crucial role in the well-being and development of an infant. In addition to the benefits of developmental care, there is a growing body of evidence on the effects of sensory stimulation. Animal studies have shown that positive prenatal sound stimulation with maternal voice results in increased neurogenesis and strengthens synaptic connectivity, while negative stimuli could lead to developmental disorders (Chaudhury et al. 2016). As the auditory, olfactory, visual, and nociceptive systems emerge earlier, but mature and become more functional gradually during the last trimester of pregnancy (Borsani et al. 2019), they significantly influence the preterm infant's developmental trajectory in the NICU environment. The information on the impact of sensory stimulation on the development of preterm infants remains somewhat inconsistent, as many studies are ongoing, and there are controversial and inconclusive results from different studies.

2.5.2.1 Auditory stimulation

A systematic review by Best et al. (2018) concluded that preterm infants in the neonatal unit are exposed to more noise than language. Noise and sound peaks trigger discomfort in preterm infants (Marchal et al. 2021). A loud and noisy environment has negative short-term effects on preterm infants' cardiac, respiratory, and behavioral stability (McMahon et al. 2012). Conversely, frequent singing during SSC is associated with improved neural processing of speech sounds at term age and therefore might improve the development of the auditory system (Kostilainen et al. 2021; Partanen et al. 2022). Exposure to human and maternal voices during neonatal care improved short-term outcomes of the preterm infants in terms of heart and respiratory rate, oxygen saturation, and behavioral measures (reduction in distress, crying, more deep sleep) (Saliba et al. 2018; Filippa et al. 2017), although many inconsistencies between different studies still exist (Provenzi et al. 2018; Filippa et al. 2020).

In terms of long-term outcomes, Caskey et al. (2011) reported that there were more adult words and infant vocalizations during parental presence in the NICU, and adult talk during neonatal care was associated with better cognitive and language scores at seven and 18 months of corrected age (Caskey et al. 2014). Additionally, a recent randomized, controlled, parent-driven language enrichment study in the SFR NICU, where the intervention group was taught various language activities (reading, singing to the preterm infant), found that increase in parent-infant conversational turns and adult word count was positively associated with improved language scores at two years of corrected age (McGowan et al. 2024). Our study group has previously reported that high numbers of overheard adult words in the NICU were negatively

associated with language processing skills at 18 months of corrected age (Ståhlberg-Forsén et al. 2022). Another randomized control singing intervention study, including 74 preterm infants from Finland and Sweden, found that parental singing during the neonatal period did not improve cognitive or language outcomes in preterm infants at two to three years of corrected age (Kostilainen et al. 2023).

2.5.2.2 Visual, olfactory and nociceptive stimulation

Preterm infants react to variations in illumination, even within the minimal recommended light level range, with an increase in heart and respiratory rate, changes in cerebral oxygenation (Zores et al. 2015), and disruption in sleep quality (Zores et al. 2018).

Smell and taste might play a role in the transition to the postnatal feeding rhythm through recognition of the mother and initiating metabolic pathways (Bloomfield et al. 2017). Recent meta-analyses, with 871 and 1638 preterm infants respectively, concluded that olfactory and gustatory stimulation during neonatal care reduces the time to full enteral feeds (Zhang et al. 2024) and the time to reach full oral feeds (Alenezi et al. 2024). Another recent meta-analysis from the Cochrane database with 1277 preterm infants concluded that the available evidence about the smell and taste of milk is uncertain, with little to no effect on feeding outcomes (Delgado Paramo et al. 2024). An experimental study from a South Korean university hospital described that the study group who received olfactory stimulation with maternal breast milk had a significantly lower frequency of apnea compared to the control group ($p = 0.021$) (Lee & Ra 2021). Furthermore, a recent review highlighted that breast milk has potential bioactive components that could modify the epigenetic mechanisms and therefore influence both preterm- and term-born infants' health (Gialeli et al. 2023).

A study using near-infrared spectroscopy to measure preterm infants' cortical responses to irritative odors (such as disinfectant, and adhesive remover) found that preterm and term infants exhibit olfactory and nociceptive cortical activation, eliciting behavioral pain responses (Frie et al. 2018). A recent meta-analysis, with 961 preterm infants, about non-pharmacological interventions in reducing pain described with moderate confidence that sugars, non-nutritive sucking, maternal heart sounds, lullabies, breast milk taste/odor, and SSC reduce pain in preterm infants compared to no intervention (Lopes et al. 2024).

These limited studies further highlight the significance of sensory stimulation in early environments, contributing to the well-being of preterm infants. However, due to inconsistencies, additional research is needed.

2.6 Gaps in the literature and rationale for the thesis

Even though neonatal intensive care has improved during recent decades, and the survival rate of preterm infants has increased, neurodevelopmental impairments are still prevalent in preterm infants (Pascal et al. 2018; O'Reilly et al. 2020; Morgan et al. 2022; McGowan et al. 2022). Since parent-infant bonding seems to be crucial for neurobehavioral development and the outcomes of preterm infants, neonatal care should prioritize supporting their parents' presence and participation in the NICU. Although many units have already implemented FCC practices and welcome the parents' presence and participation in neonatal care, there is still a wide variation in the parents' presence and FCC quality between different units and countries (Raiskila et al. 2016). Developmental and FCC principles are commonly used in NICUs around the world, but integrating parents into the medical rounds and shared decision-making needs wider consideration and implementation (Axelin et al. 2018). According to a recent Dutch national survey with 344 parents, only one-third of them felt that they could participate in decision-making during medical rounds (Hoeben et al. 2024). To our knowledge, no previous studies have evaluated the parents' own perspectives on their role in the decision-making process during neonatal care on an international level. Further evaluation is necessary to identify the factors that may hinder parents' active involvement in decision-making.

There is increasing evidence about the effects of developmentally supportive family-centered care interventions on preterm infants' short- and long-term outcomes, although inconsistencies still exist. As there are few studies that have shown the potential positive effects of a child's parents' speech in the NICU environment on later child development (Caskey et al. 2014; McGowan et al. 2024), a lot is still unknown. There is a need to explore the mechanisms behind the benefits shown by FCC interventions – for example, the effects of the parents' speech and auditory environment. Additionally, the impact of variation in word exposure has not been studied using objective measures of attention.

3 Aims

The aim of this thesis was to study the quality of family-centered care practices that involve parental participation in decision-making, as well as the mechanisms of how parental presence and vocal contact in the neonatal environment affect the child's later social-cognitive and language development.

The specific aims of this study were:

1. To study the parents' own perception about their presence and participation in decision-making during medical rounds across Europe. (Study I)
2. To study how exposure to parental speech in the neonatal environment affects the infant's social-cognitive development at seven months of corrected age. (Study II)
3. To study how exposure to their parents' speech and parent-infant communication in the neonatal environment affects child language development at one and two years of corrected age. (Study III)

4 Materials and Methods

This thesis is based on three original publications described in **Table 3**.

Table 3. Study designs for the original publications of the thesis.

Research aim	Population	Study design	Outcomes
Study I: To evaluate the parents' presence and the degree of their participation in discussions during medical rounds in 11 European NICUs.	<35 GW infants and their parents from 11 NICUs in six European countries Prospective International Closeness Survey	-Parental Closeness Diary during the first two weeks of hospitalization that measured parents' presence, skin-to-skin contact, and holding -Likert scale text-message question sent to the parent: <i>"To what extent did you participate in discussions during the doctor's round/visit?"</i> .	- the parents' presence during medical rounds -the parents' participation during medical rounds - family and hospital characteristics that may facilitate or hinder the parents' integration in medical rounds.
Study II: To study the association between parental speech in the neonatal environment and preterm infants' social-cognitive development	<32 GW infants and their parents from two NICUs, from Turku, Finland, and Tallinn, Estonia Longitudinal APPLE Study	- Parental Closeness Diary during 32–34 weeks of infant's PMA - LENA recording of the auditory environment in the NICU for 16 hours during 32–34 weeks of PMA - Eye-tracking disengagement test at seven months of corrected age	Attention to faces and non-face patterns, with the preference for parents over unfamiliar faces
Study III: To test whether the parents' speech and parent-infant conversational turns in the neonatal environment are associated with the preterm infants' language outcomes at one and two years of corrected age.	<32 GW infants and their parents from two NICUs from Turku, Finland, and Tallinn, Estonia Longitudinal APPLE Study	- Parental Closeness Diary during 32–34 weeks of infant's PMA - LENA recording for auditory environment in the NICU for 16 hours during 32–34 weeks of PMA - the infant's lexical abilities tested at one year of corrected age - the child's general language development tested at two years of corrected age	- receptive and expressive lexicon size at one year of corrected age - receptive and expressive language skills at two years of corrected age

NICU – Neonatal Intensive Care Unit, GW – gestational weeks, PMA – postmenstrual age, LENA – Language Environment Analysis; APPLE Study – Auditory environment by Parents of Preterm infant; Language development and Eye-movements

4.1 Parental presence and participation during medical rounds in an international survey

The International Closeness Survey was a multi-centered prospective study conducted together with the Separation and Closeness Experiences in Neonatal Environment (SCENE) Study Group. SCENE is a multidisciplinary group of international professionals doing research to improve parents' and infants' experiences and outcomes of neonatal care. The focus of the SCENE collaboration was to undertake research into how and why parent-infant physical and emotional closeness varies in neonatal units within and between countries; the short- and long-term effects of closeness and separation on infants, parents, and the infant-parent dyad; as well as how to optimize parental and infant health and wellbeing. (<https://sites.utu.fi/scene>).

This prospective survey evaluated the quality of FCC experienced by mothers, fathers, and nurses. The survey considered various components of FCC: active listening; parental participation in infant care; individualized guidance given to parents; the parents' participation in decision-making, trust in staff in relation to infant care, sense of being trusted by the staff, participation in discussions in medical rounds; individualized information, and emotional support (**Table 4**).

The survey was conducted in 11 NICUs in six European countries: Finland (Turku), Sweden (Danderyd, Huddinge, and Uppsala), Norway (Bergen, Drammen and Tromsø), Estonia (Tallinn and Tartu), Spain (Madrid) and Italy (Como). The participating neonatal units were level II–IIIc, as defined by the American Academy of Pediatrics (2012; Stark et al. 2023). Preterm infants born before 35 weeks of gestation and their parents were recruited in the survey. The exclusion criteria were multiple pregnancies of more than two fetuses, no common language, the parent(s) not having a mobile phone, or life-threatening disease. The sample size was predetermined to 30 families for every participating NICU, based on the pilot study and the development of the data collection tools for measuring FCC in NICUs described by Axelin et al. 2020. The study period was from September 2013 to August 2014. Out of 528 eligible families, 440 were approached at the infants' postnatal age of two to six days. Due to the parents' refusal or missing data in 172 cases, a total of 262 families participated in the closeness survey (mother and partner, 208; only mother, 48; only father, 6).

The quality of family-centered care was measured using nine text-message questions sent to the infant's parents every evening during the infant's hospital stay, in random order (**Table 4**). The nurses' perspectives were measured using web questions answered after each shift they worked at the infant's bedside. The questions were answered on a 7-point Likert scale (1–7, with higher values being more positive; 0 was used if the parent was not in the unit that day). Parental satisfaction with family-centered care and nurse perceptions have been previously

reported by Raiskila et al. (2016). The parents' presence and participation in medical rounds (Study I) was analyzed using question nr 7 posed to the parents – to what extent did you participate in discussions during the doctor's round/visit? A total of 241 families were included in Study I: 630 text-message answers from mothers and 474 answers from fathers.

Table 4. International Closeness Survey questions.

Text-message to the parents	Web questions for the nurses
1. To what extent did the staff listen to you today?	To what extent did you listen to parents today?
2. To what extent did you participate in your baby's care today?	To what extent did you make it possible for parents to participate in the care of their baby today?
3. To what extent did the guidance provided by the staff meet your needs today?	To what extent was the guidance you provided adapted to meet the individual needs of parents' today?
4. To what extent was your opinion considered in decisions made about your baby today?	To what extent did you consider parents' opinions in decisions concerning their baby today?
5. To what extent did you trust the staff in the care of your baby today?	To what extent did parents trust you in the care of their baby today?
6. To what extent did the staff trust you in the care of your baby today?	To what extent did you trust parents in the care of their baby today?
7. To what extent did you participate in discussions during the doctor's round/visit?	To what extent was the information you gave adapted to meet the individual needs of parents' today?
8. To what extent did the information provided by the staff meet your needs today?	To what extent did you offer parents emotional support today?
9. To what extent did the staff offer you emotional support today?	

Parents were requested to respond to a questionnaire about infant and family characteristics at discharge. Infant and family characteristics included in Study I were gestational age at birth; when the first text-message was sent to the parent; distance from home to hospital; whether there was a sibling at home; the parents' age, education, and employment; and any foreign language spoken at home. The following classifications for the parents' education were used: obligatory school, more than obligatory school but less than university, and university degree. In all countries except Finland, university of applied sciences degrees were recognized as equivalent to university degrees. Foreign languages were defined as any language other than the native languages of each country. In Estonia, Estonian and Russian were considered as native languages, and in Finland, Finnish and Swedish were native languages.

Hospital characteristics were collected using a questionnaire sent to every unit's principal investigator. Hospital characteristics in the analysis of Study I included unit

size, when was the first skin-to-skin contact, the unit's policy for parents staying overnight, and the unit's policy for inviting parents to the medical rounds.

In the statistical analysis of Study I, the parents' non-presence in the unit was calculated using text-message answers 0, meaning that the parent was not in the unit that day.

