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**SOCIAL FUNCTIONING
IN YOUNG ADOLESCENTS
BORN VERY PRETERM**

Susanna Salomäki



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To my children and dearest friends

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ABSTRACT

Very preterm birth poses a long-term risk for social development. The social functioning of very preterm children has been mainly assessed by parents and teachers, although the children's subjective experience of social functioning may have greater predictive value for well-being in the future. This dissertation is part of the PIPARI study (PIeniPAinoisten RIskilasten käyttäytyminen ja toimintakyky imeväisiästä kouluikään), which follows very preterm-born infants (<32 weeks of gestation and/or birth weight ≤ 1500 g), as well as their healthy controls, from birth onwards. Self-reported loneliness and social competence were evaluated at 11 years of age. This dissertation aimed to identify profiles (Study I) and neurological correlates (Study II) of experienced social functioning in young adolescents born very preterm and term. Furthermore, potential risk factors for social functioning in the very preterm-born group were examined (Studies I, II, and IV).

Most frequently, young adolescents born very preterm reported a profile of average social competence and average level of loneliness. Preterm-born boys reported a profile of low social functioning less frequently than term-born boys, and preterm-born girls reported a profile of high social functioning less often than term-born girls. Social functioning was more frequently associated with brain volumes in the very preterm group than in the term-born group. Higher levels of maternal stress and depression, when the child was from two to four years, associated with lower levels of social functioning in 11-year-old girls born very preterm. Difficulties shifting attention were associated with a higher level of social loneliness in young adolescents born very preterm. Better working memory and better maternal education were associated with heightened social functioning in young adolescents born very preterm. Very preterm birth exerts a longitudinal effect on experienced social functioning, which appears to have neurodevelopmental origins. Female sex, early maternal depression, and difficulties shifting attention may indicate an increased risk of poor social functioning in 11-year-old children born very preterm, whereas high maternal education and better working memory may serve as protective factors.

KEYWORDS: Very preterm birth, early adolescence, loneliness, social competence, brain volumes, parenthood, mood and behavioral problems, executive function

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TIIVISTELMÄ

Pikkukeskosuus lisää sosiaalisten vaikeuksien riskiä. Aiemmin pikkukeskosten sosiaalista toimintakykyä ovat arvioineet pääasiassa vanhemmat ja opettajat, vaikka pikkukeskosten oma kokemus voisi ennustaa paremmin heidän hyvinvointiaan. Tämä väitöskirja on osa PIPARI- pitkittäistutkimusta (PieniPAinoisten RIskilasten käyttäytyminen ja toimintakyky imeväisiästä kouluikään), jossa on seurattu pikkukeskosten (<32 raskausviikkoa ja/tai syntymäpaino ≤ 1500 g) ja täysiaikaisena syntyneiden verrokkilasten kehitystä. Tutkittavat arvioivat 11-vuotiaana yksinäisyyttään ja sosiaalista kompetenssiaan. Arvioita käytettiin sosiaalisen toimintakyvyn mittareina. Ensimmäisessä osatyössä tutkittiin, miten pikkukeskoset ja verrokkit kokevat sosiaalisen toimintakykynsä. Toisessa osatyössä tutkittiin pikkukeskosten ja verrokkien sosiaalisen toimintakyvyn yhteyttä heidän neurologiseen kehitykseensä. Osatyöissä I, III ja IV kartoitettiin sosiaaliseen toimintakykyyn vaikuttavia tekijöitä.

Pikkukeskoset arvioivat sosiaalisen toimintakykynsä tavallisimmin kohtalaiseksi. Pikkukeskospojat arvioivat sosiaalisen toimintakykynsä harvemmin heikoksi kuin verrokkipojat. Pikkukeskostytöt taas arvioivat sosiaalisen toimintakykynsä harvemmin korkeaksi kuin verrokkitytöt. Pikkukeskosten sosiaalinen toimintakyky oli vahvemmin yhteydessä neurologiseen kehitykseen. Pikkukeskostytöt arvioivat sosiaalisen toimintakykynsä sitä heikommaksi, mitä enemmän heidän äitinsä olivat kokeneet stressi- ja masennusoireita keskosien varhaislapsuudessa. Pikkukeskoset kokivat sitä enemmän sosiaalista yksinäisyyttä, mitä enemmän heillä oli vaikeuksia kognitiivisessa joustavuudessa. Keskosien hyvä työmuisti ja äidin korkea koulutustaso olivat yhteydessä parempaan sosiaaliseen toimintakykyyn. Pikkukeskosuus vaikuttaa pitkäkestoisesti sosiaaliseen toimintakykyyn. Ilmiön taustalla ovat aivojen kehityksen poikkeavuudet. Riskitekijöitä pikkukeskosien heikommalle sosiaaliselle toimintakyvylle ovat kognitiivisen joustavuuden vaikeudet, naissukupuoli ja äidin masennus ja stressi tyttökosien varhaislapsuudessa. Suojaavia tekijöitä ovat keskosien hyvä työmuisti ja äidin korkea koulutustaso.

AVAINSANAT: Erittäin ennenaikainen syntymä, varhaisnuoruus, yksinäisyys, sosiaalinen kompetenssi, aivovolyymit, vanhemmuus, mieliala- ja käytösoireet, toiminnanohjaus

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Kaarina, November 2024

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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 Salomäki S, Rautava P, Junttila N, Huhtala M, Leppänen M, Nyman A, Koivisto M, Haataja L, Lehtonen L, Korja R, the PIPARI Study Group. Social functioning questionnaires of adolescents born preterm show average profiles and attenuated sex differences. *Acta Paediatrica*, 2020; 00: 1–8.
- II Lind A, Salomäki S, Parkkola R, Haataja L, Rautava P, Junttila N, Koikkalainen J, Lötjönen J, Saunavaara V, Korja R. Brain volumes in relation to loneliness and social competence in preadolescents born very preterm. *Brain and Behavior*, 2020; 10: e01640.
- III Salomäki S, Junttila N, Setänen S, Rautava P, Huhtala M, Leppänen M, Lehtonen L, Korja R. Longitudinal associations between parental early psychological distress and children’s emotional and behavioural problems during early childhood and self-reported social functioning in 11-year-old children born very preterm. *European Journal of Developmental Psychology*, 2023; 00: 1–6.
- IV Salomäki S, Nyman A, Junttila N, Moazami Goodarzi A, Lehtonen L, Rautava P, Korja R. Associations between executive functions and loneliness in young adolescents born very preterm. Manuscript submitted.

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1 Introduction

“The most disgusting thing ever. Feeling like an outsider and utterly useless in the whole world.” (Junttila, 2015, p. 58)

This is how one adolescent described their experience of loneliness. Loneliness is not only painful but also, when chronic, associated with poor social competence (Junttila & Vauras, 2009; Schinka et al., 2013), poor mental and physical health, low cognitive performance, and even increased mortality (Hawkley & Cacioppo, 2010). Experienced loneliness has been shown to alter brain functioning by increasing hypervigilance to social threats (Cacioppo et al., 2014; Layden et al., 2017). Low trust in one’s social competence and feelings of loneliness may be especially harmful in adolescence, when a need for friends and peer acceptance increases at the same time as sensitivity to social cues (Laursen & Veenstra, 2021; Orben et al., 2020), and the growing demands of one’s social environment (Junge et al., 2020).

Very preterm birth (gestational age <32 weeks and/or birth weight \leq 1500 g) has been considered a chronic condition (Crump, 2020; Raju et al., 2017) that increases the likelihood of social difficulties, internalizing mood and behavioral problems, and attention deficits at the clinical and sub-clinical levels (Cacioppo et al., 2014; Johnson & Marlow, 2011; Johnson & Wolke, 2013). While many problems affecting quality of life in very preterm born populations seem to be resolved by adulthood, social, and mental health-related challenges appear to persist (Baumann et al., 2016; van der Pal et al., 2020).

The rationale for this dissertation stemmed from the observation that loneliness had not been directly studied in very preterm–born populations, although related subjects, such as the number of friends, had been studied. Overall, little was known about how very preterm children perceive their own social functioning in early adolescence. It felt clinically relevant to highlight the experiences of young adolescents born very preterm and to identify potential risk and protective factors for their social functioning in this crucial life stage. Hopefully, in the future, the findings of this dissertation can be utilized to enhance social functioning and quality of life in adolescents born very preterm.