4.2 Language environment assessment in a Finnish and an Estonian NICU

The APPLE Study (Auditory environment by Parents of Preterm infant; Language development and Eye-movements, Clinical Trials ID NCT04826978, <https://sites.utu.fi/apple/>) was a longitudinal study conducted in two neonatal units – in Turku University Hospital, Turku, Finland, and in Tallinn Children's Hospital, Tallinn, Estonia. This study explored the importance of very early parental speech and the parents' presence at the neonatal intensive care unit for the later development of premature infants during the first two years of life (<https://sites.utu.fi/apple/>).

Preterm infants born before 32 weeks of gestation and their parents, speaking Finnish, Swedish, Estonian, or Russian, were recruited in the study. The exclusion criteria were multiple pregnancies of more than two fetuses, life-threatening disease, major congenital anomalies, chromosomal anomalies, syndromes of clinical significance, and infant being transferred to other hospital after delivery. The recruitment period was from February 2017 to December 2020, and the participants were followed up until the corrected age of two years (Gantt chart in **Figure 1**). Overall, 115 children born preterm and their parents were recruited for the study (62 infants from Turku University Hospital, and 53 infants from Tallinn Children's Hospital). The flow-chart for the APPLE Study is presented in **Figure 2**.

	2016	2017	2018	2019	2020	2021	2022
Approval of the ethical committee in Finland	17.5.2016						
Approval of the ethical committee in Estonia		20.3.2017					
Recruitment of the patients in Turku University Hospital		February 2017 – December 2020					
Recruitment of the patients in Tallinn Children's Hospital		April 2017 – June 2018					
Data collection		<ol style="list-style-type: none"> 1. Auditory environment in the NICU at 32–34 weeks of postmenstrual age 2. Eye-tracking test at seven months of corrected age 3. Infant's lexical abilities at one year of corrected age 4. Child's general language development at two years of corrected age 					

Figure 1. Gantt chart for the APPLE study. NICU – *Neonatal Intensive Care Unit*.

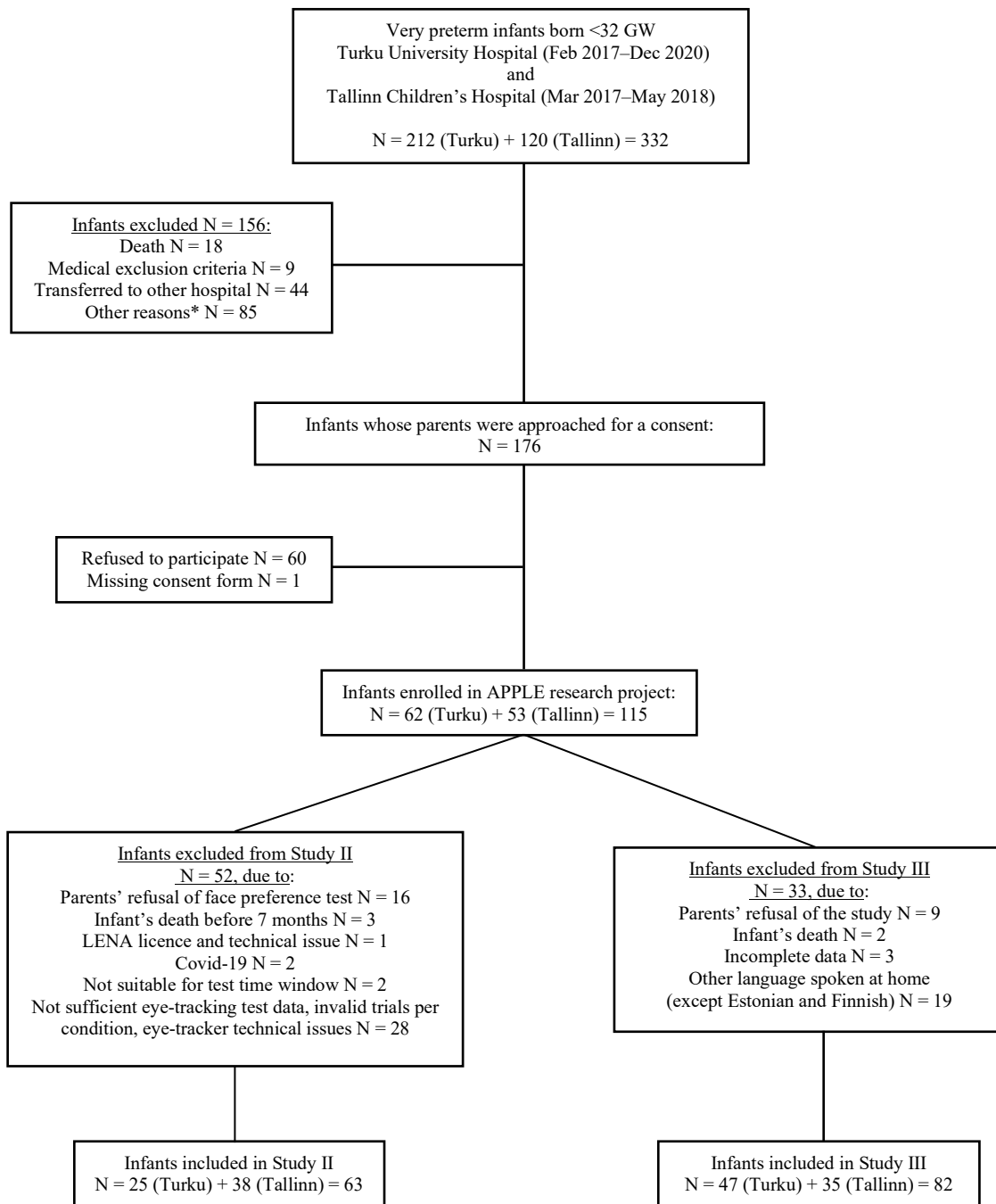


Figure 2. Flow chart of the APPLE research project. The flow chart presents the recruitment process and additional exclusion criteria. *Other reasons to exclude infants from the study included technical issues, social reasons, native language, and multiple pregnancies of more than two fetuses.

4.2.1 Parental Closeness Diary

This data collection tool was first developed in Finland and used in SCENE research group studies. Parental Closeness Diary is a data collection tool for parents to report the duration of their presence in the neonatal unit, holding their infant, and being skin-to-skin with their infant, each reported with a 5-minute resolution (**Figure 3**).

Presence in the unit was defined as being within the unit's premises, even if not continuously in the same room as the infant. This approach avoided the need to record brief interruptions, such as a bathroom or coffee breaks. During SSC, the infant was lying on the parent's bare chest, wearing only a diaper and optionally a cap. Holding the infant was defined as the infant being clothed and held in their parent's arms outside the bed, cot, or incubator. For the APPLE Study, the parents filled in the Closeness Diary continuously for 14 days when their infant was at 32–34 weeks of postmenstrual age, and the diaries were kept privately and securely near the infant's bedside during the data collection period. Language environment analysis was recorded for 16 hours during the Closeness Diary collection period.

Study II and Study III utilized the data from the Parental Closeness Diary to identify the parents' presence during the recording day and during a period of two weeks, so it would be possible to identify which adult words are potentially the parents' own words in the recording data. Development of the Parental Closeness Diary is described in Axelin et al. 2020.

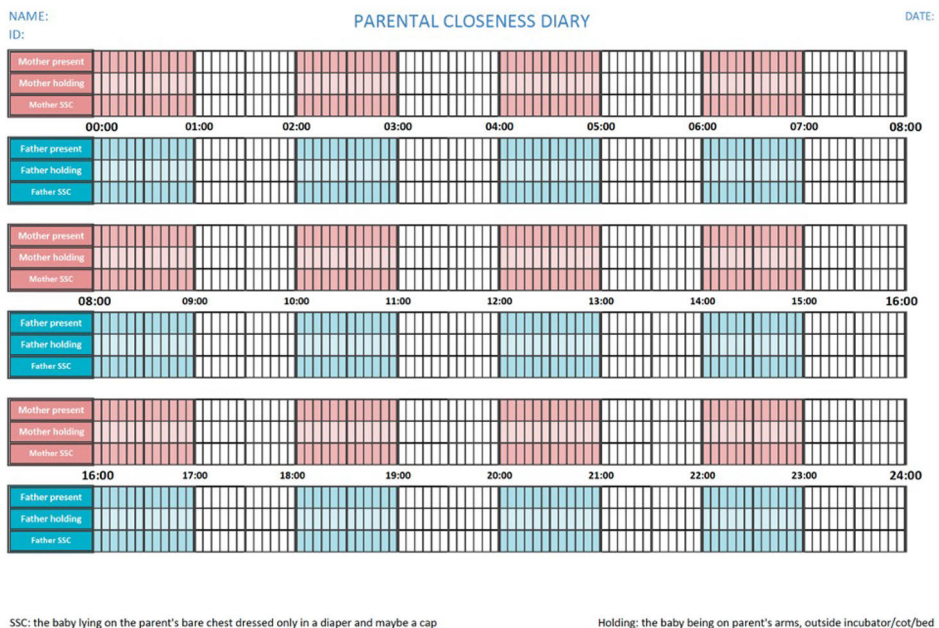


Figure 3. Parental Closeness Diary.

4.2.2 Language Environment Analysis

Language Environment Analysis (LENA®, Boulder, Colorado) is an automated analysis of language environment. The LENA system includes a digital processor that records an infant's natural language exposure and sound environment, coupled with software that performs automated analyses of the recorded data using algorithm-based speech processing. The system extracts and segments audio data into primary and secondary segments. Primary segments include key child (the child wearing the recorder), adult female, adult male, and TV/electronic media. The secondary segments include other child, overlapping speech, noise, and silence. The algorithms distinguish adult speech from child speech, as well as the speech of the key child from the speech of other children or non-speech sounds such as cries or vegetative sounds. (Gilkerson and Richards 2020, Ford et al. 2008).

Adult male and female segments are processed further to generate estimates of total adult word count. The conversational turns count is the number of conversational turns the child engages in with the adult, and it is calculated using key child and adult female/male segments that are separated by no more than five seconds of silence or other sounds. Child vocalization counts are the communicative, speech-related vocalizations produced by the key child, surrounded by 300 milliseconds of silence or other sounds, and excluding vegetative sounds (related to respiration or digestion) and cries. Child vocalization counts are generated only for the key child segments. (Gilkerson and Richards 2020, Ford et al. 2008).

The validity of the LENA system in the Finnish and Estonian languages has been evaluated in the APPLE Study. The agreement between the LENA labels and human coders was highest (86%) in female labels, and modest or fair in male (47%), key child (39%), and silence (42%) labels (Ståhlberg-Forsén et al. 2021).

In the APPLE Study, the auditory environment of the preterm infants in the neonatal unit was assessed for 16 hours at the infant's postmenstrual age of 32–34 weeks. The LENA recorder was positioned near the infant – within 10 cm from the head when staying in the cot or incubator, and within 30 cm during holding or skin-to-skin contact with the parent.

The parents' presence in the NICU was reported using the closeness diaries. LENA data was analyzed for the periods during which at least one parent was present in the NICU, specifically within the time frame of 7 a.m. to 10 p.m., assuming the parents' potential verbal communication with the infant while awake. From the LENA data, adult word count, female and male word counts, conversational turns count, and child vocalization count were used in the statistical analysis in Study II and Study III. The mother's and father's variables were obtained from the LENA recordings using female and male word counts, conversational turn counts, and child vocalization counts from the time intervals when each parent was present according to the diary data. The exposure measurements were based on the frequency

measurements (words or count per hour) when the parent was present during the recording day and the information on the parents' presence for two weeks. For example, exposure to the parent speech = [total number of words when the parent was present during the analyzed recording (count) / total time the parent was present during the analyzed recording (hours)] x the parent's presence (hours) for 14 days.

4.3 Face preference assessment by an eye-tracking test

The APPLE study participants were assessed at the age of seven months of corrected age. The infants' face preference was measured using an eye-tracking-based test, which assessed the infant's attention to faces and non-face patterns under conditions of distraction when adding a competing stimulus to the screen.

During the testing, the infant sat on his/her parent's lap at an approximately 60 cm distance from a 17-inch (1280x1024) computer screen. The task started with a fixation stimulus (a white circle or a "+"-sign) displayed at the center of the monitor against a black background. Once the infant fixated on the stimulus, two stimuli were presented with a 1000-msec onset asynchrony. The first stimulus, either a face or a non-face pattern, was displayed at the center of the screen with dimensions of 9.6°x10.2°. The second stimulus, a black-and-white checkerboard pattern (a "distractor"), was presented laterally to the left or right of the center for 2000 msec with dimensions of 3.5°x12.7°. Each child completed a total of four 12-trial blocks during the test (48 trials). In half of the trials, the first stimulus was an image of a face displaying a neutral, happy, or fearful expression, either posed by the infant's parent (mother, father) or by an unfamiliar adult female model. In the other half of the trials, this stimulus was a luminance/color-matched pattern unrecognizable as a face. The non-face patterns were generated by randomizing the phase spectra of the face images while preserving their amplitude and color spectra. The order of face and non-face pattern trials was randomized for each child, with the condition that each 12-trial block contained an equal number of face and non-face trials. Parent faces were shown in blocks 2 and 3, while the faces of two unfamiliar female adults were in blocks 1 and 4. The block order was consistent for all children. The side of the lateral "distractor" was randomly assigned for each trial, but the total number of trials with the distractor on the left and right sides of the screen was balanced within each block, as well as within the face and non-face conditions. During the test, the infants' moment-by-moment gaze data were recorded using a 30-Hz video camera (Canon Legria, HFR806) and an infrared eye-tracking camera (Eye Tribe; Copenhagen, Denmark, or Tobii X2-60 camera; Tobii Technology, Stockholm, Sweden).