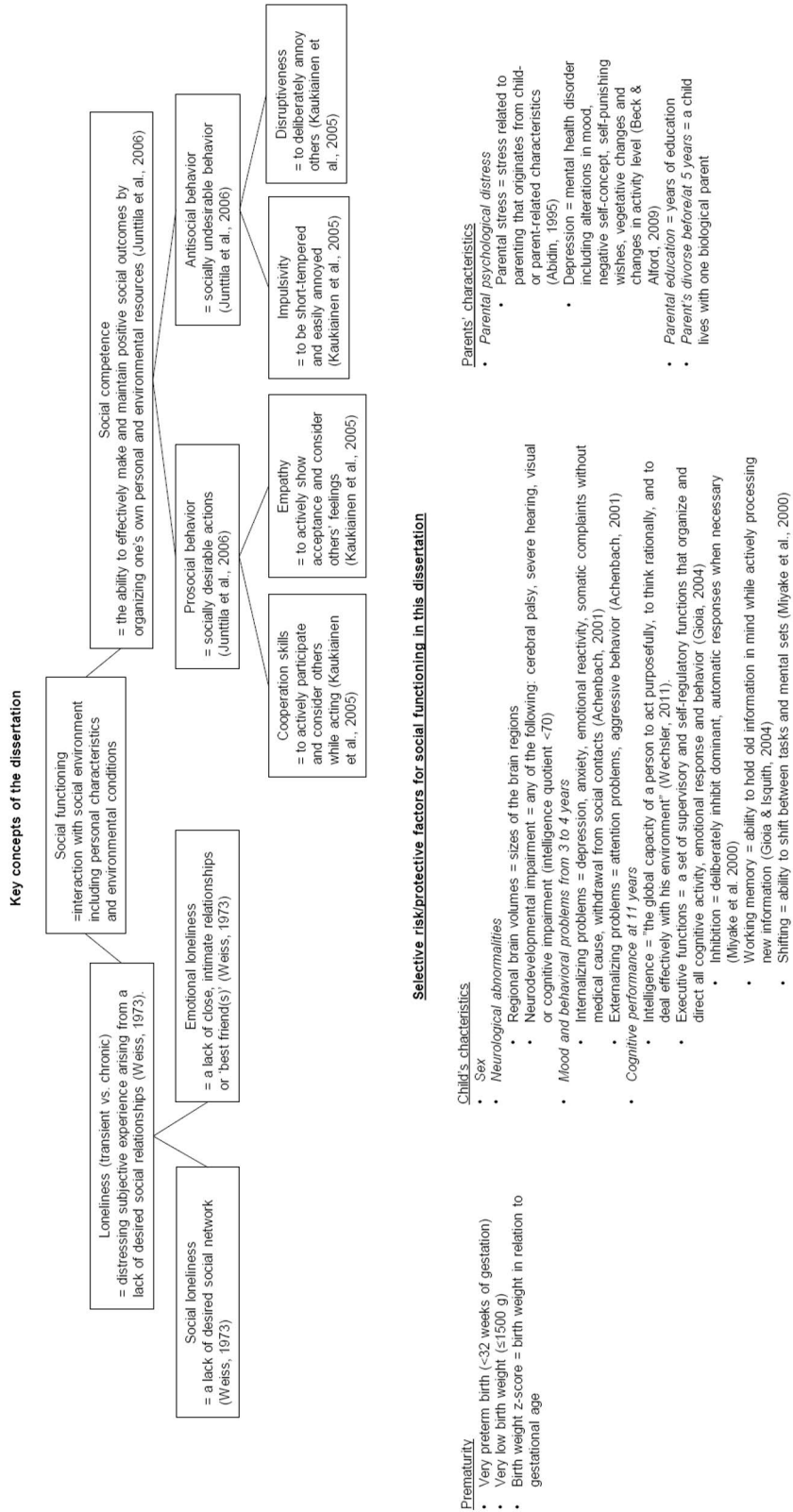


Figure 1. Overview of the key concepts and selected risk/protective factors for social functioning in this dissertation.

2 Literature Review

2.1 Preterm birth

The World Health Organization (WHO, 2024) defines preterm birth as birth before 37 weeks of gestation. Infants born between 32 and 37 weeks of gestation has been defined as moderate to late preterm, between 28 and 32 weeks as very preterm, and before 28 weeks as extremely preterm (WHO, 2024). The other commonly used way to classify preterm born infants is birth weight criterion. Low birth weight has been defined as <2500g, very low birth weight as ≤ 1500 g, and extremely low birth weight as ≤ 1000 g. In the field of preterm literature, both criteria have been used simultaneously, e.g., very preterm/very low birth weight. Globally, nearly 11% of births occur preterm and around 15% of preterm births occur very to extremely preterm (Chawanpaiboon et al., 2019). In Finland, approximately 6% of births occur preterm, and 0-8 – 1.0% of all births occur very to extremely preterm (Heino et al., 2022). It means that around 400 infants are born very (or extremely) preterm and/or very (or extremely) low birth weight each year (Heino et al., 2022).

2.1.1 Preterm birth's longitudinal effects

Preterm birth has been considered a chronic condition that needs to be taken into account in clinical practices from childhood to adulthood (Crump, 2020; Raju et al., 2017). Preterm birth has been associated with increased risk of cardiovascular, endocrine/metabolic, respiratory and renal disorders; cerebral palsy; severe hearing and visual impairment; autism; attention-deficit/hyperactivity disorder; and depression and anxiety (Crump, 2020). Furthermore, individuals born preterm have been shown to have poor cognitive (Nyman et al., 2017; Pascal et al., 2018), executive (van Houdt et al., 2019), motor (Evensen et al. 2020), social (Bilgin et al., 2021; Ritchie et al., 2015), and behavioral functions (Linsell et al., 2016) compared to term-born counterparts.

With improvements in neonatal medical care, the risk of severe impairments, such as cerebral palsy, has decreased over the decades (Pascal et al., 2018; Raju et al., 2017). However, the prevalence of minor social, cognitive and behavioral problems has not decreased (Burnett et al., 2018; Crump, 2020; van Houdt et al.,

2019), and motor impairments such as developmental coordination disorder have even increased over time (Spittle et al., 2021). Despite these problems, adolescents and adults born preterm have not been shown to report lower quality of life compared to those born at term (Bilgin et al., 2021; Crump, 2020; S. van der Pal et al., 2020). Detailed information is needed on the subjective significance of minor deficits in individuals born preterm to focus on factors that enhance well-being in preterm-born populations.

2.1.2 Mechanisms mediating the effects of preterm birth

The mechanisms underlying the disadvantageous outcomes of preterm birth are multifaceted. Very preterm birth is usually caused by maternal health problems during pregnancy or fetal growth restrictions in utero, which harm the fetus's development (Ylijoki et al., 2019). Preterm births interrupt natural intrauterine growth and maturation process exposing preterm born infants to prematurity-related illnesses and environmental stressors, such as medical treatments, altered parenting, and pain (Montagna & Nosarti, 2016; Raju et al., 2017). Preterm birth has been shown to increase the risk of brain injury (Yates et al., 2021), and in milder forms, it alters brain development longitudinally (Kelly et al., 2023; Montagna & Nosarti, 2016; Raju et al., 2017). Abnormalities in the brain have been associated with longitudinal cognitive, socio-emotional and behavioral effects of preterm birth (Kelly et al., 2023; Montagna & Nosarti, 2016; Raju et al., 2017).

For parents, the preterm birth is highly stressful and has longitudinal effect on psychological well-being, especially if the child has medical and developmental problems (Mendelson et al., 2017; Treyvaud, 2014). Parent's readiness to support the infant's development vary, and parent's socioeconomic status and education, and mother's prenatal health and lifestyle have been shown to be associated with preterm birth outcomes (Raju et al., 2017; Ritchie et al., 2015; Ylijoki et al., 2019). The impact of parental psychological distress on child development can be mediated through direct genetic inheritance of characteristics (Goodman & Gotlib, 1999; Lean et al., 2020; Maughan et al., 2007), epigenetic mechanisms related to stress exposure (Provenzi et al., 2018), and altered parenting behaviors (Faure et al., 2017; Goodman & Gotlib, 1999; Neel et al., 2018). To better understand the relevance of multiple prematurity-related and environmental mechanisms on the development of preterm-born children, it is important to include several potential risk factors in the same study and follow their impact longitudinally.

2.2 Social functioning

Social functioning has been defined as a person's active interaction with his/her social environment that can be seen in their interpersonal relationships and their activities in communities and society (Tiikkainen & Pynnönen, 2018). According to the International Classification of Functioning, Disability and Health, social functioning results from an interplay between individual characteristics and environmental possibilities for social activity (WHO, 2001). In this study, social functioning has been defined as social competence reflecting a young adolescent's perceptions of his/her resources to act in peer relations and loneliness reflecting his/her experience of adaptation to a peer group in a Finnish primary school.

2.2.1 Social competence

Social competence is a meta-level concept that broadly describes effectiveness in social interaction. It indicates an individual's regulatory competencies while interacting with other people (Junge et al., 2020; Rose-Krasnor, 1997). Furthermore, it has been defined as "the ability to take another's perspective concerning a situation and to learn from past experiences and apply that learning to the ever-changing social landscape" (Semrud-Clikeman, 2007, p. 1) or "the ability to effectively make and maintain positive social outcomes by organizing one's own personal and environmental resources" (Junttila et al., 2006). Social competence has been seen as a hierarchical structure in which social skills manifested as behavior in social situations form a foundation for social adaptation, such as peer popularity (Cavell, 1990; Junge et al., 2020; Rose-Krasnor, 1997). Prosocial behaviors, such as empathy or active collaboration, promote social relationships, whereas antisocial behaviors, such as impulsivity or disrupting others, inhibit social relationships (Junttila, Voeten, Kaukiainen, & Vauras, 2006). Low social competence has been defined as a disadvantageous combination of prosocial and antisocial behaviors (Junttila et al., 2006). Social competence develops through the interaction between biological (e.g., temperament), psychological (e.g., attachment, regulation skills) and environmental (e.g., parent-child relationships, school contexts, and peer relations) factors, which change as a child grows (see also Junge et al., 2020). Due to the interactive nature of social competence, different raters (e.g., self vs. peer) provide divergent pictures of a person's social competence (Junge et al., 2020, Junttila et al., 2006).

2.2.2 Loneliness

Loneliness (or perceived social isolation) refers to a distressing subjective experience arising from a lack of desired social relationships (Weiss, 1973). Distinct from feelings of aloneness or solitude, which also include positive aspects, loneliness

is a painful and distressing perception that one's social needs are not being met in terms of quantity and/or quality even when among others (Cacioppo & Cacioppo, 2018; Hawkley & Cacioppo, 2010). Loneliness has been shown to be divided into two distinct types, each with its own developmental trajectories: social loneliness and emotional loneliness (Hoza et al., 2000; Junttila & Vauras, 2009; Qualter & Munn, 2002; Salo et al., 2020; Weiss, 1973). Social loneliness refers to feelings that arise from a lack of a desired social network, whereas emotional loneliness refers to a lack of close, intimate relationships or "best friend(s)" (Hoza et al., 2000; Weiss, 1973). Feelings of devaluation, helplessness, powerlessness, shame, and stigma have been associated with social loneliness, whereas feelings of sadness, fear, anxiety, and worry have been associated with emotional loneliness (Mansfield et al., 2021). A third type of loneliness has been proposed: collective loneliness (Cacioppo et al. 2015) or existential loneliness (Mansfield et al., 2021). Collective loneliness refers to feelings that arise from a discrepancy between one's valued social identities and connections with similar others (Cacioppo et al., 2015). Existential loneliness describes the feeling of fundamental separateness from others, and it has been recognized in adults (Mansfield et al., 2021).

Chronic loneliness has been associated with many longitudinal negative health and developmental outcomes (Hawkley & Cacioppo, 2010; Heinrich & Gullone, 2006; Qualter et al., 2013; Qualter et al., 2010; Schinka et al., 2013; Vanhalst et al., 2013). Adolescence has been suggested to be a particularly risky stage of life for longitudinal effects of loneliness, because social isolation has been shown to modulate the development of the social brain, potentially explaining the long-term effects of loneliness on mental health and behavior (Orben et al., 2020).

The prevalence of loneliness has been shown to vary across cultures (Surkalim et al., 2022). Transient loneliness is a common experience. On a population level, a third of all individuals in industrialized countries have been suggested to experience transient loneliness (i.e., sometimes feel lonely) (Cacioppo & Cacioppo, 2018). Chronic loneliness is less common. According to a recent meta-analysis, the prevalence of chronic loneliness ranges from 2.7% and 21.3% among European adults, and it is the most common in Eastern European countries and among elderly people (Surkalim et al., 2022). In adolescents (12–17 years), the prevalence of chronic loneliness has been shown to vary between 9.2%–14.4% worldwide (Surkalim et al., 2022). In Finland, approximately 20% of children eight years of age have been shown to report frequent feelings of loneliness, 5% of children reported that they were always lonely, and 25% of children wished they had more friends (Lempinen et al., 2018). Loneliness has been shown to be a characteristic that is relatively stable across the lifespan, but has the potential to change as a result of life experiences (Mund et al., 2020) and interventions (Eccles & Qualter, 2021; Osborn et al., 2021).

2.3 Impaired social functioning as a risk for development in early adolescence

Adolescence is a period of rapid physical, emotional, and social changes between puberty and adult independence (Blakemore, 2019) that occurs between the ages of 10 and 19 (WHO, 2021). In early adolescence, the need for peer relations increases, and the sensitivity to social cues and the need to conform to the peer group is at its peak (Dawes, 2017; Laursen & Veenstra, 2021; Orben et al., 2020). Expectations for friendships change, with intimate, reciprocal, and romantic relationships beginning to be valued (Junge et al., 2020; Semrud-Clikeman, 2007). In addition, a high status in the hierarchy of the peer group is desired (Dawes, 2017). More sophisticated social skills, such as perspective taking and self-regulation, are needed to navigate more complex social environments, and they are developed further (Junge et al., 2020; Semrud-Clikeman, 2007). Many mental illnesses first manifest in adolescence and continue into adulthood (Blakemore, 2019). It has been estimated that 13% of adolescents worldwide have mental disorders, most likely anxiety, depression, or behavioral problems (WHO, 2021). Better self-regulation skills and a supportive social environment have been suggested to promote mental health in adolescence (WHO, 2021).

Social functioning in childhood and early adolescence has been shown to predict well-being and performance in adolescence. Low social competence in childhood has been found to predict higher levels of behavioral problems (Bornstein et al. 2010), higher levels of loneliness (Qualter et al., 2013; Schinka et al., 2013,) and lower school grades (Rabiner et al., 2016) in adolescence. Perceived low social competence in early adolescence has been determined to predict high levels of loneliness and social anxiety in adolescence (Junttila et al., 2012). High levels of loneliness during childhood and adolescence have also been shown to predict high levels of social anxiety, and vice versa (Maes et al., 2017). In addition, loneliness in early adolescence has been associated with a lower number of friends and lower experienced quality of friendships (Lodder et al., 2017), while stable, high, and increasing trajectories of loneliness from childhood to adolescence have been associated with increased depression, aggression, suicidal ideation, perceived social deficits, perceived health problems, and alcohol use (Qualter et al., 2013; Schinka et al., 2013).

2.4 Effect of biological sex on social functioning in early adolescence

Girls in early adolescence have been shown to exhibit more prosocial behavior, while boys have been shown to exhibit more antisocial behavior (Junttila et al., 2006). However, boys' social competence tends to increase during adolescence, whereas

girls experience a drop in social competence in middle adolescence (Semrud-Clikeman, 2007). Boys experience slightly more loneliness than girls from middle childhood to early adulthood but not in later adulthood (Maes et al., 2019). Girls' friendships in early adolescence have been found to be based on feelings of intimacy (Semrud-Clikeman, 2007), and they report a higher quality of friendships than boys (Hoza et al., 2000). Boys' friendships are typically based on shared interests and activities (Semrud-Clikeman, 2007), and boys tend to report more emotional loneliness than girls (Hoza et al., 2000; Junttila & Vauras, 2009).

2.5 Social functioning in preterm-born populations

The combination of social problems, internalizing behavioral problems, and attention deficits at clinical and sub-clinical levels compared to term-born peers is referred to as the preterm behavioral phenotype (Johnson & Marlow, 2011; Johnson & Wolke, 2013; Taylor, 2020) (see **Figure 2**). In infancy and childhood, individuals born preterm tend to be more passive in social interaction (Jones et al., 2013; Taylor, 2020). They have been reported to experience greater difficulties in regulating social interaction, emotions, behavior, and social cognition compared to term-born peers (Arpi & Ferrari, 2013; Jones et al., 2013; Taylor, 2020). The prevalence of attention-deficit hyperactivity disorder (ADHD), autism spectrum disorder (ASD), and anxiety disorder in childhood is higher in preterm-born children than in term-born children (Mathewson et al., 2017; Morris et al., 2021; Taylor, 2020). In adolescence, internalizing behavioral symptoms, such as social withdrawal and depressed/anxious behaviors, are emphasized (Jansen et al., 2022; Mathewson et al., 2017; Ritchie et al., 2018; Twilhaar et al., 2019). In adulthood, peer problems persist and extend to challenges in forming romantic relationships and making sexual contact (Taylor, 2020; van der Pal-de Bruin et al., 2015). Relationships with peers are viewed as difficult, although relationships with partners and family members are understood to be satisfactory (Ni et al., 2021). Adults born preterm have a lower level of risk-taking and antisocial behavior but a higher level of internalizing and social problems compared to term-born peers (Mathewson et al., 2017; Pyhälä et al., 2017; van der Pal-de Bruin et al., 2015; van der Pal et al., 2019).

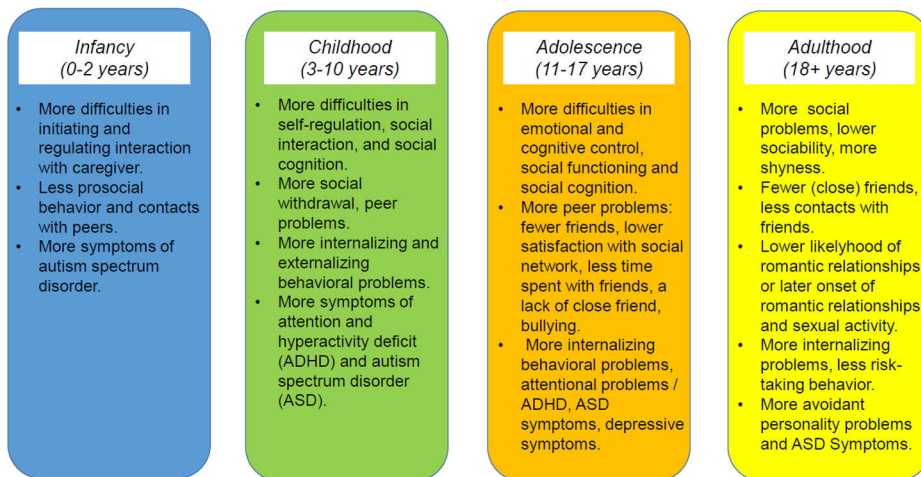


Figure 2. Overview of characteristics of socioemotional development in preterm born populations compared to full-term populations. (references in text)

2.6 Social functioning in young adolescents born very preterm

Parents and teachers have been shown to report more social problems in young adolescents born very and extremely preterm than in young adolescents born at term (Farooqi et al., 2007; Ritchie et al., 2018; Taylor, 2020; Twilhaar et al., 2019; van der Pal-de Bruin et al., 2015). Parents of preterm adolescents also report more behavioral problems related to social functioning, including withdrawal, anxiety, depressed behavior, and attention deficits (Farooqi et al., 2007; van der Pal-de Bruin et al., 2015). There is some evidence that parents tend to report concerns about young adolescents' emotional development, whereas teachers are more concerned about their interpersonal difficulties and social skills (Jansen et al., 2022). Parents reported more behavioral problems among boys, while teachers reported that girls had more behavior problems (van der Pal-de Bruin et al., 2015). Although young adolescents born very preterm face an increased risk of social and behavioral problems compared to term-born peers, it is noteworthy that the majority of them have only minor issues (van Houdt et al., 2020). However, for those with such problems, these issues manifest across various domains of behavior and functioning (van Houdt et al., 2020).