The data were analyzed on a trial-by-trial basis to identify whether and when gaze disengagement (i.e., a shift) from the central stimulus to the lateral distractor occurred, within an analysis period beginning after the onset of the lateral stimulus (150–1000 msec). All analyses were conducted using video camera recordings, as technically valid eye-tracking data were unavailable for many of the participants. Importantly, gaze disengagement can be reliably measured from both video and eye-tracking recordings, with the results from these two methods showing high consistency (Leppänen et al. 2015).

Disengagement data were extracted for trials that met the following inclusion criteria adapted for video-based coding:

- i) the duration of the fixation on the central stimulus was sufficient (i.e., $\geq 75\%$ of the time),
- ii) valid video data were available to determine whether gaze disengagement occurred during the analysis period,
- iii) the gaze disengagement (if any) was not premature (i.e., occurring at least 150 msec after the onset of the lateral stimulus.
- iv) the gaze shift was aimed at the lateral stimulus.

All infants with more than two valid trials per stimulus condition were included in the final statistical analyses. The disengagement values (0, 1) were averaged across trials to calculate the probability of no disengagement for each stimulus condition (familiar face, unfamiliar face; familiar non-face, unfamiliar non-face) for each infant.

A preference for faces is indicated by a higher probability of no disengagement in the face condition than the non-face condition. Since the current paradigm was adopted from studies that estimated disengagement probabilities separately for different facial expressions, we used neutral, happy, and fearful expressions as stimuli. However, recent research using this approach has shown that disengagement estimates are strongly correlated across neutral, happy, and fearful expressions, with no evidence of unique individual variance for specific expression categories (Pyykkö et al. 2019, Peltola et al. 2018). For these reasons, and to increase the number of trials within each condition, we adhered to our a priori plan and averaged the data across different facial expressions.

4.4 Language development assessments at one and two years of corrected age

The development of each infant's lexical abilities was assessed at 12 months of corrected age using Finnish and Estonian versions of the parental report method MacArthur-Bates Communicative Development Inventory (MCDI) (Lyytinen 1999, Schults & Tulviste 2016). The MCDI is a parental report form instrument for screening early lexicon, providing information of receptive and expressive words from different lexical categories. The number of receptive and expressive words in the word lists included in the Finnish MCDI is 379 words, and in the Estonian version, the respective number is 386 words. The parents reported how many words in these word lists the child comprehended or expressed at one year of corrected age. For statistical analysis, the number of words reported by the parent in the MCDI lexical ability test was converted into percentages relative to the total number of words in the word lists.

The development of each child's general language (lexicon and grammatical knowledge) was tested at two years of corrected age using the Finnish version of the Reynell Developmental Language Scales third edition (RDLS) (Kortesmaa et al. 2001). The RDLS is an assessment tool for measuring children's receptive and expressive language abilities and to evaluate the child's language skills compared to developmental norms. An Estonian version translated from the Finnish version of the RDLS was used for the Estonian dataset. As the RDLS has not been standardized for Estonian, raw scores were used for the statistical analysis for both study sites.

4.5 Ethics

The International Closeness Survey was approved by all participating countries' local Ethics Committees, in Finland, Sweden, Norway, Estonia, Italy, and Spain. The APPLE Study protocol was approved by The Ethics Committee, Hospital District of Southwest Finland, and the Research Ethics Committee of the University of Tartu, Estonia. Written informed consent was gathered from parents before their families participated in the study.

AI (Grammarly, Deepl, ChatGPT) was used for language editing in the dissertation.

4.6 Statistical analysis

Descriptive statistics were used to describe the infant and family characteristics in Study I, II, and III. In Study III, descriptive statistics were also used to describe recording day characteristics, the parents' presence, and the LENA measures (parent word frequency, conversational turn frequency, child vocalization frequency).

Categorical variables are presented as numbers and percentages, continuous variables are described as means with the SD or medians with minimum and maximum ranges.

In Study I, the mothers' and fathers' mean scores for participation were calculated as arithmetic means of all answers on a 7-point Likert scale (excluding zero-responses). The parents' non-presence at units (zero-responses proportions) and participation scores by unit were compared using Chi-square and Kruskal-Wallis tests respectively. Associations between participation scores, the proportion of zeros out of all responses, and the parents' total scores for the quality of FCC (excluding the question about participation) were studied using the Spearman correlation coefficient. The association between participation scores and the number of times the question was responded to was assessed using mixed generalized linear models with the responding parent as a random factor. The impact of the parents' presence and participation on family/hospital characteristics was assessed using uni- and multivariate mixed generalized linear models with the hospital as a random factor. For multivariate modeling, independent variables were chosen based on previous knowledge about the topic (without considering the results of the univariate models). In the cases where several units were included in one center, such as with Tallinn and Tartu, Estonia, the characteristics of the unit with the biggest number of admissions were used in the model. These were the step-down units in both study centers in Estonia. Missing values were not imputed. SAS software was used for statistical analysis.

In Study II, the differences between the study sites in word count and parental presence were tested using the Wilcoxon rank-sum test. As some of the outcome variables were not normally distributed and could not be normalized using common transformations, the pairwise differences were analyzed using the Wilcoxon test (effect sizes were estimated as z/\sqrt{N}) and the correlations using Spearman rank correlations (r_s). In the hypothesis-testing analyses, we calculated Spearman's partial rank correlation coefficients (r_s) between the variables describing the exposure to the parents' speech and the mean proportion of no disengagement in the face condition, adjusted for the proportion of no disengagement in the non-face condition. To examine whether these correlations were affected by the covariates, we calculated partial r_s adjusted for gestational age, parental education, delivery type, sex, and birth weight. In an analysis testing the association between exposure to the parents' speech and parent face preference, correlations between exposure to the parents' speech and the proportion of no disengagement in the parent face condition were calculated, adjusted for the proportion of no disengagement in the unfamiliar face condition. The analyses and data visualizations were performed using the R and pResiduals, RVAideMemoire, dplyr, and ggplot2 packages.

In Study III, the environmental contexts of the study sites were compared using Fisher exact or Wilcoxon rank sum tests depending on the data type. The associations between the language outcome measures (receptive and expressive scores of MCDI and RDLS as dependent variables) and the LENA measures (adult word frequency, parent word frequency, conversational turn frequency, and child vocalization frequency as independent variables) were assessed using separate mixed linear models with the hospital and twin pair as random factors. All models were adjusted for gestational age, sex, twin status, and parent education. The natural logarithms of both the dependent and independent variables were used to fulfill the linear model assumptions. Statistical assumptions were tested. The Stata 16.0 software was used for the statistical analyses.

5 Results

5.1 Parents' presence and participation during medical rounds in the neonatal units

A total of 241 families were included in Study I, which evaluated the parents' presence and the degree of their participation in discussions during medical rounds in 11 European NICUs. A total of 630 text-message answers from mothers and 474 answers from fathers were subjected to analysis. Every parent gave 1 to 10 responses to the text-message questions. Mothers responded an average of 2.4 times, and the fathers responded an average of 2.0 times. The mothers answered 511 times, and the fathers 290 times to the text-message questions about the degree of participation in discussions during medical rounds. Of the total answers, 303 were zero, indicating that the parent had not participated in the medical rounds that day.

There were significant differences between the participating units, related to the level of care, unit size, and parental involvement practices. In six units, most infants were reported to have had their first skin-to-skin contact within 10 hours of birth. Six hospitals out of 11 made it possible for parents to stay overnight in the unit. In eight hospitals out of 11, parents were routinely invited to the medical rounds. The units' characteristics are presented in **Table 5**.

Exceptionally, in Estonia a preterm infant may be treated in three separate units during the hospital course after the birth. Preterm infants are referred from maternity hospitals to pediatric intensive care units or step-down units at the children's hospital, depending on the need for invasive respiratory support, perioperative care, and/or longer-term hospital care. The preterm infants treated in pediatric intensive care units will be transferred to a step-down unit after recovery.

Table 5. Characteristics of the units in the International Closeness Survey.

Country	Finland			Sweden			Estonia			Italy	Spain			Norway		
	Turku	Uppsala	Danderyd	Huddinge	Tallinn MH	Tallinn PICU	Tallinn step-down	Tartu MH	Tartu PICU		Tartu step-down	Como	Madrid	Drammen	Bergen	Tromsø
Level of care	IIIB	IIIA	IIIA	IIIA	IIIA	IIIB	II	II	IIIB	II	IIIA	IIIC	IIIA	IIIB	IIIB	
Admissions per year, n	638	414	1031	646	479	150	598	411	135	412	210	935	401	468	326	
<37 GW	240	217	365	325	354	86	140	203	68	120	192	388	176	207	78	
<32 GW	72	104	48	92	75	49	99	10	50	54	51	130	61	63	8	
<28 GW	23	63	4	24	28	30	30	12	15	15	17	52	17	21	8	
Opportunity to stay overnight in the unit	No	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	No	No	Yes	No	No	
Family/single rooms, n	1	11	12	15	10	0	10	6	0	8	2	0	15	3	3	
Time to first SSC <10h, %	16.0	52.0	82.6	75.0	40.0		66.7				29.4	11.1	81.5	48.2	88.9	
Parents invited to rounds	Yes	Yes	Yes	Yes	No	+/-	Yes	+/-	+/-	+/-	No	No	Yes	Yes	Yes	

MH – maternity hospital, PICU – pediatric intensive care unit, GW – gestational weeks, SSC – skin-to-skin contact, +/- – inconsistent

Table 6. Infant and Family Characteristics.

	FINLAND	SWEDEN			ESTONIA		ITALY	SPAIN	NORWAY			Overall
	Turku	Uppsala	Danderyd	Huddinge	Tallinn	Tartu	Como	Madrid	Drammen	Bergen	Tromso	Mean
N	30	28	26	19	21	14	18	27	27	27	11	
Gestational age (weeks), mean	31 ^{3/7}	28 ^{0/7}	33 ^{1/7}	32 ^{2/7}	32 ^{4/7}	32 ^{4/7}	31 ^{0/7}	30 ^{4/7}	32 ^{4/7}	30 ^{6/7}	31 ^{5/7}	
Time to first message (days), mean	7.0	6.9	8.4	7.1	7.2	5.9	6.2	7.1	7.1	7.4	9.2	7.2
Time to hospital (min), %												
<30	60.7	50.0	82.6	50.0	73.7	69.2	76.5	92.6	59.3	63.0	60.0	
30–60	7.1	0	13.0	33.3	0	0	23.5	7.4	33.3	11.1	0	
>60	32.2	50.0	4.4	16.7	26.3	30.8	0	0	7.4	25.9	40.0	
Home living sibling, yes %	59.3	53.6	33.3	31.2	31.6	61.5	27.8	29.6	59.3	55.6	45.5	
Maternal education, higher %	8.0	60.0	73.9	50.0	63.2	38.5	41.2	37.0	77.8	25.9	62.5	
Paternal education, higher %	12.0	52.0	65.2	21.4	41.2	15.4	11.8	29.2	65.4	37.0	25.0	
Maternal employment, paid work %	59.3	88.5	73.9	78.6	63.2	76.9	83.3	77.8	92.6	88.9	90.0	
Paternal employment, paid work %	88.5	84.6	87.0	92.9	94.7	92.3	83.3	84.0	96.2	96.3	88.9	
Maternal age (year), mean	31.0	32.1	32.9	30.9	30.5	29.2	35.9	34.8	33.2	31.6	31.5	
Paternal age (year), mean	32.6	32.9	34.0	32.5	33.6	33.7	39.5	35.8	34.3	33.2	34.9	
Foreign language, %												
No	85.2	85.7	75.0	62.5	100	100	100	92.6	74.1	81.5	100	
one parent	3.7	7.1	20.8	18.8	0	0	0	7.4	14.8	11.1	0	
both parents	11.1	7.1	4.2	18.8	0	0	0	0	11.1	7.4	0	

The infants' mean gestational age at birth varied within the participating units from 28^{0/7} to 33^{1/7} weeks. The families mostly lived within a 30-minute drive from the hospital, and 27.8% to 61.5% of the families had a sibling living at home. Infant and family characteristics for the 11 neonatal units are presented in **Table 6**.

5.1.1 Parents' presence during medical rounds

Mothers were present during medical rounds most days, varying between units from a mean of 62.5% to a mean of 91.0% of the days ($p = 0.002$). Compared to the mothers, the fathers were less frequently present during medical rounds. Their presence varied between units from a mean of 30.8% to a mean of 77.8% of the days ($p = <0.001$). **Figure 4**.

In a multivariate model, the family and hospital characteristics that facilitated or hindered the parents' presence during medical rounds were the infant's gestational age at birth, the father's education, and the unit's policy towards inviting parents to the medical rounds. The likelihood of the mother's presence during medical rounds increased with the infant's gestational maturity at birth ($p = 0.010$) and with the unit's policy including routinely inviting parents to the medical rounds ($p = 0.036$). Fathers with a higher level of education were more likely to be present during medical rounds ($p = 0.009$) – table 3 from the original article, Study I.