Despite the consistent views of parents and teachers, young adolescents born very preterm do not always report social problems (Twilhaar et al., 2019). Other studies have suggested that young adolescents born very preterm are dissatisfied with

their social relationships even when they are satisfied with other areas of life (Bilgin et al., 2021; Ritchie et al., 2018). Those born extremely preterm are typically more susceptible to social problems (Ritchie et al., 2018). They report having fewer friends (often having no friends at all), dissatisfaction with the number of friends, spending less time with friends, and experiencing bullying more frequently than young adolescents born very preterm and at term (Ritchie et al., 2018). However, they perceived the quality of their relationship with their best friends to be as good as those born very preterm and term. The duration of friendships was similar in all groups (Ritchie et al., 2018).

2.7 Potential predictors of social functioning in preterm born populations

While social functioning has been found to develop as a result of the bidirectional effects between a child's characteristics and his/her social environment (Ding et al., 2020), the mechanisms underlying impaired social functioning are complex and varied (Linsell et al., 2017). In very preterm-born populations, problems in social functioning have been shown to be more prominent in those born at earlier gestational weeks, with neurodevelopmental and health-related complications, and less advantageous family circumstances, including low socio-economic status and parental mental health (Jones et al., 2013; Ritchie et al., 2015; Taylor, 2020). Overall, the accumulation of risk factors appears to be the best indicator of low social functioning. In this chapter, the selected risk factors and potential protective factors for this study will be examined.

2.7.1 Gestational weeks, birth weight, and growth restriction

There is strong evidence that earlier gestational weeks and lower birth weight are associated with poorer longitudinal outcomes in preterm born populations (Crump, 2020; Hosozawa et al., 2021; Leppänen et al., 2023; Pascal et al., 2018; Raju et al., 2017; Ritchie et al., 2015). Social functioning is usually more impaired for those born in earlier gestational weeks (Hosozawa et al., 2021; Jones et al., 2013; Ritchie et al., 2015; Taylor, 2020). However, there are mixed findings on the degree of prematurity associated with impaired social functioning in early adolescence, probably reflecting the heterogeneity of preterm populations (Linsell et al., 2017). In one study involving young adolescents born extremely preterm, very preterm, and full term, peer problems were limited only to those born extremely preterm (Ritchie et al., 2018). In another study comparing social competence in children and adolescents born very preterm, moderate to late preterm, early term, and full term, those born very preterm had more pronounced problems across all ages. Those born

moderate to late preterm had difficulties in early childhood, but they caught up with their term-born peers during middle childhood and early adolescence (Hosozawa et al., 2021).

Restricted antenatal growth manifests in small birth weight in relation to gestational weeks (SGA and low birth weight z score) and has been associated with poor longitudinal outcomes in very preterm-born populations, including lower cognitive performance (Nyman et al., 2017), poorer executive function (Taylor & Clark, 2016), attention problems (Hall et al., 2012), greater risk of contracting illnesses in adulthood (van der Pal-de Bruin et al., 2015), and low social competence in infancy (Spittle et al., 2009). Good postnatal growth has been associated with better longitudinal neurocognitive outcomes (Leppänen et al., 2014; Ong et al., 2015). Although growth restriction has not been widely associated with social functioning, it has been linked to poorer cognitive and regulatory competencies that have been connected to lower social functioning (Bilgin et al., 2021; Heuser et al., 2018; van Houdt et al., 2020).

Gestational weeks, birth weight, and antenatal growth restriction are not uniformly associated with poorer social and behavioral functioning in children, young adolescents, and adults born very preterm (van der Pal et al., 2019; van Houdt et al., 2020); however, those born extremely preterm have been shown to be likelier to have persistent problems in social functioning affecting daily life in adulthood (Linsell et al., 2019; Mathewson et al., 2017).

2.7.2 Biological sex

In normal populations, the biological sex of young adolescents is associated with their social functioning (Hoza et al., 2000; Junttila & Vauras, 2009; Junttila et al., 2006; Maes et al., 2019; Semrud-Clikeman, 2007). Several studies have indicated that girls' socio-emotional development might be more sensitive to parental psychological distress than boys' (Junttila & Vauras, 2009; Nolvi et al., 2019), and socio-emotional development might be more sensitive to same-sex parent's psychological well-being in early adolescence (Salo et al., 2020). In preterm-born populations, male sex has been associated with poorer longitudinal health and neurological, cognitive, and social outcomes. These differences have been small in some cases, and the findings have not been consistent (Jones et al., 2013; O'Driscoll et al., 2018; Raju et al., 2017; Taylor, 2020). In the cohort of the present study, male sex has also been associated with lower working memory and processing speed in young adolescents born very preterm (Nyman et al., 2017), which might lead to difficulties for boys navigating complex social environments. Biological sex has not been found to be systematically associated with internalizing and externalizing behavioral problems in very preterm-born populations (Pyhälä et al., 2017; Spittle

et al., 2009). Brain abnormalities associated with social functioning in early childhood have been shown to differ for between boys and girls born very preterm (Rogers et al., 2012).

2.7.3 Neurological abnormalities

Moderate to severe white matter abnormalities (Jones et al., 2013; Taylor, 2020; Spittle et al., 2009) and regional alterations in brain development (Rogers et al., 2012) at term equivalent ages have been associated with social problems later in life in preterm-born populations. Further, amygdala functional connectivity at term equivalent age (Rogers et al., 2017) and in early adulthood (Johns et al., 2019) have been linked to socioemotional functioning in preterm born individuals. Altered gray and white matter volumes, especially in the emotion-processing brain areas, have been associated with social difficulties in adolescence and early adulthood (Botellero et al., 2016; Healy et al., 2013). In this study cohort, major brain pathology at term age has been shown to be associated with poor general cognition at 11 years of age (Nyman et al., 2017).

2.7.4 Mood and behavioral problems

A combination of internalizing behavior, anxiety, depression, emotional problems, and attention deficits have been shown to accompany impaired social functioning in very preterm and extremely preterm born cohorts (Taylor, 2020). In young adolescents born extremely preterm, higher levels of peer problems are associated with higher levels of emotional, attentional, and motor problems (Ritchie et al., 2018), parent- and teacher-rated internalizing behaviors, internalizing mood problems, thought problems, and self-reported depression symptoms (Farooqi et al., 2007). Furthermore, lower levels of behavioral problems have been shown to predict more friends in children born very preterm (Heuser et al., 2018). In normal populations, lower social competence has been associated with higher levels of internalizing and externalizing behavioral problems (Bornstein et al., 2010). Higher levels of loneliness have been consistently shown to accompany increased social anxiety (Danneel et al., 2020; Maes et al., 2019).

2.7.5 Cognitive performance and executive function

Generally, impaired cognitive performance and specific deficits in cognitive functioning have been shown to indicate a higher risk for impaired social functioning in preterm-born populations (Taylor, 2020). Very preterm-born children and young adolescents experiencing high levels of difficulty in socioemotional and behavioral

functioning have been shown to have lower IQ, poorer working memory, and poorer inhibition compared to very-preterm born peers experiencing low levels of difficulty in socioemotional and behavioral functioning (van Houdt et al., 2020). Cognitive impairment and behavioral problems in infancy have been shown to predict adult social, emotional, and attentional problems in individuals born extremely preterm (Linsell et al., 2019). Furthermore, higher cognitive performance, among other protective factors, has been determined to predict better social outcomes in children born very preterm (Heuser et al., 2018). However, some evidence has suggested that social functioning problems in very preterm-born populations persist even when intelligence is controlled for (Taylor, 2020).

Poorer social and behavioral functioning has also been associated with poorer executive function (Alduncin et al., 2014; Bilgin et al., 2022; Schnider et al., 2020), and difficulties in emotion recognition (Della Longa et al., 2022) in children born very preterm. However, there is some evidence that executive function skills may play a more central role in the social functioning of very preterm-born children than emotion recognition skills (Twilhaar et al., 2019).

2.7.6 Parental psychological distress

Parental psychological distress exhibits a strong and longitudinal effect on a child's social functioning in very preterm-born populations (Heuser et al., 2018; Hosozawa et al., 2021; Huhtala et al., 2014; Jones et al., 2013; Montagna & Nosarti, 2016), even after controlling for other social risks and children's developmental difficulties (Taylor, 2020). Parents of very preterm-born infants have been shown to report an elevated amount of psychological distress, including stress, anxiety, and depression symptoms, especially during infancy (Mendelson et al., 2017; Treyvaud, 2014). Maternal stress has been shown to decrease sensitivity to infants' needs (Neri et al., 2015), and depression has been shown to increase emotional remoteness from the infant (Korja et al., 2008; Neri et al., 2015), affecting children's socioemotional development through altered parenting behavior. The effects of parental psychological distress might also be transmitted to a child's social functioning through genetic inheritance (Lean et al., 2020; Maughan et al., 2007). Although most studies have focused on the effects of maternal psychological distress, paternal psychological distress has also been proven to be influential in child's development (Martin et al., 2010; van Eldik et al., 2019). Evidence from term-born children suggests that girls might be more sensitive to parental psychological distress than boys (Junttila & Vauras, 2009; Nolvi et al., 2019) and that boys might be more sensitive to paternal psychological distress rather than maternal psychological distress (Salo et al., 2020).

2.7.7 Parental education

Low socioeconomic status in general (Jones et al., 2013; Ritchie et al., 2015; Taylor, 2020) and low parental education level, in particular (van Houdt et al., 2020) are associated with low socioemotional functioning in children and adolescents born very preterm. Children of two parents with low levels of education have been shown to be in the most disadvantaged position, and children with only one highly educated parent are in a worse position than children with two highly educated parents (van Houdt et al., 2019). In this study cohort, low paternal education is associated with poorer cognitive functioning at 11 years of age (Nyman et al., 2017).

3 Aims of the Study

This study aimed to profile experienced social functioning (loneliness and social competence) and both long-term and current risk and protective factors for social functioning in young adolescents born very preterm and/or very low birth weight.

3.1 Social functioning and background factors

The experienced social functioning of boys and girls born very preterm was compared to their same-sex peers born at term at 11 years. Social functioning was defined as social and emotional loneliness, and social competence (co-operating skills, empathy, impulsivity, and disruptiveness). We also studied whether earlier gestational weeks, lower cognitive performance (full-scale intelligence quotient, FSIQ; verbal reasoning, VCI; perceptual reasoning, PRI; working memory, WMI; processing speed, PSI) at 11 years of age, and lower parental education associated with lower social functioning in young adolescents born very preterm. It was hypothesized that boys and girls born very preterm report lower social functioning compared to their full-term controls. Earlier gestational weeks, lower cognitive performance and lower parental education were hypothesized to associate with lower social functioning in young adolescents born very preterm. (Study I)

3.2 Social functioning and brain volumes

This part of the study aimed to assess how the experienced social and emotional loneliness and social competence (co-operating skills, empathy, impulsivity, and disruptiveness) at 11 years associated with regional brain volume at 12 years in very preterm and term-born young adolescents. The focus was on differences between the groups. It was hypothesized that loneliness and social competence are more closely related to brain volumes in young adolescents born very preterm than in those born full-term. (Study II)

3.3 Social functioning, parental psychological distress, and children's mood and behavioral problems

It was aimed to evaluate how parental psychological distress (stress and depression) when the child was 2 and 4 years old, as well as the child's mood and behavioral symptoms (internalizing and externalizing) at ages 3 to 4, were associated with experienced social functioning (social and emotional loneliness, co-operating skills, empathy, impulsivity, disruptiveness) in 11-year-old children born very preterm. We were interested in the sex-specific trajectories of social functioning, and the role of background characteristics (gestational age, weeks; birth weight in relation to gestational weeks, birth weight z score; neurodevelopmental impairment at 11 years, NDI; maternal education, paternal education, and parents' divorce at or before the child was five years old) as risk factors for poorer social functioning in young adolescents born very preterm. It was hypothesized that a higher level of parental psychological distress and a child's mood and behavioral symptoms during early childhood are associated with a lower level of experienced social functioning in young adolescents born very preterm, especially in girls. (Study III)

3.4 Loneliness and core executive functions at school

The last part of the study aimed to assess how experienced social and emotional loneliness is associated with the core executive functions (inhibition, shifting, working memory) at school in 11-year-old children born very preterm and at term. The focus was on the differences between the young adolescents born very preterm and at term. We examined whether sex of the child moderated associations between the core executive functions and loneliness. Furthermore, we studied whether general cognitive performance, defined as full-scale intelligence quotient, moderated associations in young adolescents born very preterm. It was hypothesized that the core executive functions are more related to loneliness in young adolescents born very preterm than those born at term. (Study IV)

4 Methods

4.1 Participants

4.1.1 Children born very preterm

This study is part of a longitudinal cohort study titled “Development and Functioning of Very Low Birth Weight Infants from Infancy to School Age” (PIPARI). The PIPARI study included all ($n = 289$) very low birth weight (≤ 1500 g) infants born from 2001 to 2006 at Turku University Hospital, Finland. In addition, all infants born < 32 weeks of gestation were included for data from 2004 to 2006. The exclusion criteria were as follows: 1) major congenital anomalies or syndromes or chromosomal anomalies ($n = 12$), 2) a family residing outside the hospital’s catchment area ($n = 7$), and 3) parents who did not speak or understand Finnish or Swedish ($n = 6$). Nine families declined participation. Thirty-four infants died during the neonatal period. Two participants died, and 47 dropped out during the follow-up. Studies I, III, and IV included all the participants who had completed the questionnaires assessing social functioning at the age of 11 years ($n = 172$). Study II included participants born from May 2004 to December 2006 ($n = 91$). A total of 45 declined to participate in magnetic resonance imaging at the age of 12 years, one could not be reached, seven were excluded due to neurodevelopmental impairment at 11 years of age, and four had missing data. The final number of very preterm-born participants in Study II was 34.

4.1.2 Term-born controls

The control group included healthy infants born in Turku University Hospital after ≥ 37 weeks of gestation ($n = 200$). Every Monday, the first boy and girl born at term were recruited at the maternity ward. If their parents refused, the next boy/girl was recruited. The inclusion criteria were as follows: 1) birth weight $\leq -2SD$ according to the age and sex-specific Finnish growth charts, 2) no admission to neonatal care during the first week of life, 3) Finnish or Swedish as native language of at least one of the parents, and 4) a family residing inside the hospital’s catchment area. The exclusion criteria were as follows: 1) congenital anomalies or syndromes or

chromosomal anomalies, and 2) the mother's self-reported use of illicit drugs or alcohol during the pregnancy. From the original total of 200 children, 66 dropped out or did not return the assessments of social functioning at 11 years of age. The final number of term-born controls was $n = 134$ in Studies I and IV. Study II included participants born in 2003 and 2004 ($n = 96$). Fifty-seven declined to participate at the age of 12 years, and eight had missing data. The final number of term-born controls in Study II was 31.

4.2 Procedure

Data were collected at various time points, as illustrated in **Figure 3**. Questionnaires assessing parental psychological distress were sent out four weeks before the child reached the age of two years (corrected age) and four years. A questionnaire assessing the child's mood and behavioral symptoms was sent out four weeks before the child turned three and four years old. Parents completed a questionnaire assessing additional family information at the follow-up visit when the child was five years old. Young adolescents born very preterm independently completed the questionnaires assessing social functioning at the follow-up visit at 11 years. They were offered assistance if required, and their cognitive performance was assessed during the same visit. Term-born controls received the same questionnaires of social functioning via mail at the same age, and they completed the questionnaires at home. There were two reminders: the questionnaires were resent once after three months, and if no response was received, the parents were contacted by telephone after one to three more months to remind their children to complete the questionnaires. Teachers of young adolescents born very preterm received the questionnaires assessing executive function from the parents during the first semester of the school year when the children turned 11 years old. The parents of term-born children received this questionnaire via mail if they had agreed to participate. The teachers were requested to return the questionnaire by mail within 2 weeks. However, if the child was new to the teacher, the teacher was encouraged to become acquainted with the child for 2 months, and to complete the questionnaire after that.