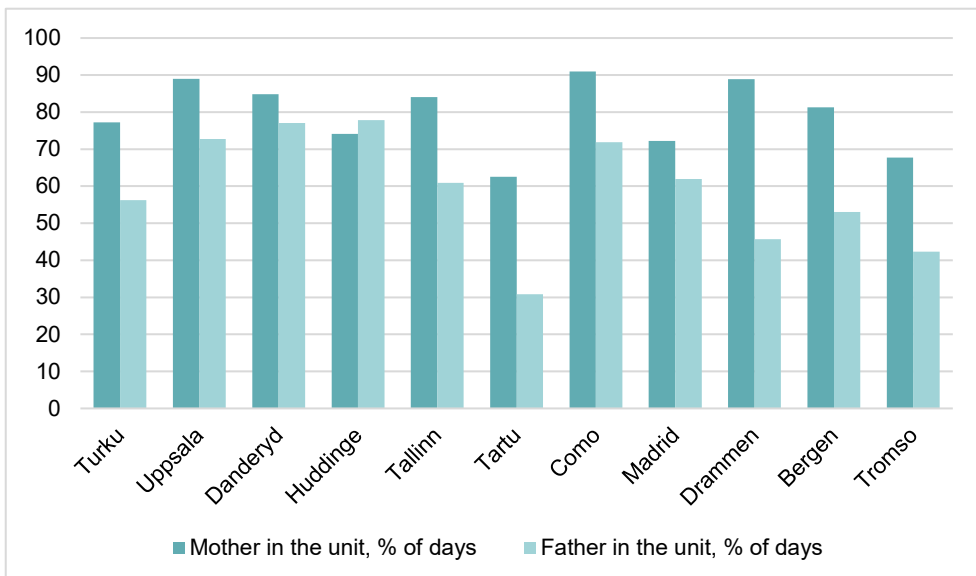


Figure 4. The parents' presence during medical rounds.

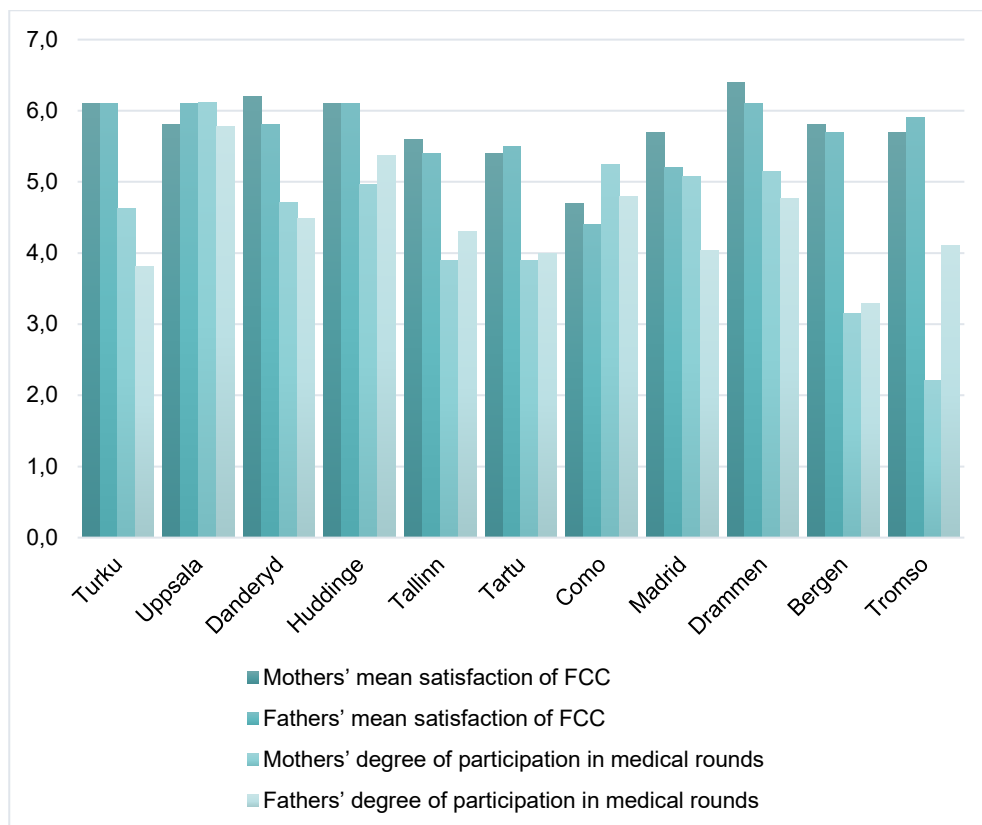


Figure 5. The mothers' and fathers' satisfaction with the overall FCC and participation in medical rounds in a 7-point Likert scale. FCC – Family Centered Care.

5.1.2 Parents' participation during medical rounds

The first text-message about the degree of parental participation in medical rounds was sent to the families on average 7.2 days after birth so that the parents were already familiar with the unit's daily routine. In eight out of 11 units it was regular practice to invite parents to the medical rounds (**Table 5**).

The parents' degree of participation during medical rounds was statistically different between and within countries (difference of median by hospitals, Kruskal-Wallis test for mothers $p = <0.001$, for fathers $p = 0.022$) (**Figure 5**).

Table 7. The parents' degree of participation in the discussions during medical rounds in 11 neonatal units. A boxplot from the same data is shown in the original article (Study I).

Hospital	Mother score question 7				Father score question 7			
	mean	SD	median	IQR	mean	SD	median	IQR
Turku	4.63	1.62	4.50	3.00	3.81	2.02	4.63	4.00
Uppsala	6.12	0.79	6.00	1.11	5.78	0.74	6.00	1.00
Danderyd	4.71	2.16	5.00	4.33	4.49	2.21	5.00	4.33
Huddinge	4.96	1.71	5.00	2.50	5.37	2.33	7.00	3.83
Tallinn	3.90	2.10	4.00	3.17	4.30	2.23	4.50	3.50
Tartu	3.90	2.17	4.00	3.60	4.00	2.58	4.00	4.00
Como	5.24	1.20	5.29	1.75	4.79	1.22	4.50	2.00
Madrid	5.07	1.92	5.50	3.25	4.04	1.88	4.00	2.25
Drammen	5.15	1.73	5.67	2.83	4.77	1.87	5.00	2.00
Bergen	3.15	2.11	2.25	3.67	3.29	2.19	3.25	4.00
Tromso	2.21	1.63	1.50	1.50	4.11	1.97	4.17	1.67
Total	4.60	1.98	5.00	3.20	4.51	1.95	5.00	2.73

SD – Standard Deviation, IQR – Interquartile Range

In six units, mothers gave higher mean scores than fathers. Parents in Uppsala, Sweden, reported the highest levels of satisfaction with their participation in discussions during medical rounds (**Table 7**).

In the univariate model, staying overnight in the neonatal unit was statistically significantly associated with the fathers' participation in medical rounds. The multivariate model revealed no significant associations between background characteristics and the parents' participation in medical rounds.

The mothers' and fathers' total satisfaction with the FCC in the unit (measured based on eight questions from the International Closeness Survey, on a 7-point Likert scale) varied significantly between units ($p = <0.001$ for mothers and for fathers) (**Figure 5**). The mothers' and fathers' total satisfaction with the quality of FCC correlated with the degree of their participation in discussions during medical rounds ($r_s = 0.2447$ for mothers, $r_s = 0.3154$ for fathers) (Figure 2 in the original paper, Study I, and **Table 8**). The parents' high rating for the overall quality of FCC appears to be essential for fostering more active participation during medical rounds.

Table 8. Correlations between satisfaction with FCC and participation in medical rounds.

		Mother, participation in medical rounds (question 7)	
	n	rho	p
Mother, total satisfaction with FCC (8 questions)	209	0.2447	0.0004
		Father, participation in medical rounds (question 7)	
	n	rho	p
Father, total satisfaction with FCC (8 questions)	144	0.3154	0.0001

FCC – Family Centered Care

5.2 Exposure to the parents' speech in the neonatal environment

5.2.1 Preterm infants in the Finnish and Estonian populations

In the last three decades (1995–2025) in Finland, the prevalence of preterm births (<37 GW) has been 5,5–6% of all live births. The prevalence of very preterm births (born <32 GW) was 0,8–1,0 % of all live births during the same period (Hauhio et al. 2024). In the last three decades in Estonia, the prevalence of preterm births (<37 GW) has been 5,3–5,9%, and the prevalence of very preterm births 0,8–1,0% of all live births (Karro et al. 2022, National Institute for Health Development 2019).

Birth rates have decreased significantly in recent years in both countries. In Estonia, from around 14 000 live births in 2015, the birth rate has decreased to below 10 000 live births in 2024 (Statistics Estonia database 2025). In Finland, from approximately 56 000 live births in 2015 to 44 000 in 2023 (Hauhio et al. 2024). Despite the decline in birth rates, the prevalence of preterm births has not changed.

5.2.2 Background of the study population

A total of 115 infants were included in the APPLE Study, which evaluated the extent to which preterm infants were exposed to their parents' speech in the neonatal environment and how this exposure was associated with later child development.

The infants' mean gestational age at birth for the APPLE Study population was 28^{4/7} weeks. Fifty-two percent of the population were male, and 37% were twins. One infant characteristic that was significantly different between the study sites was the severity of bronchopulmonary dysplasia – more severe cases in Turku and more mild cases in Tallinn. This can be explained by the current practice in Turku, where patients without severe complications are transferred to level II hospitals closer to

home at 32–34 weeks, while patients requiring substantial respiratory support stay in the level III hospital. Additionally, the incidence of intraventricular hemorrhages, periventricular leukomalacia, and positive blood culture sepsis rates were higher in Tallinn. It is noteworthy that during the recording days, mothers in Turku were less depressed than in Tallinn according to the Edinburgh Postnatal Depression Scale (EPDS) ($p = 0.006$). There were no differences in the fathers' EPDS scores. Infant, neonatal, and family characteristics for the whole APPLE Study population, and separately for Turku and Tallinn are shown in **Table 9**.

Table 9. Infant and family characteristics.

	All APPLE study population N = 115	APPLE Turku N = 62	APPLE Tallinn N = 53	p-value
GA at birth (weeks), mean (min;max)	28 ^{4/7} (23 ^{0/7} ;31 ^{6/7})	28 ^{5/7} (23 ^{0/7} ;31 ^{6/7})	28 ^{3/7} (23 ^{3/7} ;31 ^{4/7})	0.286
Male	60 (52)	32 (52)	28 (53)	0.896
Birth weight (g), mean (min;max)	1156	1156 (470;1860)	1157 (600;1935)	0.920
Cesarean section	69 (60)	38 (61)	31 (58)	0.760
Twin	42 (37)	23 (37)	19 (36)	0.617
BPD at 36 PMA, of which	52 (45)	23 (37)	29 (55)	<0.001
Mild	26 (50)	3 (13)	23 (79)	
Moderate	17 (33)	12 (52)	5 (17)	
Severe	9 (17)	8 (35)	1 (4)	
IVH, of which				0.042
Grade III	1 (1)	0	1 (2)	
Grade IV	3 (3)	0	3 (5)	
Cystic PVL	4 (3)	0	4 (8)	0.042
Treated ROP	6 (5)	3 (5)	3 (6)	0.060
Operated NEC	2 (2)	2 (3)	0	0.499
Positive blood culture sepsis	17 (15)	4 (6)	13 (25)	0.008
Hearing status				0.846
Normal	106 (92)	58 (93)	48 (90)	
Pathological	3 (3)	1 (2)	2 (4)	
Unknown	6 (5)	3 (5)	3 (6)	
Hearing aid needed at one year of corrected age	0	0	0	
Maternal age (year), mean	31.8	31.5	32.0	0.623
Paternal age (year), mean	33.9	33.8	34.0, unknown 2	0.887
Maternal education level				0.001
Basic education	18 (16)	4 (6)	14 (26)	
General upper secondary school or vocational education and training	29 (25)	13 (21)	16 (30)	
University of applied sciences	23 (20)	19 (31)	4 (8)	
University	43 (37)	24 (39)	19 (36)	
Unknown	2 (2)	2 (3)	0	
Paternal education level				0.001

Basic education	20 (17)	4 (6)	16 (30)	
General upper secondary school or vocational education and training	41 (36)	28 (45)	13 (25)	
University of applied sciences	13 (11)	10 (16)	3 (5)	
University	33 (29)	14 (23)	19 (36)	
Unknown	8 (7)	6 (10)	2 (4)	
Maternal employment				0.128
Paid work	94 (82)	47 (76)	47 (89)	
Unemployed	14 (12)	10 (16)	4 (7)	
Student	6 (5)	5 (8)	1 (2)	
Unknown	1 (1)	0	1 (2)	
Paternal employment				1.000
Paid work	106 (92)	56 (90)	50 (94)	
Unemployed	3 (3)	2 (3)	1 (2)	
Student	1 (1)	1 (2)	0	
Unknown	5 (4)	3 (5)	2 (4)	
The mother's native language				
Estonian	39 (34)	0	39 (74)	
Russian	16 (14)	2 (3)	14 (26)	
Finnish	56 (49)	56 (90)	0	
Swedish	1 (1)	1 (2)	0	
Other (Kurdish, Thai)	3 (2)	3 (5)	0	
The father's native language				
Estonian	42 (36)	2 (3)	40 (75)	
Russian	13 (11)	2 (3)	11 (21)	
Finnish	55 (48)	55 (89)	0	
Swedish	1 (1)	1 (2)	0	
Other (Kurdish, Daria)	2 (2)	2 (3)	0	
Unknown	2 (2)	0	2 (4)	
Sibling living at home	55 (48)	30 (48)	25 (47)	0.523
Previous child in the NICU	7 (6)	5 (8)	2 (4)	0.449
Mother EPDS during recording day, mean (min; max)	7.8 (0; 21)	6.6 (1; 21)	9.3 (0; 21)	0.006
Father EPDS during recording day, mean (min; max)	4.9 (0; 22)	4.0 (0; 13)	5.9 (0; 22)	0.198

Data is presented as absolute numbers (percentage).