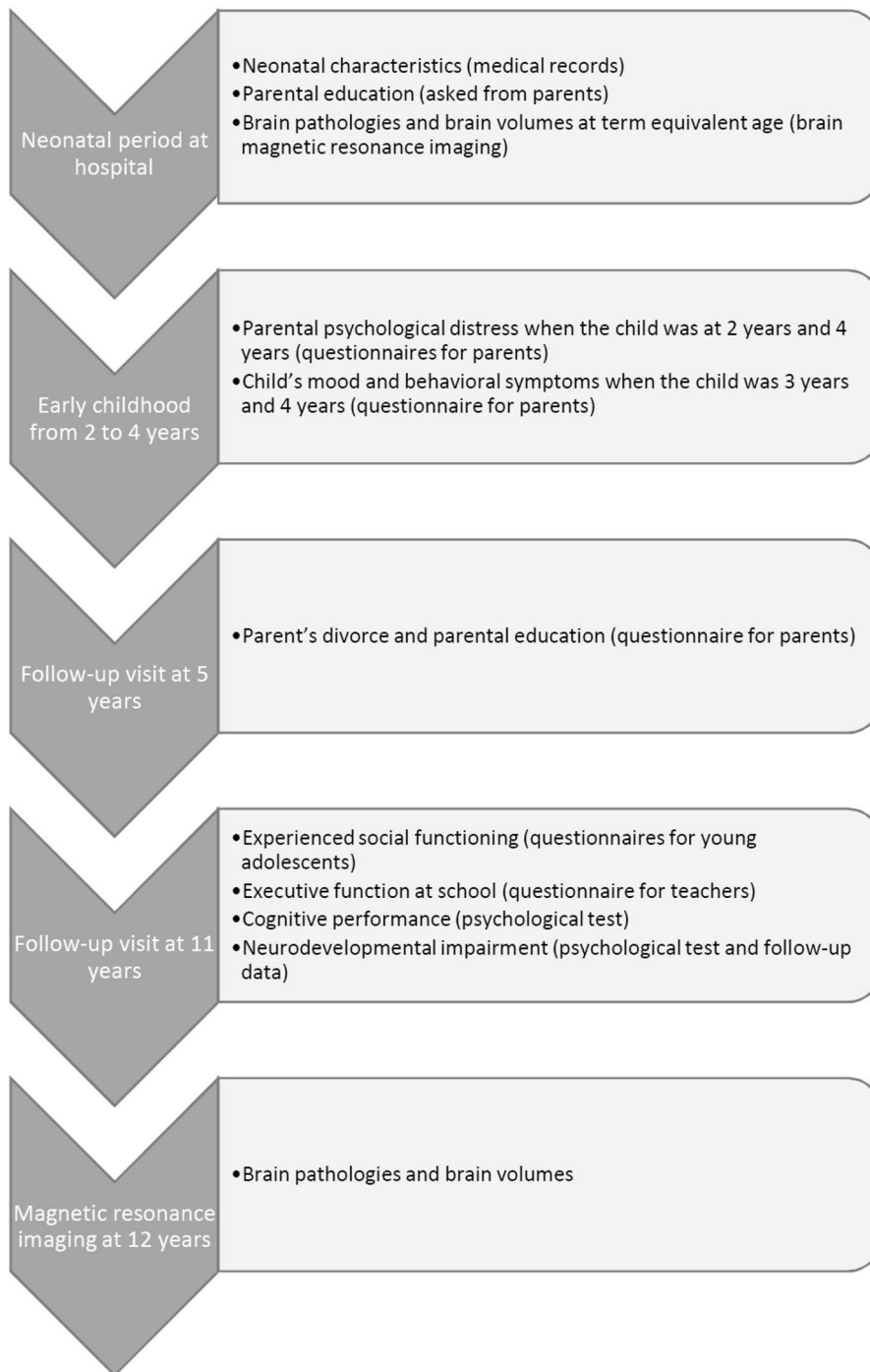


Figure 3. Timeline of data collection.

4.3 Measures

4.3.1 Background characteristics

Neonatal characteristics were obtained from medical records as part of the PIPARI study protocol. Data on maternal and paternal education was requested from the parents before the children were discharged home from the hospital. Parents were asked if they were divorced, and parental education levels were determined with a questionnaire at the follow-up visit.

The cognitive performance of very preterm-born children was evaluated with a standardized psychological test: the Wechsler Intelligence Scale for Children, Fourth Edition (Wechsler, 2011), which comprises FSIQ, VCI, PRI, WMI, and PSI.

Neurodevelopmental impairment (NDI) was defined as having any of the following at 11 years: cerebral palsy, severe hearing impairment or severe visual impairment at two years, or severe cognitive impairment at 11 years. Cerebral palsy was diagnosed at the corrected age of two years after clinical follow-up. Severe hearing impairment was defined as having a need for amplification in one or both ears. Severe visual impairment was defined as a visual acuity < 0.3 or blindness. Severe cognitive impairment was defined as FSIQ < 70 at 11 years.

4.3.2 Neurological abnormalities

Brain magnetic resonance imaging (MRI) scans were performed on very preterm born infants with a 1.5 T Philips Intera scanner (Philips Medical Systems) at term equivalent age. At 12 years of age, a brain MRI was performed on very preterm- and term-born children with 3 T Philips Ingenuity TF PET/MR (Philips Medical Systems). The MRI protocol at 12 years involved a T2-weighted set of axial slices with a 4.82-s repetition time (TR) and an 80-ms echo time (TE) and 3 mm slice thickness; a coronal fluid attenuation inversion recovery sagittal images with a 10-s TR, a 2.8-s inversion time, a TE of 125 ms, a slice thickness of 4 mm; and a 3D T1 set of sagittal slices with a 8.1-ms TR, a 3.7-ms TE, and isotropic 1 mm voxel. The volumes of the brain structures were measured from T1 images using an automated image quantification tool (Combinostics Ltd.), which divides the brain into 133 regions using a multi-atlas method. The 28 best-matching atlases were selected, and nonrigidly registered with the T1 image to generate the brain segmentation using the expectation-maximization algorithm.

At term equivalent age, the brain MRI findings were categorized into three groups: a) normal findings marked by normal brain signal intensity and anatomy (cortex, basal ganglia, thalami, posterior limb of internal capsule, white matter, germinal matrix, corpus callosum, cerebellum, pons, and medulla oblongata), a

width of extracerebral space of < 5 mm, and a ventricular/brain ratio of < 0.35 ; b) minor pathologies consisting of the consequences of intraventricular hemorrhages (grades I and II), caudothalamic cysts < 3 mm, a width of the extracerebral space of 5 mm, and a ventricular/brain ratio of 0.35; and c) major pathologies consisting of the consequences of intraventricular hemorrhages (grades III and IV), an injury in cortex, basal ganglia, thalamus, internal capsule, corpus callosum, cerebellum, or white matter, a width of the extracerebral space by >5 mm, a ventricular/ brain ratio of >0.35 , ventriculitis, or focal infarctions.

Brain MRI findings at 12 years of age were categorized as a) normal consisting of normal brain signal intensity; normal anatomy of the cortex, basal ganglia, thalami, internal and external capsule, white matter, corpus callosum, cerebellum, pons and medulla oblongata; and normal cerebrospinal fluid spaces; b) minor pathologies including, for example, minor punctuate cerebral white matter T1 hyperintensity; and c) major pathologies consisting of T2 hyperintensity in the cerebral or cerebellar parenchyma corresponding to focal hemosiderin collection, white matter damage corresponding to white matter gliosis, marked dilatation of the ventricles or marked dilatation of the cortical cerebrospinal fluid spaces or signs of infarcts or cystic and/or hemorrhagic white or gray matter damage.

The following regional brain volumes relevant to socioemotional functioning were analyzed: amygdala (right and left), caudate (right and left), cerebellum exterior (right and left), cerebellum white matter (right and left), cerebellar vermal lobules I–V, cerebellar vermal lobules VI–VII, cerebellar vermal lobules VIII–X, hippocampus (right and left), pallidum (right and left), putamen (right and left), thalamus proper (right and left), fusiform gyrus (right and left), total cerebral white matter, frontal lobe (right and left), temporal lobe (right and left), parietal lobe (right and left), and occipital lobe (right and left).

4.3.3 Parental psychological distress

The Parenting Stress Index (PSI; Abidin, 1995) was used to evaluate mothers' and fathers' perceptions of their parenting stress. The first 101 items assess stress originating from child and parent characteristics and form the parenting stress total score used in this study. The items were rated on a 5-point Likert scale (1 = "strongly agree" and 5 = "strongly disagree") and scored according to the PSI manual. Higher scores indicated a higher level of parenting stress.

The Beck Depression Inventory (BDI-13; Salmela-Aro et al., 2001) was used to evaluate the depression symptoms of mothers and fathers. The BDI-13 is a modified 13-item Finnish translation (Salmela-Aro et al., 2001) of the original BDI-21 (Beck et al., 1961). The items were rated on a 5-point Likert scale (1 = "not at all true of me" to 5 = "very true of me") and summed. The scores varied between 0 and 39.

Higher scores indicated higher levels of depression. A more detailed description of the PSI and the BDI-13 is presented in **Table 1**.

4.3.4 Children's mood and behavioral symptoms

The Child Behaviour Checklist (CBCL; Achenbach, 2001) was used to evaluate parents' perception of their child's mood and behavioral symptoms in early childhood. The CBCL for ages 1½ to 5 years (Achenbach, 2001) comprises the internalizing and externalizing symptoms subscales were used in this study. Internalizing and externalizing symptoms were rated on a 3-point Likert scale (0 = "not true" to 2 = "very true or often true"). The scores varied between 0 and 72 for internalizing symptoms and between 0 and 48 for externalizing symptoms. Higher scores indicated a higher level of mood and behavioral problems. A more detailed description of the CBCL is presented in **Table 1**.

4.3.5 Executive function

The Behavior Rating Inventory of Executive Function teacher form (BRIEF; Gioia et al., 2000) was used to evaluate executive function of young adolescents at school. The BRIEF teacher form consists of 86 items on executive function and includes items on three subscales assessing behavioral regulation alongside items on five subscales assessing metacognition. In this study, three subscales (Inhibit, Shift, and Working Memory) assessing the key components of executive function were used. The BRIEF was rated on a 3-point Likert scale (1 = "no" to 3 = "often"), and raw scores were converted into age- and sex-specific standardized T-scores. Higher scores indicated a lower level of executive function. A more detailed description of the BRIEF is presented in **Table 1**.

4.3.6 Social functioning

The Finnish version of the Peer Network and Dyadic Loneliness Scale (PNDLS; Junttila & Vauras, 2009) was used to assess young adolescents' perceptions of their social and emotional loneliness. The original version of the PNDLS was developed by Hoza et al. in 2000. The PNDLS consist of five paired statements concerning social loneliness and five paired statements concerning emotional loneliness. First, respondents selected a paired statement; then, they evaluated whether the statement described them "quite well" or "very well." The scores for social and emotional loneliness varied between 5 and 20. Higher scores indicated higher levels of loneliness.

The Multisource Assessment of Children’s Social Competence Scale self-rating form (MASCS; Junttila et al., 2006) was used to assess young adolescents’ perceptions of their social competence (Junttila et al., 2006). The MASCS consists of 15 items that form two subscales measuring prosocial behavior—co-operating skills and empathy—and two subscales measuring antisocial behavior: impulsivity and disruptiveness. The items were rated on a 4-point Likert scale (1 = “never” to 4 = “very often”). Weighted sum scores were calculated for each subscale according to the Finnish manual of the MASCS (Kaukiainen et al., 2005). Higher scores indicated higher attribute levels. A more detailed description of the PNDLS and the MASCS is presented in **Table 1**.