GA – gestational age, BPD – bronchopulmonary dysplasia, PMA – postmenstrual age, IVH – intraventricular hemorrhage, PVL – periventricular leukomalacia, ROP – retinopathy of prematurity, NEC – necrotizing enterocolitis, NICU – Neonatal Intensive Care Unit, EPDS – Edinburgh Postnatal Depression Scale

There were statistically significant differences between the study sites in the environmental context (**Table 10**). Most patients in Turku were treated in SFR, whereas in Tallinn, most of the patients were treated in rooms for 2–4 patients ($p = <0.001$). Only two percent of the patients in Turku were treated in the incubator, whereas 42% of the patients in Tallinn were treated in the incubator during the recording day. All infants needed a feeding tube to support enteral feeding.

Table 10. Environmental context during the recording day.

	APPLE study population N = 115	APPLE Turku N = 62	APPLE Tallinn N = 53	p-value
Patients per room				<0.001
1	38 (33)	34 (55)	4 (8)	
2	47 (41)	28 (45)	19 (36)	
3	8 (7)	0	8 (15)	
4	22 (19)	0	22 (41)	
Temperature control				<0.001
Incubator	23 (20)	1 (2)	22 (42)	
Thermal mattress	40 (35)	19 (30)	21 (40)	
None	52 (45)	42 (68)	10 (18)	
Breathing support				0.721
Invasive ventilation	9 (8)	9 (15)	0	
CPAP/NIV-NAVA	10 (9)	7 (11)	3 (6)	
CPAP/High Flow Nasal Cannula alternating	3 (2)	2 (3)	1 (2)	
High Flow Nasal Cannula	40 (35)	19 (31)	21 (40)	
None	53 (46)	25 (40)	28 (52)	

Data are shown as absolute numbers (percentage).

CPAP continuous positive airway pressure, NIV-NAVA non-invasive neurally adjusted ventilatory assist.

5.2.3 Parents' presence in the NICU

During the recording day between 7 a.m. and 10 p.m., the mothers were present in the NICU in Turku, Finland for a median of 7.2 hours, and a median of 8.8 hours in the NICU in Tallinn, Estonia. Respectively, the fathers were present in the NICU in Turku, Finland for 4 hours, and 0.7 hours in the NICU in Tallinn, Estonia (**Table 11**).

During the whole diary period, the mothers were present for an average of 100 hours in Turku, Finland, and 186 hours in the NICU in Tallinn, Estonia. The fathers were present for an average of 49 hours in Turku, Finland, and 13 hours in the NICU in Tallinn, Estonia (**Table 11**).

Table 11. Parental presence, LENA measures from the recording day and for 14 days.

Measures	All APPLE Study population		Turku		Tallinn		p-value
	N = 115		N = 62		N = 53		
	Median	Min–Max	Median	Min–Max	Median	Min–Max	
DURING THE RECORDING DAY							
Mother's presence in the NICU (hours)	8.0	0–13.8	7.2	0–13.8	8.8	0.8–13.2	0.016
Father's presence in the NICU (hours)	1.8	0–13.7	4	0–13.7	0.7	0–4	<0.001
Total adult word count	5522	4–37070	9152	767–37070	2086	4–13396	<0.001
Total mother presence word count	3789	4–20304	6317	91–20304	1815	4–12820	<0.001
Total father presence word count	641	0–9831	1081	0–9831	22	0–4872	<0.001
Adult word frequency (word/hour)	474	0.4–2633	699	94–2633	230	0.4–1015	<0.001
Mother's word frequency (words/hour)	546	0.4–3591	1014	50–3591	216	0.4–971	<0.001
Father's word frequency (words/hour)	231	0–2291	287	8–2291	24	0–1561	0.006
Conversational turn frequency when the mother was visiting (count/hour)	5	0–77	6	0.5–77	3	0–54	<0.001
Conversational turn frequency when the father was visiting (count/hour)	5	0–107	6	0–107	2	0–75	0.012
Child vocalization frequency when the mother was visiting (count/hour)	17	0–204	21	2–156	16	0–204	0.448
Child vocalization frequency when the father was visiting (count/hour)	15	0–261	16	2–212	11	0–261	0.437
EXPOSURE IN A 14 DAY PERIOD							
Mother's presence in the NICU (hours)	128	34–210	100	50–192	186	34–210	<0.001
Father's presence in the NICU (hours)	33	0–166	49	0–166	13	0–94	<0.001

Exposure to mother's speech (words)	67194	76–283115	88289	3190–283115	31146	76–196455	<0.001
Exposure to father's speech (words)	7630	0–105029	14067	656–105029	427	0–98506	<0.001
Conversational turns count (CTC) when the mother was visiting	523	0–4857	552	35–4056	460	0–4857	0.099
CTC when the father was visiting	190	0–3514	381	0–1522	71	0–3514	0.001
Child vocalizations count (CVC) when the mother was visiting	2258	0–39194	1984	176–8223	2616	0–39194	0.022
CVC when the father was visiting	733	0–8285	969	107–4291	235	0–8284	0.028

5.2.4 Parents' speech and parent-infant communication in the neonatal environment

During the recording day between 7 a.m. and 10 p.m., the median word frequency (words/hour) for mothers in Turku, Finland was 1014 words/hour, and 216 words/hour for mothers in Tallinn, Estonia ($p = <0.001$). The median word frequency for fathers in Turku, Finland was 287 words/hour, and 24 words/hour for fathers in Tallinn, Estonia ($p = 0.006$). During the two-week period, the median exposure to the mother's words was 88289 words in the NICU in Turku, Finland, and 31146 words in Tallinn, Estonia ($p = <0.001$). The median exposure to the father's words was 14067 words in the NICU in Turku, Finland, and 427 words in Tallinn, Estonia ($p = <0.001$). The fathers were significantly less present in the unit than the mothers during the recording day, and also during the two-week period. The fathers' word frequency and the infant's exposure to the fathers' speech were significantly lower than to the mothers' speech.

The median number of conversational turns between the mother and the infant during the two-week period in the neonatal environment was 552 in Turku and 460 in Tallinn ($p = 0.099$). The number of conversational turns between the father and the infant during the two-week period was 381 in Turku and 71 in Tallinn ($p = 0.001$).

The median number of child vocalizations during the times when the mother was visiting during the two-week period was 1984 in Turku and 2616 in Tallinn ($p = 0.022$). The number of child vocalizations when the father was visiting during the two-week period was 969 in Turku and 235 in Tallinn ($p = 0.028$).

The whole APPLE Study population's descriptive statistics for parental presence and the LENA measures from the recording day and the 14-day period are presented in **Table 11**.

5.2.5 Overall adult words in the NICU

The median of the total amount of adult words heard during the recordings in the NICU between 7 a.m. and 10 p.m. was 5522 words; the median total word count during the mother's presence was 3789, and during the father's presence 641 words (**Table 11**). The overall adult words consisted, in addition to the parents' speech, of discussions between the staff members (during medical rounds and procedures), parent-staff discussions or staff-infant speech. However, the LENA recording data captures only clearly audible speakers in the immediate vicinity, excluding the potential speech of neighboring parents (Xu et al. 2009).

5.3 Exposure to the parents' speech and the preterm infant's face preference

5.3.1 Attention to faces *versus* non-face patterns

The study (Study II) about the association between the parents' speech in the neonatal environment and the infants' attention to faces involved 63 preterm infants and their parents (63 mothers and 60 fathers). Infant and family characteristics for this subpopulation are described in the original article (Table 1, Study II). The environmental context during the recording day for this subpopulation is described in the original article (Table 2, Study II). These characteristics did not differ significantly from the overall APPLE Study population.

The probability of no disengagement was greater in the face condition ($M = 0.55$, $SD = 0.26$) than in the non-face condition ($M = 0.24$, $SD = 0.22$), indicating a preference for faces ($p = <0.001$, effect size = 0.84) (**Figure 6a**). There were no significant differences between the study sites: in Turku, the mean probability of no disengagement for the face condition was 0.62 ($SD = 0.24$), and in Tallinn $M = 0.50$ ($SD 0.27$), $p = 0.10$. In Turku, the mean probability of no disengagement for the non-face condition was 0.26 ($SD = 0.23$), and in Tallinn $M = 0.22$ ($SD 0.21$), $p = 0.52$.

Exposure to the parents' speech (mother + father) during two weeks in the NICU was positively correlated with a preference for faces at seven months of corrected age ($r_s = 0.34$, $p = 0.009$) (**Figure 6c**), but not with preference for non-face patterns ($r_s = 0.11$, $p = 0.38$) (**Figure 6d**). In separate analyses, exposure to the mother's speech was positively correlated with face preference ($r_s = 0.32$, $p = 0.01$), whereas exposure to the father's speech was not significantly correlated with face preference ($r_s = 0.20$, $p = 0.14$).

In adjusted analyses, face preference was positively associated with gestational age ($r_s = 0.27$, $p = 0.04$), and negatively associated with the mother's education ($r_s = -0.26$, $p = 0.03$), but not with other background variables. The relation between

exposure to the parents' speech and infant face preference remained in an analysis adjusted for the background variables ($r_s = 0.31$, $p = 0.025$). In our analysis, there were seven pairs of twins. We conducted a further sensitivity analysis with infants without a twin pair and with one individual infant from each twin pair. The correlation coefficient between total exposure to the parents' speech and the infant's face preference ranged from 0.29 to 0.42 between the subsets, Med = 0.36.

5.3.2 Attention to parent *versus* unfamiliar adult face

There were no statistically significant differences between the probabilities of no disengagement from parent versus unfamiliar faces (**Figure 6b**), meaning there was no preference for the parent face over unfamiliar adult face. However, exposure to the parents' speech during the two-week period was positively correlated with a preference for the parents' faces ($r_s = 0.28$, $p = 0.034$) (**Figure 6e**), but not with unfamiliar adult faces ($r_s = 0.2$, $p = 0.121$) (**Figure 6f**). Further sensitivity analyses showed marginal association when excluding infants without pictures of both parents ($n = 5$), $r_s = 0.23$, $p = 0.096$, or in the analysis of subsets of infants without twin pairs r_s range 0.21–0.38, Med = 0.29.

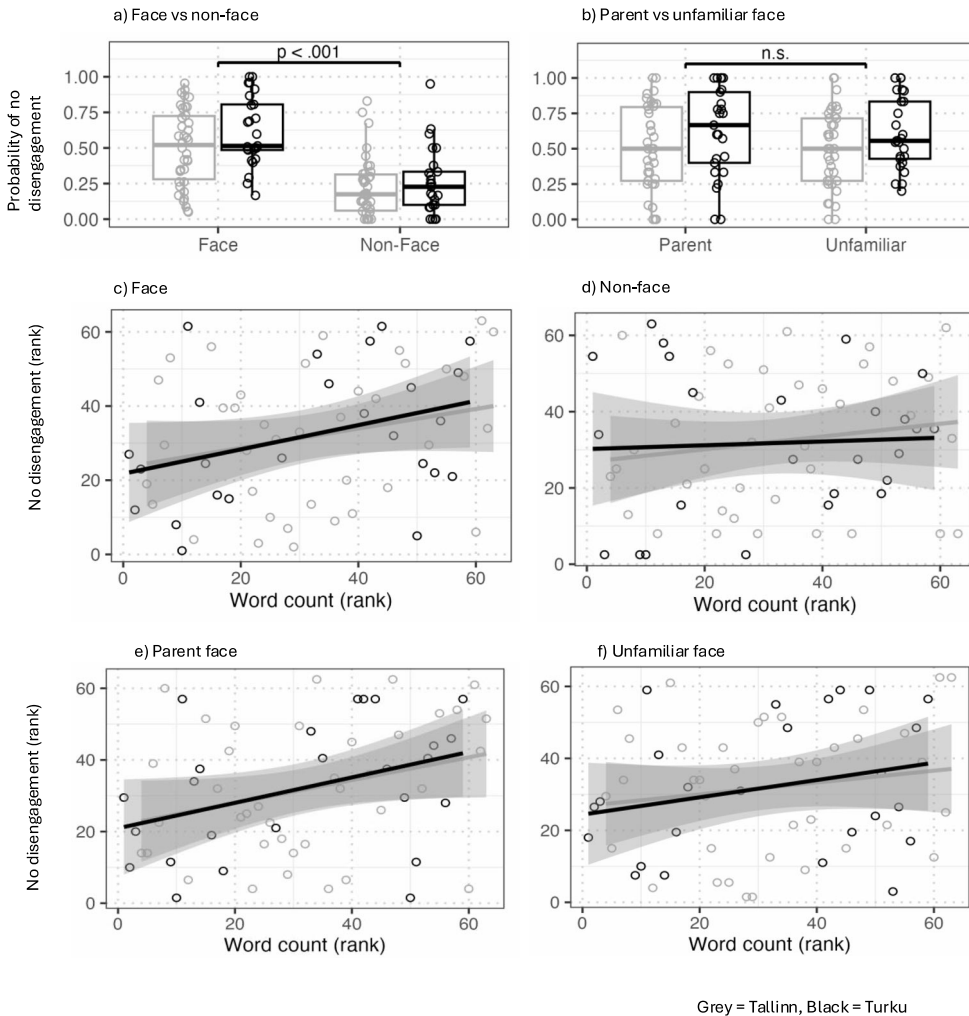


Figure 6. Exposure to the parents' speech and face preference. N.s – not significant.

5.4 Speech in the NICU and later language development in preterm infants

The study (Study III) examining the association between the parents' speech, parent-infant communication, and the children's language development involved 82 preterm infants and their parents (82 mothers and 79 fathers). Infant and family characteristics for this subpopulation are described in the original article (Table 1, Study III). The environmental context during the recording day for this subpopulation is described in the original article (Table 2, Study III). These characteristics did not differ significantly from the overall APPLE Study population.

The infants' language development at the age of one and two years of corrected age, measured with the MCDI and RDLS tests, was not statistically different between the study sites (**Table 12 and Figure 7**).