Table 1. Summary of the questionnaires used in this dissertation.

Measure name	Description of measure	Scale and scoring	Subscales and items	Informant(s)
<p>The Peer Network and Dyadic Loneliness Scale (PNDL)</p>	<p>A self-rating questionnaire for school-aged children containing five paired statements concerning social loneliness, and five paired statements concerning emotional loneliness.</p>	<ul style="list-style-type: none"> - The scale ranges from 1 to 4 (1 = "very low loneliness" and 4 = "very high loneliness"). - The sum of the scores for social and emotional loneliness ranges from 5 to 20. - Higher scores indicate higher levels of loneliness. 	<ul style="list-style-type: none"> - Items 1–5 assess social loneliness (i.e., a child's perception of his/her social network), for example: "Some kids feel like they really fit in with other kids, but other kids don't feel like they fit in very well with other kids." - Items 6–10 assess emotional loneliness (i.e., a child's perception of close relationships), for example: "Some kids have someone their age who is a really close friend. Other kids don't have anybody their age who is a really close friend." 	<ul style="list-style-type: none"> - Very preterm-born children at 11 years. - Term-born children at 11 years.
<p>The Multisource Assessment of Children's Social Competence Scale (MASCS)</p>	<p>A questionnaire containing 15 items assessing four dimensions of social competence in school-aged children: cooperating skills, empathy, impulsivity, and disruptiveness. Separate forms are provided for parents, teachers, and self-ratings.</p>	<ul style="list-style-type: none"> - The scale ranges from 1 to 4 (1 = "never" and 4 = "very often"). - The scores are summed for each subscale, and weighted sum scores are calculated according to the Finnish manual of the MASCS. - The range of weighted sum scores for cooperating skills is 3.22–12.88, 1.76–7.04 for empathy, 2.23–8.92 for impulsivity, and 2.63–10.52 for disruptiveness. - Higher scores indicate a higher level of the assessed trait. 	<ul style="list-style-type: none"> - Items 1–5 assess cooperating skills, for example: "Offers help to other students." - Items 6–8 assess empathy towards others, for example: "Is sensitive to the feelings of others." - Items 9–11 assess impulsivity, for example: "Has temper outbursts of tantrums." - Items 12–15 assess disruptiveness, for example "Teases and makes fun of other students." 	<ul style="list-style-type: none"> - Very preterm-born children at 11 years. - Term-born children at 11 years.

Measure name	Description of measure	Scale and scoring	Subscales and items	Informant(s)
the Parenting Stress Index (PSI)	A self-rating scale with 120 items concerning parenting stress originating from the child's characteristics, the parents' own vulnerabilities, and stressful life situations	<ul style="list-style-type: none"> The scale ranges from 1 to 5 (1 = "strongly agree" and 5 = "strongly disagree"). The total score for items 1–101 is determined according to the PSI manual. The other 19 questions are categorized as yes-or-no questions. Higher scores indicate higher levels of parenting stress. 	<ul style="list-style-type: none"> Items 1–101 make up the parenting stress total score, including the child domain and the parent domain. The child domain consists the subscales of distractibility/ hyperactivity, adaptability, reinforces parent, demandingness, mood, and acceptability. The parent domain contains the following dimensions: competence, isolation, attachment, health, role restriction, depression, and spouse. Items 102–120 assess stressful life situations. 	<ul style="list-style-type: none"> Parents of children born very preterm as their children are aged two and four years.
the Beck Depression Inventory (BDI-13)	A modified 13-item self-rating concerning the symptoms of depression.	<ul style="list-style-type: none"> The scale ranges from 1 to 5 (1 = "not at all true of me" and 5 = "very true of me"). The scores vary between 0 and 39. Higher scores indicate higher levels of depression. 	<ul style="list-style-type: none"> The items comprise symptoms of depression including depressed mood, diminished interest and pleasure, feelings of worthlessness and guilt, loss of energy, poor appetite, suicidal ideation. 	<ul style="list-style-type: none"> Parents of children born very preterm as their children are aged two and four years.
the Child Behavior Checklist (CBCL)	A questionnaire with 99 closed and 1 open-ended items assessing parent's perception of their child's internalizing and externalizing symptoms at ages 1.5–5 years.	<ul style="list-style-type: none"> The scale ranges from 0 to 2 (0 = "not true", 1 = "somewhat or sometimes true", and 2 = "very true or often true"). The scores for internalizing symptoms vary between 0 and 72; for externalizing symptoms, the scores range between 0 and 48. Higher scores indicate a higher amount of symptoms. 	<ul style="list-style-type: none"> The internalizing symptoms subscale contains 36 items assessing depression/anxiety, emotional reactivity, somatic complaints with no medical cause, and withdrawal from social contact. The externalizing symptoms subscale is made up of 24 items assessing attention problems and aggressive behavior. 	<ul style="list-style-type: none"> Parents of children born very preterm as their children are aged three and four years.

Measure name	Description of measure	Scale and scoring	Subscales and items	Informant(s)
<p>The Behavior Rating Inventory of Executive Function (BRIEF)</p>	<p>A questionnaire with 86 items assessing eight subdomains of executive function in children and adolescents at 5–18 years. Parents and teachers are given separate forms.</p>	<ul style="list-style-type: none"> – The scale ranges from 1 to 3 (1 = “no,” 2 = “sometimes,” and 3 = “often”). – The sum of the scores for each subdomain are converted into age- and sex-specific standardized T-scores according to the BRIEF manual. – T-scores >64 indicate clinically significant symptoms. – Higher scores indicate higher-level problems in executive function. 	<ul style="list-style-type: none"> – Global executive composites comprise the behavioral regulation index and metacognition index. – Behavioral regulation index is comprised of the subdomains of Inhibit, Shift and Emotional Regulation. – The metacognition index is comprised of the subdomains of Initiate, Working Memory, Plan/organize, Organization of Materials, and Monitor. 	<ul style="list-style-type: none"> – Teachers of children born very preterm as their children are aged 11 years. – Teachers of term-born children at 11 years of age.

4.4 Statistical analyses

Statistical analyses were run on SPSS 25 (Study I), SPSS 24 (Study II), SPSS 26 (Study III) (IBM Corp.), and R software (Version 4.3.2; R Core Team, 2023) (Study IV). Additionally, latent profile analyses in Study I, as well as linear regression and structural equation models in Study III, were performed using Mplus version 8 (Muthén & Muthén, 2019). For hypothesis testing, p-values of less than 0.05 (two-tailed) were considered statistically significant in Studies I, III, and IV. In Study II, a significance level of $p < 0.01$ was applied.

Categorical variables included the child's sex, parental education, brain pathologies, prematurity-related medical complications, and neurodevelopmental impairment. Continuous variables comprised gestational age (weeks), birth weight, birth weight z score, scores of the cognitive assessment, scaled regional brain volumes, and questionnaire scores. For cases where the same questionnaire (PSI, BDI-13, and CBCL) was administered at two time points, the mean score of Time 1 and 2 was calculated and used in the statistical analyses.

Descriptive statistics were reported as means, standard deviations (SD), and ranges (min–max) for continuous variables and frequencies and percentages for categorical variables. Comparisons between groups were conducted using the independent samples t-test, the chi-square test (χ^2) or the Mann–Whitney U test based on the data distribution and/or the nature of the variables. Drop-out analyses were performed in Studies I, II, and IV to assess potential biases caused by participant attrition.

In Study I, Mplus was utilized for latent profile analysis to construct profiles of social functioning to identify patterns of loneliness and social competence in the sample of preterm- and term-born participants. The auxiliary options of Mplus were employed to determine whether prematurity and sex were evenly distributed across the latent profiles. Multinomial logistic regression analysis assessed the likelihood of participant subpopulations (preterm- vs. term-born, girls vs. boys) belonging to the latent profiles, and examined how gestational age (weeks), cognitive performance, and parental education influenced the likelihood of belonging to a specific latent profile among preterm-born participants. Comparisons were presented as odds ratios (ORs) with 95% confidence intervals along with p-values. The average social functioning class served as the reference category in all models.

In Study II, the Spearman's rank correlation test analyzed the associations between the scaled brain volumes and the questionnaire scores (PNDLS, MASCS). The partial Spearman's rank correlation test was used to evaluate the impact of gender and age on MRI assessment. Additionally, the z test (Fisher's r-to-z transformation) was used to calculate significant differences between the correlation coefficients in the preterm and term-born groups.

In Study III, linear regression analysis was conducted to identify the controlling variables for the main models. We examined whether background variables predicted children's internalizing and externalizing symptoms at 3–4 years, and/or their loneliness and social competence at 11 years. The child's gestational age and neurodevelopmental disability were selected as potential risk factors based on statistically significant associations. Additionally, multigroup structural equation modeling was employed to analyze whether maternal and/or paternal stress or depressive symptoms were associated with girls' or boys' internalizing or externalizing symptoms at 3–4 years and/or their loneliness and/or social competence at 11 years. Models for boys and girls were fit to the covariance matrix using the maximum likelihood method with Mplus 7 (Muthén & Muthén, 2013). The fit of the models was evaluated using several indices: the chi-square test, the root mean square error of approximation (RMSEA), the comparative fit index (CFI), the Tucker–Lewis index (TLI), and the standardized root mean square residual (SRMR). The chi-square difference test was used to analyze the invariance between groups in the multigroup model and to test the difference between the unrestricted and loadings restricted models of the CFI.