Table 12. Language development at one and two years of corrected age.

	All APPLE Study population MCDI N = 72 RDLS N = 75		Turku MCDI N = 42 RDLS N = 41		Tallinn MCDI N = 30 RDLS N = 34		
Language outcome measures	Median	Min-Max	Median	Min-Max	Median	Min-Max	p-value
MCDI receptive, 1y	33	1–177	35.5	1–169	29	5–177	0.851
MCDI expressive, 1y	2.5	0–31	2	0–16	3	0–31	0.944
RDLS receptive, 2y	13	0–39	15	1–39	11	0–33	0.399
RDLS expressive, 2y	3	0–19	5	0–19	3	0–13	0.279

MCDI – MacArthur-Bates Communicative Development Inventory; RDLS – *Reynell Developmental Language Scales third edition*

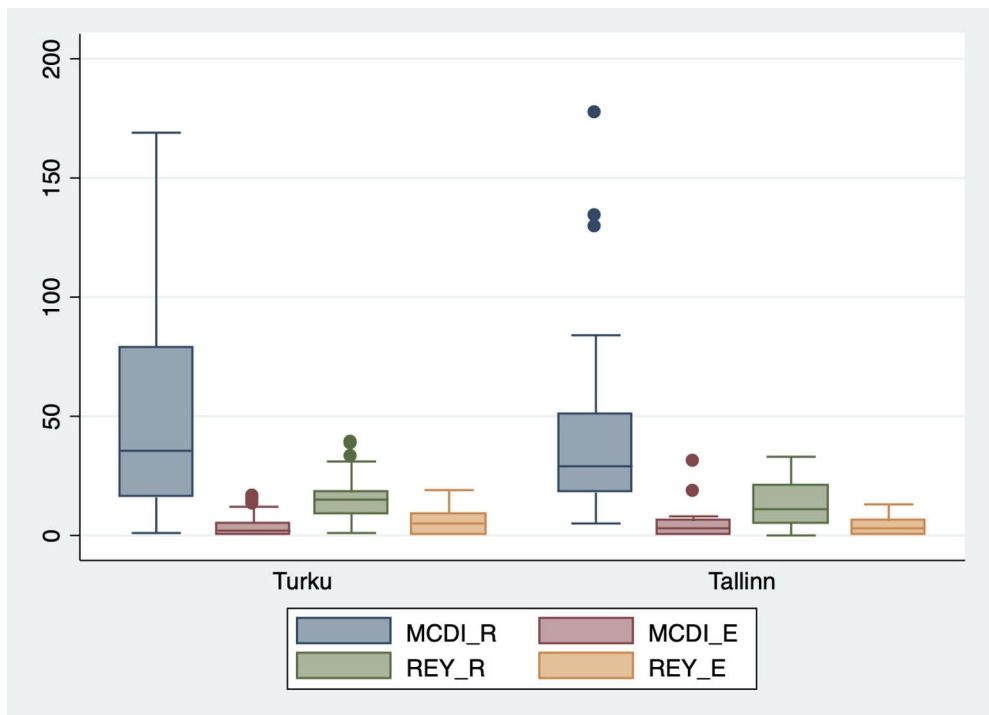


Figure 7. Boxplots for language development scores. MCDI_R – MCDI receptive; MCDI_E – MCDI expressive; REY_R – RDLS receptive; REY_E – RDLS expressive. MCDI – *MacArthur-Bates Communicative Development Inventory*; RDLS – *Reynell Developmental Language Scales third edition*.

5.4.1 Parents' speech in the NICU

In adjusted separate linear mixed models, the father's word frequency per hour during the recording day (b in ln-scale 0.05 [95%CI 0.003–0.09] $p = 0.04$) and the exposure to the father's words during the two-week period in the NICU (b in ln-scale 0.03 [95%CI -0.0002–0.06] $p = 0.05$) were positively associated with expressive lexicon size at one year of corrected age (**Table 13 and 14**). There were no significant associations with the mother's speech in the NICU.

5.4.2 Parent-infant communication in the NICU

In the adjusted separate linear model, conversational turns between the mother and the infant in the NICU during the whole diary period were positively associated with expressive lexicon size at one year of corrected age (b in ln-scale 0.08 [95%CI 0.01–0.16] $p = 0.03$) (**Table 14**). There were no significant associations with the father-infant conversational turns in the NICU.

5.4.3 Overall adult words in the NICU

In the *post hoc* analyses, which included all adult word input regardless of parental presence, total adult word frequency was negatively associated with the child's expressive language skills at two years of corrected age (b in ln-scale -0.13 [95%CI -0.24– -0.01] $p = 0.03$) (**Table 13**).

Table 13. Associations between LENA measures during the recording day and language outcome measures.

	Coefficient in ln-scale	p-value	95% CI
Overall adult word frequency (words/hour)			
MCDI receptive	-0.03	0.47	-0.11–0.05
MCDI expressive	0.02	0.59	-0.06–0.10
RDLS receptive	0.01	0.94	-0.14–0.15
RDLS expressive	-0.13	0.03	-0.24– -0.01
Mother's word frequency (words/hour)			
MCDI receptive	-0.05	0.14	-0.12–0.02
MCDI expressive	-0.01	0.81	-0.08–0.07
RDLS receptive	-0.01	0.84	-0.14–0.12
RDLS expressive	-0.06	0.28	-0.18–0.05
Father's word frequency (words/hour)			
MCDI receptive	-0.03	0.23	-0.08–0.02
MCDI expressive	0.05	0.04	0.003–0.09
RDLS receptive	0.03	0.59	-0.08–0.13
RDLS expressive	-0.01	0.87	-0.09–0.08
Conversational turns when mother present (count/hour)			
MCDI receptive	0.05	0.59	-0.12–0.21
MCDI expressive	0.10	0.12	-0.03–0.23
RDLS receptive	-0.02	0.89	-0.23–0.20
RDLS expressive	0.04	0.75	-0.19–0.27
Conversational turns when father present (count/hour)			
MCDI receptive	0.14	0.14	-0.05–0.32
MCDI expressive	0.05	0.47	-0.08–0.18
RDLS receptive	-0.001	0.99	-0.23–0.23
RDLS expressive	0.04	0.73	-0.19–0.27
Child vocalizations when mother present (count/hour)			
MCDI receptive	0.01	0.86	-0.14–0.17
MCDI expressive	0.04	0.47	-0.07–0.16
RDLS receptive	-0.02	0.84	-0.21–0.17
RDLS expressive	0.06	0.55	-0.14–0.26
Child vocalizations when father present (count/hour)			
MCDI receptive	0.11	0.16	-0.04–0.26
MCDI expressive	0.08	0.21	-0.04–0.20
RDLS receptive	-0.01	0.97	-0.24–0.23
RDLS expressive	0.07	0.52	-0.14–0.28

Fixed effects: gestational age, sex, twin status, parent's education;

Random effect: twin pair, hospital.

$P < 0.05$ marked in bold text.

MCDI with mother variable $n = 72$, RDLS with mother variable $n = 75$

MCDI with father variable $n = 60$; RDLS with father variable $n = 58$

MCDI – *MacArthur-Bates Communicative Development Inventory*; RDLS – *Reynell Developmental Language Scales third edition*

Table 14. Associations between LENA measures during the two-week diary period and language outcome measures.

	Coefficient in In-scale	p-value	95% CI
Exposure to mother’s words for 14 days			
MCDI receptive	-0.05	0.15	-0.12–0.02
MCDI expressive	0.01	0.79	-0.07–0.09
RDLS receptive	-0.01	0.90	-0.15–0.13
RDLS expressive	-0.05	0.39	-0.17–0.07
Exposure to father’s words for 14 days			
MCDI receptive	-0.02	0.10	-0.05–0.004
MCDI expressive	0.03	0.05	-0.0002–0.06
RDLS receptive	0.03	0.43	-0.04–0.10
RDLS expressive	0.005	0.86	-0.05–0.06
Conversational turns when mother present for 14 days			
MCDI receptive	0.03	0.51	-0.06–0.11
MCDI expressive	0.08	0.03	0.01–0.16
RDLS receptive	-0.01	0.86	-0.16–0.13
RDLS expressive	-0.05	0.44	-0.18–0.08
Conversational turns when father present for 14 days			
MCDI receptive	-0.004	0.93	-0.10–0.09
MCDI expressive	0.01	0.83	-0.07–0.09
RDLS receptive	0.03	0.67	-0.09–0.14
RDLS expressive	0.06	0.35	-0.06–0.18
Child vocalizations when mother present for 14 days			
MCDI receptive	0.03	0.66	-0.12–0.19
MCDI expressive	0.08	0.16	-0.03–0.20
RDLS receptive	-0.01	0.94	-0.20–0.18
RDLS expressive	0.11	0.29	-0.09–0.31
Child vocalizations when father present for 14 days			
MCDI receptive	0.04	0.54	-0.08–0.15
MCDI expressive	0.03	0.50	-0.06–0.12
RDLS receptive	-0.004	0.96	-0.16–0.15
RDLS expressive	0.07	0.37	-0.08–0.22

Fixed effects: gestational age, sex, twin status, parent’s education;

Random effect: twin pair, hospital.

P <0.05 marked in bold text.

MCDI with mother variable n = 72, RDLS with mother variable n = 75

MCDI with father variable n = 60; RDLS with father variable n = 58

MCDI – *MacArthur-Bates Communicative Development Inventory*; RDLS – *Reynell Developmental Language Scales third edition*

Summaries of the main results

- In the International Closeness Survey, the parents' presence and their participation in the decision-making process during the medical rounds varied significantly between the units in Europe (I).
- Higher participation of the parents in the medical rounds was associated with overall satisfaction with FCC (I).
- Higher parental presence during medical rounds was dependent on the unit's policy regarding inviting parents to the medical rounds, the infant's higher gestational age, and the higher education of the father. Results highlight the importance of the unit's culture in integrating parents into their infant's care. (I)
- In the APPLE study, infants heard more parental speech in the unit that had implemented the Close Collaboration with Parents training and had more SFRs. Additionally, the mothers' postnatal depression scores were significantly lower in the unit with the Close Collaboration with Parents training and SFRs. (II, III)
- Exposure to the mother's words in two neonatal units was nearly 10 times higher than to the father's words, as both paternal presence and speech input were significantly smaller. (II, III)
- Exposure to the parents' speech during neonatal care in the NICU was associated with the infant's preference for faces over non-face patterns at seven months of corrected age. This indicates that exposure to the parents' speech in the NICU is a potential early marker for later social-cognitive development. (II)
- The more the infant heard the father's words in the NICU, the larger his/her expressive lexicon size was at one year of corrected age. Higher conversational turn count between the mother and the infant was associated with a larger expressive lexicon size at one year of corrected age. A negative association was observed between the total adult word count and the child's expressive language skills at two years of corrected age. As the associations between the language exposure measures and the language outcomes were not consistent, further research is needed to confirm these results and to build a robust foundation for recommendations on an optimal auditory environment for preterm infants. (III)

6 Discussion

6.1 Increasing parental presence and participation with FCC interventions

Study I, an international survey from six countries and 11 neonatal units that had implemented FCC practices, showed that parental presence varied significantly across the units, from 63% to 89% among the mothers and from 31% to 78% among the fathers. The unit's policy in inviting parents to the medical rounds, higher gestational age of the infant, and the fathers' higher education level were factors that increased parental presence in medical rounds. Importantly, the unit's policy in terms of inviting parents to the medical rounds was associated with parental presence in the medical rounds, but none of the background factors were associated with their degree of participation. This suggests that unit culture plays a crucial role in promoting the parents' active presence and participation in the care of their preterm infant during a NICU stay.

Parental involvement in infant care and the use of SSC are widely accepted in NICUs, although their implementation into unit policies and practices varies widely across countries (Pallás-Alonso et al. 2012). The neonatal staff often lack training and knowledge about FCC practices (Weber et al. 2022). Unfortunately, parent-infant separation during neonatal care is still common, as reported by a study looking at 19 countries and 45 NICUs from Europe and Canada (van Veenendaal et al. 2022). Integrating parents into the medical rounds and shared decision-making seems to be one of the most challenging practice changes to achieve in the daily routines of neonatal care, as the parents' participation in medical rounds is shown to be one of the most frequently persisting restrictions across units (Greisen et al. 2009). Parents have reported a strong desire to participate in medical rounds (Davidson 2013; Rea et al. 2018).

Family-centered medical rounds have been shown to reduce parental anxiety, increase parental satisfaction with care, and improve communication between the parents and the staff (Cameron et al. 2009; Voos et al. 2011; Rea et al. 2018). In our study, higher participation in medical rounds was associated with overall satisfaction with other components of FCC (active listening, parental participation in infant care, individualized guidance given to the parents, the parents' participation in decision-

making, the parents' trust in the staff concerning infant care, the parents' sense of being trusted by the staff, individualized information and emotional support). Previous literature has shown that both the parents' and nurses' satisfaction with the overall FCC quality increased after the implementation of FCC intervention programs (van Veenendaal et al. 2020; Toivonen et al. 2023; Itoshima et al. 2025). Unit culture could be improved by implementing specific training with FCC intervention programs. Promoting developmentally supportive FCC intervention programs in the NICUs could increase the overall quality of the FCC. Providing specific training for the staff, including the nurses and neonatologists, can foster a welcoming atmosphere and supportive attitude, thus enabling more effective integration of the parents into the discussions during medical rounds (Axelin et al. 2018; Thébaud et al. 2017). A recent study that explored nurses' and physicians' opinions about FICare implementation found that implementation of the program improved shared decision-making and parent-staff relationship during medical rounds (Franck et al. 2023). Supporting NICU professionals in communicating with the parents with the Reflective Group Dialogue tool could guide the shared decision-making process during medical rounds (Ahlqvist-Björkroth et al. 2023).

Parents of preterm infants have described their experiences in the NICU as a rollercoaster of closeness and separation (Mäkelä et al. 2018). There are times when they feel emotionally close to their infant when being present in the unit, even without physical closeness. And there are times when they feel emotionally detached even in close SSC. Already in 1972, Klaus et al. showed that extended mother-infant contact after delivery affected mother-infant interaction at one month of age (Klaus et al. 1972). Several FCC interventions have shown beneficial effects on the well-being of the preterm infant as well as enhancing closeness and bonding between the parent and the infant. For example, early SSC and SFR interventions increased parent-infant closeness (Tandberg et al. 2018; van Veenendaal et al. 2020) and bonding (Lilliesköld et al. 2022). Some intervention programs have been shown to increase parental presence in the NICU (Klein et al. 2021; Tandberg et al. 2018; van Veenendaal et al. 2020; He et al. 2021) and their empowerment and confidence in taking part in the care of their preterm infant (van Veenendaal et al. 2020; Pineda et al. 2020; Ansari et al. 2023).

The unit's policy and culture are important factors that facilitate parental well-being and participation. When the staff offers support to parents, they have a crucial role in promoting early closeness and bonding between the parent and the infant (Mäkelä et al. 2018). Some intervention programs (e.g., Family Nurture Intervention, Family-Integrated Care, Close Collaboration with Parents, Couplet Care) have been shown to decrease maternal depression and anxiety (Welch et al. 2016; O'Brien et al. 2018; Ahlqvist-Björkroth et al. 2019; Doughty et al. 2024), although it is yet

unclear which exact elements of the interventions are effective in decreasing the parents' depressive symptoms (Lehtonen et al. 2022).

Although there are several positive aspects to integrating parents into the neonatal care and decision-making process, there may also be some negative effects. Greater attention and effort are needed in integrating parents into the medical rounds and shared decision-making, as the parents may feel incompetent with medical terminology when professional centeredness dominates, and active listening is missing (Axelin et al. 2018). Participation in decision-making may increase parents' confusion and anxiety, especially in critical conditions (Davidson 2013; Axelin et al. 2018; Van der Voorden et al. 2023). More responsibility can be demanded of the patient than they wish to accept (Van der Voorden et al. 2023). Shared decision-making could also negatively affect patient-professional relationship, and the staff may have to spend additional time on a patient (Van der Voorden et al. 2023). Parents' participation in the decision-making process increases when the child is in a stable condition and as discharge approaches (Axelin et al. 2018). FCC should strive for shared decision-making, where parents are consistently invited to participate but are given the autonomy to decide the extent of their involvement.

Knowing barriers and facilitators in promoting parental participation and parent-infant closeness demonstrates a notable step forward. An international study from 46 NICUs summarized the main themes related to the facilitators in promoting FCC principles and parent-infant closeness (van Veenendaal et al. 2022): Culture (collectively held values and behaviors in the unit relating to parental presence and participation), Collaboration (proficiency in working together between and within the different scales), Capacities (policies and resources), Coaching (educating the staff and parents in acquiring and transferring knowledge and skills). Parental involvement in neonatal care is influenced by organizational policies and by the availability of resources (space, unit design, the availability of nursing staff), though SSC and roles assigned to the parents also appear to be shaped by sociocultural factors at the national level (Pallás-Alonso et al. 2012). Presumably, there are prejudices and cultural beliefs that influence the integration of parents into neonatal care, not only resources and policies. Therefore, changing the unit's culture with specialized training programs is a possible tool to integrate parents purposefully and safely into neonatal care and decision-making.

6.2 Early Vocal Contact in the NICU environment

In Studies II and III, we analyzed the associations between parental speech exposure in the NICU and later infant social and language development at 7, 12, and 24 months of corrected age. Study II found a significant association between exposure to the parents' speech in the NICU and the infant's perceptual preference for faces at seven

months of corrected age. Study III found positive associations between parental speech and parent-infant communication and the language development of the infant at one and two years of corrected age, whereas the total amount of adult words in the NICU had a negative impact on the preterm infant's language development.

6.2.1 Background of the units

In the NICU, the auditory environment is often characterized by two extremes – “too quiet” or “too noisy” (Rand & Lahav 2014). The immature and lower gestational age preterm infants are often treated inside incubators to provide temperature regulation and to protect the infant from high sound levels. However, it is shown that incubator walls also reduce meaningful language input (Monson et al. 2020), and therefore, fetuses are five times more exposed to adult speech than preterm infants (Monson et al. 2023). A study by Pineda et al. (2014) has shown that private rooms that had very little parental presence and communication had a negative association with language development at two years of corrected age, meaning that being “too quiet” has potential negative effects on a child's language development. Lester et al. (2016) have described that high maternal involvement in infant care is associated with better cognitive and language scores at 18 months of corrected age, and the effect emerges more in SFR NICU design. Vohr et al (2017) showed – in a study including an overlapping study population with Lester's – that the very preterm infants cared for in a SFR unit had better language development at 18 months of corrected age than their peers cared for in the previous open-bay unit. Our results are consistent with this, as exposure to the parents' speech was significantly higher in the unit where the infants were treated mainly in the SFRs. SFR design has been shown to increase parents' presence (Kainiemi et al. 2021; van Veenendaal et al. 2020) and decrease high sound levels (Aita et al. 2021) and provide privacy for the family. In our study, fewer infants were treated inside an incubator during the recording day in the SFR unit, which potentially allowed more verbally meaningful communication with the infant.

Our APPLE study has described that although both participating units had adhered to FCC practices, there were still significant differences between the study sites. The unit that had implemented the Close Collaboration Program and where the infants were mainly treated in the SFRs had significantly more exposure to the parents' words and communication/conversational turns between the parent and the infant. Interestingly, in the unit that had implemented the program and where infants were more exposed to parental speech, the mothers' depression scores were also significantly lower. Notably, parental presence was not associated with the amount of parental speech, as e.g., mothers were significantly more present in Tallinn, however the number of their words was lower compared to Turku. However, there

were no significant differences in receptive or expressive language scores between the two study sites. Speculation connected to this could be based on the Programme for International Student Assessment (PISA) report, which evaluates students' knowledge and skills in reading, mathematics, and science globally. Estonian and Finnish students have consistently demonstrated strong educational outcomes, as the latest reports have ranked Estonia and Finland as the top performers in Europe and globally (OECD 2023). It is common in Estonian and Finnish families to read to the children daily, even during infancy. Strong educational backgrounds in these countries could explain why there were no differences in language scores between these two study sites. Additional studies for further assessments and evaluation are needed.

6.2.2 Attention and social-cognitive development

Previous studies have shown that infants, even as young as three months, prefer to look at faces more than non-face objects (Leppänen 2016; Pyykkö et al. 2019; Kelly et al. 2019). It has also been shown that compared to term infants, preterm infants have reduced attention to faces and reduced response to social stimuli (Telford et al. 2016) and are less focused on the target and slower to fixate attention at 12 months of corrected age (Downes et al. 2018). Additionally, these deficits in visual attention have been shown to be linked with lower cognitive scores at two years of corrected age (Beunders et al. 2021).

Study II measured exposure to the parents' speech in the NICU and its association with the infant's attention, measured using visual functions. Firstly, preterm infants were less likely to disengage their attention from faces than non-face patterns, and this was positively correlated with gestational age, meaning that more mature preterm infants have a lower risk for attention deficits. Secondly, we found a positive association between exposure to the parents' speech in the NICU and the preterm infants' perceptual preference for faces versus non-face patterns at the age of seven months of corrected age. Additionally, exposure to the parents' speech was positively correlated with the preference for the parent's face, but not with an unfamiliar face.

Significant results from Study II highlight the importance of early vocal contact in the NICU for later social-cognitive development. It is possible that these two different domains (language exposure and visual preference) may go hand in hand. Marcet et al. (2024) have recently shown that mono- and bilingual infants were able to form face-language associations within their first year of life. Early vocal contact in the NICU is a unique form of early intervention, as it fosters meaningful communication between the parent and the infant and, therefore, should be promoted and supported by the staff in the NICU.

6.2.3 Language development

Study III found that a higher conversational turn count between the mother and the infant predicted larger expressive lexicon size at one year of corrected age, highlighting the importance of mother-infant interactive communication.

The development of the auditory system in preterm infants occurs anatomically and functionally significantly earlier than in term-born infants (Kuhn et al. 2017). Although language impairments are multifactorial, preterm infants may experience poor language outcomes even without major disabilities (Filippa & Kuhn 2024; Vohr 2016; Stolt et al. 2009; 2013). Additionally, it has been shown by several studies conducted in healthy children that language input is essential for language development (Huttenlocher 1998; Zimmerman et al. 2009; Anderson et al. 2021), and interactive parent-child two-way conversations are more meaningful (Zimmerman et al. 2009; Preza & Hadley 2024). Compared to all human voices, the maternal voice is undoubtedly the most prominent vocal stimulus for infants (Kuhn et al. 2017). Compared to unfamiliar voices, a mother's voice is shown to trigger activity in different brain areas (Dehaene-Lambertz et al. 2010), especially emotional and infant-directed speech (Filippa & Kuhn 2017). This is also consistent with earlier literature, where Coughlan et al. (2024) observed 22 preterm infants and 25 term infants in parent-infant free-play conversations and found that the parents' speech rate and maternal interactive features were associated with better language scores in the preterm study group, whereas the fathers' interactive features were not (Coughlan et al. 2024). These facts highlight the importance of maternal/parental closeness and interactive communication in the NICU environment. Neonatal auditory environment and separation may, therefore, have a possible negative impact on preterm infants' language development through deprivation of biologically meaningful auditory stimuli produced by the mother or parents (Filippa and Kuhn 2024). Mother-infant interactive communication seems to be important to the healthy development of both term and preterm infants, highlighting that it is essential to promote the parent-infant closeness in the NICU. Additionally, Montirosso et al. (2016) have shown in a multicenter longitudinal study that higher quality of developmental care (according to infant-centered care and infant pain management) was associated with higher scores in sentence comprehension in preterm infants at three years of age.

All FCC intervention programs have similar main goals that include developmental support, promoting parent-infant closeness, parenting education, and parental psychological support. They all focus on mother-child or parent-child interaction, promoting sensitive communication using vocal, visual, and behavioral input, but none of these programs specifically promote the parent's voice or speech (Roué et al. 2017). It is not known how much auditory exposure is sufficient for language development, but skin-to-skin holding with infant-directed speech offers a

powerful basis for language development in the NICU environment (Philbin 2017). It is not always easy for parents to sing or speak to their infant through the incubator, they need confidence and supportive guidance from the staff (Monaci et al. 2021). Caskey et al. have reported that exposure to the parents' talk in the NICU predicted more infant vocalizations compared to other adult talk (Caskey et al. 2011). Guiding the parents to interpret their infant's behavioral signals and cues to increase sensitive interaction has improved infant neurobehavior (Montirosso et al. 2012). Guided infant-directed reading intervention in the NICU environment predicted more conversational turns between the parent and the infant by 36 weeks of postmenstrual age (Mayne et al. 2022). In the APPLE study (II, III), we estimated the exposure to the parents' speech during two weeks using closeness diaries, which enabled us to expand the time window for the exposure compared to earlier studies (Caskey et al. 2011; Caskey et al. 2014). We acknowledge that speech exposure during the NICU stay is only a brief timeframe within the rapid developmental phase of infancy, and other factors could potentially mediate this effect. However, tailored education and instruction provided by the staff during the NICU stay can enhance parents' understanding of how to communicate effectively with their infant. This could foster new parental skills that are likely to be continued at home, potentially leading to long-term effects. Post-discharge home and family environment influence infants' long-term neurodevelopmental outcomes alongside the interventions applied in the NICU period.

Although we report findings from Study III with precaution, as the statistical model involved multiple comparisons and the effects were not robust, we conclude that parental speech exposure seems to have a positive effect on later child development. Future studies are needed.

6.2.4 Including fathers

While mother-infant interactions have been thoroughly investigated, there has been less research on the role of paternal-driven input. These studies are mainly limited to SCC effects, suggesting that fathers are only partially involved in early developmental interventions in NICUs. Involving fathers in NICU care is beneficial for them as well as for the infant (Filippa et al. 2021). Filippa and Kuhn (2024) have described in their recent review that the fathers' vocal interactions contribute to their infants' well-being and comfort, expressed in the calmer arousal of the infant. This thesis contributed to the knowledge on fathers' involvement, which has often been ignored in earlier studies.

Study I showed that, compared to the mothers, the fathers were less present, although in five out of 11 units, the fathers gave higher scores to the participation in medical rounds than mothers. Additionally, the fathers' education level was

associated with their presence in the medical rounds. Fathers with higher education levels potentially have more knowledge about health issues, or more flexibility in their work schedule, and therefore may have more opportunities to participate in decision-making about the care of their infants.

Studies II and III showed that, compared to the mothers, the fathers were significantly less present in the NICU and therefore, the infants were significantly less exposed to the fathers' words. Study III found that despite the smaller amount of exposure to the father's words during their NICU stay, the fathers' words were associated with better expressive lexicon size at one year of corrected age. On the other hand, a separate analysis of Study II showed that exposure to the fathers' words was not associated with face preference at the age of seven months of corrected age, while there was an association between the mothers' words and face preference. However, the number of fathers' words had a positive effect on the infants' language development at one year of corrected age.

Most fathers were shown to be present at birth and to accompany their infants during the transfer to the NICU in a national web-based survey in France (Stern-Delfils et al. 2023). In cases where the mother needs medical care after the delivery and the infant is separated from the mother, the role of the father's presence and participation becomes more important. A study that documented the fathers' needs and experiences during pregnancy reported that 85% of the fathers desired additional fathering skills and parenting information (Kotelchuck et al. 2022). Fathers have described feeling unsure, unprepared, and overwhelmed during pregnancy, although they are willing to face those challenges with social support, encouragement, and practices that engage and involve them (Griffith et al. 2023). Therefore, after preterm birth, the fathers might need extra support in their transition to fatherhood. It has been shown that both the parents' and the nurses' satisfaction with the overall quality of FCC increased after implementing the Close Collaboration program (Toivonen et al. 2023; Itoshima et al. 2025). Additionally, after the intervention, the staff was able to include fathers even more, as this had been difficult before the intervention (Toivonen et al. 2023). In our study, the fathers' presence was significantly higher in the unit that had SFRs and had implemented the program (median hours of fathers' presence was 49 per 14 days in Turku and 13 in Tallinn, $p < 0.001$). This result is supported by the data from interviews with the NICU fathers, as they described feeling emotionally close to their infant when they had privacy in the NICU (Lebel et al. 2022).

Fathers often need to combine family responsibilities with work commitments, which might explain less presence in the NICU. Despite their reduced presence and therefore also a smaller amount of speech, paternal linguistic input in term infants seems to be essential for language development, complementing the overall speech input (Pancsofar & Vernon-Feagans 2006; Majorano et al. 2013; Shapiro et al. 2021).

Maternal and paternal input appear to be complementary, providing different experiences for children (Abraham & Feldman 2022). A father's brain is highly responsive to infant auditory and visual stimuli, although the time needed for their adaptation into fatherhood is still unknown (Provenzi et al. 2021). Paternal speech input may become more active during the second half of infancy, which could explain the effect from the fathers' words at one year of corrected age but not at 7 months of corrected age.

6.2.5 Noise in the early environment

In the *post-hoc* analysis of Study III, overall adult word count was negatively associated with the infants' expressive language skills at two years of corrected age. This is consistent with the results from an earlier study that included only Finnish-speaking families (Ståhlberg-Forsén et al. 2022), indicating that there is a balance between developmentally supportive language input and asynchronous talk that could be considered noise. As Suppanen et al. (2019) have shown, the synchronous, rhythmic structure of auditory input might help infants process language input and, therefore, facilitate better language development.

Besides “too quiet”, the other extreme in the NICU environment is “too noisy” (Rand & Lahav 2014). Wachman and Lahav (2011) have summarized in their review that loud transient noise in the NICU has negative short-term effects on a preterm infant's physiological stability by affecting the cardiovascular and respiratory systems. Preterm infants react physiologically and behaviorally to sounds exceeding 70 decibels (dB), and they can detect the background noise of a minimum of 5–10 dB (Kuhn et al. 2017). Loud and unpredictable noise potentially contributes to the neurocognitive burden and alterations in early communicative skills (Filippa & Kuhn 2017), and even minimal sound variations interfere with their well-being and sleep patterns (Kuhn et al. 2012; Kuhn et al. 2013). A recent systematic review recommends the SFR design for neonatal units, as this design enables more privacy, noise control, parental involvement and satisfaction, increased breastfeeding, reduction in mortality, and decrease in length of stay in the hospital (O'Callaghan et al. 2019). Even though new NICU designs and noise-limiting rules in the NICU mitigate the noise in the neonatal environment, some noise reduction challenges still remain. A study by Andy et al. (2025) showed that congregations of people are the primary source of noise, indicating that a large amount of the noise comes from the staff. Additionally, a recent study by Jungewelter et al. (2024) showed that human noise exposure during pregnancy was associated with lower language acquisition scores at one year of age. This fact highlights the impact of the unit culture and the need for specialized training programs for the staff to obtain the expertise in providing a calm and supportive environment in the NICU.

6.3 Strengths and limitations

Study I was the first study prospectively assessing the parents' presence and participation in medical rounds in the NICU from the parents' perspective at an international level. Previous studies were mainly conducted as small surveys, describing mostly unit-level or national policies, and primarily in pediatric intensive care settings (Cameron et al. 2009; Kuo et al. 2012; Stickney et al. 2014; Hoeben et al. 2024).

Study II and Study III enabled a good variation in the study populations, as we included two centers with different care cultures and architecture. The APPLE study collected observational data from real-life situations without any specific speech instructions to the parents. Additionally, the strength of Studies II and III is that the two-week monitoring period allowed us to broaden the time window for speech exposure. Another important strength of the APPLE Study is the long follow-up period with objective outcome measures (the eye-tracking test and validated language tests) until two years of corrected age. Studies involving fathers are rare. Three studies from this thesis have included both the mothers' as well as the fathers' presence and participation in infant care (participation in medical rounds and exposure to speech) in different centers.

There are limitations in the studies included in this thesis. The international survey assessed the parents' perspectives using text-message questions, which might have restricted participation to those with mobile phone access and sufficient digital literacy. Additionally, some respondents might have felt strongly about some aspects that could have influenced them to participate, and this led to the overrepresentation of certain perspectives. There might have been variations in recruitment strategies in different countries, which could have affected the generalizability of the results. The survey did not consist of disease-related or infants' medical condition data, which could have influenced the results. The technology worked smoothly in most of the countries participating in the international closeness survey (Study I), except Estonia and Norway, where there were some difficulties in delivering the text-messages, resulting in missing data from these countries.

The APPLE Study is an observational study, not randomized control study. In the APPLE study, the identification of the speakers was not possible from the audio recording, and we measured the parents' word counts from the time periods when they were present according to the closeness diary. Therefore, the word count could also have included words spoken by the staff near the infant. However, we expect not to include neighboring adult speech, as LENA word counts include only near and clear speakers. The validation study in Finnish and Estonian from the APPLE study group (Ståhlberg-Forsén et al. 2021) showed that there was a high agreement between the LENA and human estimates of adult female words, whereas male words, child vocalizations, and conversational turns were less valid, indicating the

limits of the automatic measuring. Coincidentally, some of the fathers were not present during the recording day, and therefore, we chose to use median word count (Study II) or exclude missing data from the analysis (Study III). The estimation with the median word counts separately for Turku and Tallinn was done to provide a wider time window and to use the data from the time the fathers were present during the diary days. The reason for excluding the missing data from Study III was statistical. The eye-tracking measuring in Study II was challenging for various technical reasons, and therefore, the test was deficient in 33% of the patients. For Study III, we included only families speaking Finnish and Estonian to get the most comparable data regarding language development, due to the similarity of these two Finno-Ugric languages. Some parents' refusal of the eye-tracking test (n=16) and language assessments (n=9) was another main reason why Study II and Study III included a smaller number of participants than the overall APPLE Study sample (**Figure 2**, Flow Chart). Additionally, due to Covid-19 pandemic restrictions, we were not able to test two follow-up patients. It is possible that these dropouts, due to the variety of reasons mentioned above, could have potentially influenced the results. Therefore, we recruited more patients to get a sufficient study sample.

6.4 Future perspectives

Although all various developmental care implementation practices seem to be beneficial (Ohlsson & Jacobs 2013; Puthussery et al. 2018), and some studies confirm the effectiveness to the child's stabilization or neurodevelopment, knowledge gaps and lack of implementation measures such as adherence, doses, and participant responsiveness still exist (Ahlqvist-Björkroth et al. 2024). There is a need to study the effects of early infant-directed speech and parent-infant reciprocal communication on later child development. It is important to study how these early interventions influence the patterns that are continued at home after discharge. There is a need to develop or include in the intervention programs specific intervention strategies to enhance speech exposure in the NICU environment and therefore study whether these improve language outcomes for the children born preterm.

It seems that there is a need for integrating precise and structured family-centered rounds guidelines into unit practices or implementation programs (Palka et al. 2022), since it would be possible to integrate parents into the shared decision-making process more efficiently. Also, it would be interesting to study the association between the parents' participation in medical rounds and the countries' policies about paternal leave and NICU staff workload. It is noteworthy that more studies including fathers are needed.

6.5 Conclusions and clinical implication

The three studies described above showed that parents have an important role in communicating with the staff and with their own preterm infant, as part of the developmental care team. First, we studied how often and how much the parents of preterm infants participated in medical rounds across Europe (I). Results showed that the parents take an active role in the care team, although there were variations between and within countries, highlighting the impact of the unit's care culture and the level of staff support in promoting parental presence and participation. Exposure to the parents' speech during neonatal care in the NICU was associated with the infant's preference for faces over non-face patterns at seven months of corrected age (II), indicating that exposure to the parents' speech in the NICU is a potential early marker for later social-cognitive development. Early parent-infant communication and parental speech in the NICU potentially supports the infant's language development, whereas a high total number of adult words could act like noise exposure and have a negative impact on a child's development (III).

The phase from prematurity to early infancy represents a critical window of unique plasticity, during which various interventions in the neonatal unit environment can help mitigate brain injuries (Lehtonen & White 2020). In summary, firstly, an optimal NICU environment supports the parents' presence and their engagement with their infant and with the infant's care; secondly, optimal care culture should provide nurturing sensory stimuli for the infant and support healthy parent-infant attachment; thirdly, an optimal auditory environment should be calm and quiet, and familiar parents' voice exposure should be promoted with its emotional and infant-directed components (Filippa and Kuhn 2024). This thesis has shown that including parents in the decision-making process, promoting parent-infant communication, and exposure to the parents' speech during neonatal care are important milestones in improving the NICU environment and infant outcomes and, therefore, should be promoted and implemented in clinical practice. Undoubtedly, introducing new practices and transforming the care culture represents one of the greatest challenges. Therefore, targeted implementation programs are essential to facilitate changes in NICU practices in a more convenient and structured manner.

Acknowledgements

This thesis was carried out at the Department of Pediatrics in Turku University Hospital, at the Department of Neonatal and Infant Medicine in Tallinn Children's Hospital, and in 11 NICUs in 6 European countries as part of the International Closeness Survey by the SCENE research group. I sincerely thank everyone who has contributed to this thesis, without you this would not have been possible.

I owe my deepest gratitude to my supervisors, Professor Liisa Lehtonen and Doctor Liis Toome, for your endless support and patience. You have taught me a lot in neonatology as well as in research, and you have created numerous opportunities and pathways for my growth. Without your support, I would not be the neonatologist or the researcher I am today. Liisa, you have been “my academic mother” and my greatest mentor. I admire your knowledge, your efficiency, and your dedication to neonatology and research. You have gently guided me through ups and downs, while being demanding but also inspiring. Liis, thank you for your guidance and constant belief in me. You inspire me with your ideas and thoroughness.

My sincere thanks go to the APPLE Study group and all my co-authors – Sari Ahlqvist-Björkroth, Suvi Stolt, Eva Ståhlberg-Forsén, Jukka Leppänen, Laura Aarnos, Mirka Hyvönen, Einari Vaaras – it is a privilege to work alongside such exceptional and committed researchers.

I thank the whole international SCENE research group, and the entire staff in each NICU that participated in the study in Finland, Sweden, Norway, Italy, Spain, and Estonia, and helped us gather the data. Special thanks go to Anna Axelin and Simo Raikola, who helped me a lot with the first manuscript.

I would like to give my sincerest gratitude to Minna Paaso, who agreed to be my research nurse and has been just excellent. I would like to thank all NICU nurses from Turku and Tallinn, as well as Päivi Tuomikoski, Birgit Kaasik, Örne Uus, Jenni Taulu, Suvi Vehkavuori, Tarja Virtanen, Maria Kirjanen for the help in data collection. Special gratitude goes to Marika Tammaru for guiding me through the difficult moments in statistics. I thank Sarah Holdren and Henna Raudaskoski for language proofreading. I thank my advisory committee members Anita Arola and Jorma Toppari. And Heili Varendi, my first research mentor during my university years.

I would like to thank the following foundations and institutions for their important financial support during this study: Signe and Ane Gyllenberg Foundation, Finnish Pediatric Research Foundation and Southwest Finland Newborn Research Fund, The Mannerheim League for Child Welfare Foundation, Turku University Foundation.

I warmly thank all the children and families who participated in the SCENE and the APPLE studies.

I would like to thank all my colleagues and friends from Tallinn Children's Hospital, East-Tallinn Central Hospital, and Turku University Hospital for your support and the opportunity to dedicate time for research – Reelika, Haide, Merle, Priit, Ilona, Külli, Vera, Svetlana, Johanna, Helgi, Pille, Annika, Kadri, Ruth, Kati, Kairit, Aasa, Hanna, Kalle, Monika. Special thanks go to my abs training team – Helen, Maarja, Marie, Liis, Mari-Liis, Gerda and Teele, and to my pizza team – Vilhelmiina and Heidi.

Lastly, I want to warmly thank my parents, Sirje and Mati, for your unwavering support and guidance. Lemmi, Elve, and my sister Kristi, for your support, and for helping with our children, enabling me to finish this thesis. Jenna – you are just my person.

Dear Hans and Oskar, there is nothing more important in my life than you. You have taught me patience, sincere joy, and the greatest love imaginable, and you have given me superpowers (and superpower LEGO machines). Dear Margus, you have always been a loving partner and a wonderful dad. I am deeply grateful for your advice and encouragement, both consistently and especially during this challenging period. I would not be here without the three of you, and I am deeply grateful to have you in my life.

May 24, 2025
Tallinn, Estonia

Anette Aija

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ISBN 978-952-02-0247-7 (PRINT)
ISBN 978-952-02-0248-4 (PDF)
ISSN 0355-9483 (Print)
ISSN 2343-3213 (Online)