In Study IV, multivariable linear regression was employed to examine the relationship between social and emotional loneliness and core executive functions in preterm and term-born groups separately. Two separate regression models were conducted for each sample (preterm- and term-born). Each model investigated the relationships between inhibition, shifting attention, and working memory as independent variables, and either social loneliness or emotional loneliness as the dependent variable. Sex was included as a covariate in all models to assist in comparability. Additionally, in the model for the preterm sample, IQ (≥ 70) was also controlled for as a covariate. Diagnostic tests, such as Cook's distance and standardized residuals were performed to identify and remove the influential cases in the models.

4.5 Ethics

The Ethics Committee of the Hospital District of Southwest Finland approved the PIPARI study protocol originally in December 2000, and then at several time points (March 2003, July 2007, January 2012). All parents gave written informed consent for the entire follow-up period, and all young adolescents gave written informed consent at 11 and 12 years of age.

5 Results

5.1 Profiles of social functioning in early adolescence

Three latent classes with different social functioning profiles were identified. (Study I) The profiles were named as high, average, and low social functioning classes. Participants in the high social functioning class (20% of the participants) reported high social competence and low levels of loneliness. Participants in the average social functioning class (44%) reported average social competence and loneliness levels. Participants in the low social functioning class (36%) reported low social competence and average levels of loneliness.

Both prematurity and biological sex affected the distribution of the very preterm and full-term participants between the social functioning classes ($p < .001-.008$). Distribution of the participants born very preterm and full-term into latent profile classes is presented in **Figure 4**. The same figure has been presented in the original article (Study I).

The majority of very preterm-born participants (54.5% of the girls and 52.6% of the boys) belonged to the average social functioning class. Next, the most common class among the preterm-born girls was high social functioning class (26% of the girls and 11.9% of the boys); among the preterm-born boys, low social functioning class (35.8% of the boys and 19.5% of the girls) was the next most common. The corresponding results for the term-born controls are presented in the original article (Salomäki et al., 2021).

Groupwise comparisons indicated the following statistically significant results: 1) very preterm-born participants reported average social functioning more frequently than term-born participants, 2) girls reported to have more frequently high and less frequently low social functioning than boys, 3) preterm-born girls reported high social functioning less frequently than term-born girls, 4) preterm-born boys reported low social functioning less frequently than term-born boys, and 5) term-born girls reported high social functioning more frequently than term-born boys; however, no sex-specific differences were observed in the social functioning of preterm-born participants.

In the preterm-born group, participants with better working memory and higher levels of maternal education more frequently reported high social functioning over average social functioning. There were no other statistically significant associations between the social functioning classes and the selected background variables.

Dropout analyses revealed that mothers of preterm participants were more highly educated than mothers of preterm dropouts (≤ 12 years in 35% of the participants and 57% of the dropouts, $p = .009$). The term-born participants did not differ from the term-born dropouts in this respect.

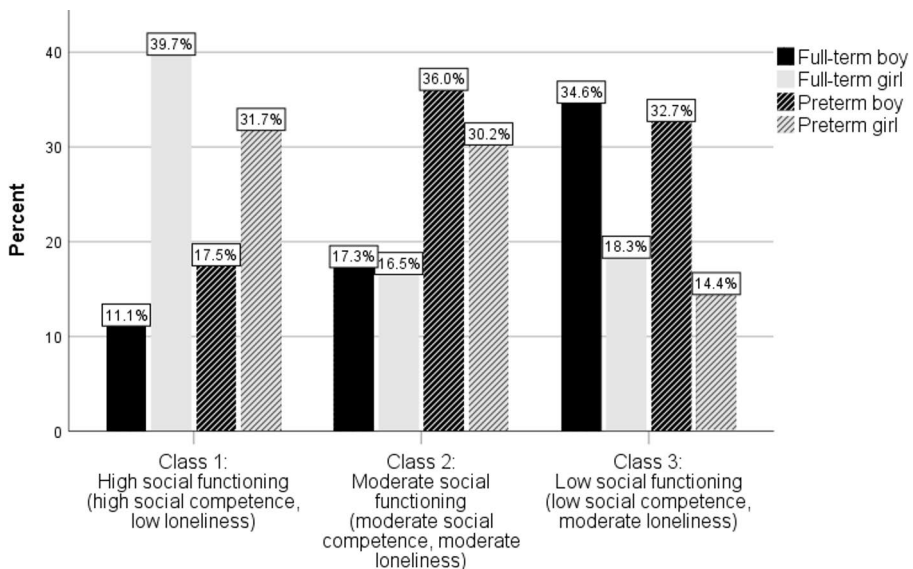


Figure 4. Distribution of the participants born very preterm and full-term into latent profile classes.

5.2 Associations between social functioning and regional brain volumes

In the very preterm group, emotional loneliness, impulsivity, and disruptiveness were significantly associated with the regional brain volumes, while in the term-born group, the only significant association was found between disruptiveness and a smaller volume of the left fusiform gyrus ($p = .006$, $r = -.508$). (Study II) The statistically significant associations between regional brain volumes and social functioning in the preterm born group are presented in **Table 2**.

Comparisons of the correlation coefficients between the very preterm group and the term-born group identified significant differences in the association between emotional loneliness and the volume of right hippocampi ($Z = 2.94$, $p = .003$) and

the link between emotional loneliness and the volume of total cerebral white matter ($Z = -2.91, p = .004$).

None of the participants had major brain pathologies. Brain volumes or elements of social functioning did not differ significantly between the preterm and term-born groups. Dropout analyses determined that social functioning scores, birth weights, and gestational ages did not differ between the participants and non-participants.

Table 2. Statistically significant associations between social functioning and regional brain volumes in young adolescents born very preterm.

	Social loneliness	Emotional loneliness	Co-operating skills	Empathy	Impulsivity	Disruptiveness
Amygdala right						
Amygdala left						
Caudate right						
Caudate left						
Cerebellum exterior right						
Cerebellum exterior left						
Cerebellum white matter right					.468 (.007)	
Cerebellum white matter left						
Cerebellar vermal lobules I-V						
Cerebellar vermal lobules VI-VII						
Cerebellar vermal lobules VIII-X						
Hippocampus right		-.567 (.001)				
Hippocampus left		-.494 (.005)				
Pallidum right						
Pallidum left						
Putamen right						
Putamen left						
Thalamus proper right						
Thalamus proper left						
Fusiform gyrus right						
Fusiform gyrus left						
Cerebral white matter, total		.515 (.003)				
Frontal lobe right						
Frontal lobe left						
Temporal lobe right						
Temporal lobe left						
Parietal lobe right					-.488 (.005)	-.605 (.000)
Parietal lobe left						
Occipital lobe right						
Occipital lobe left						

Note: Partial Spearman’s rank correlation coefficient (p-value); child’s sex and age at MRI have been controlled.

5.3 Trajectories from early parental psychological distress, and children’s mood and behavioral symptoms, to social functioning in early adolescence

In girls born very preterm, lower social functioning at 11 years was predicted by higher levels of early maternal depression, higher level of the child’s early externalizing symptoms, and lower gestational age. In boys born very preterm, lower social functioning at 11 years was predicted by lower gestational age and the

presence of neurodevelopmental disabilities. A higher level of early paternal depression was associated with higher social functioning at 11 years. The early predictors of social functioning in girls presented as standardized regression coefficients are indicated in **Figure 5**. The predictors for boys are outline in **Figure 6**. The same figures have been presented in the original article (Study III).

Dropout analyses showed that the mothers of the participants were more highly educated than the mothers of the dropouts ($p = 0.006$). Preliminary analyses for this study are presented in the original article.

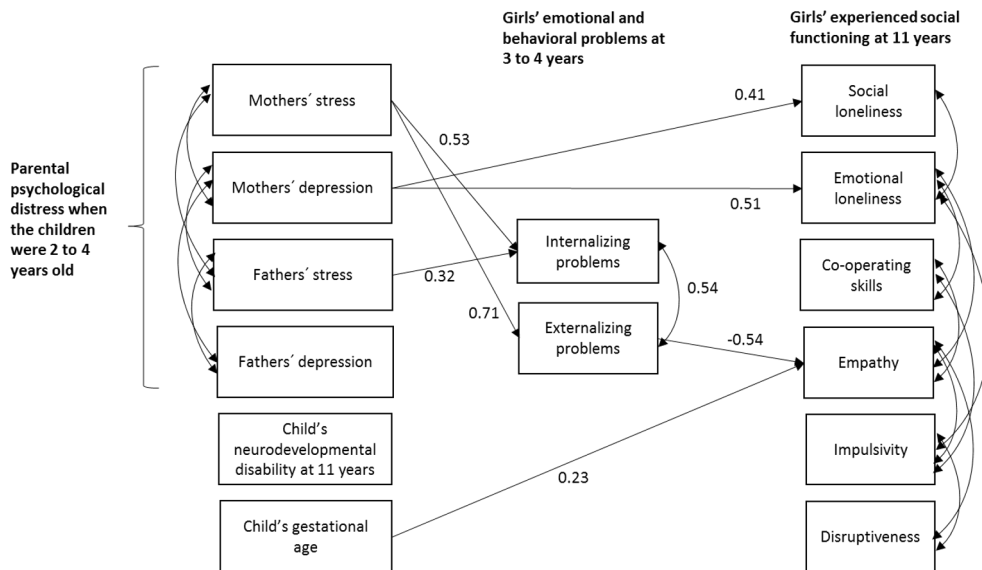


Figure 5. Associations between parental early psychological distress and a child's early mood and behavioral symptoms and experienced social functioning in 11-year-old girls born very preterm.

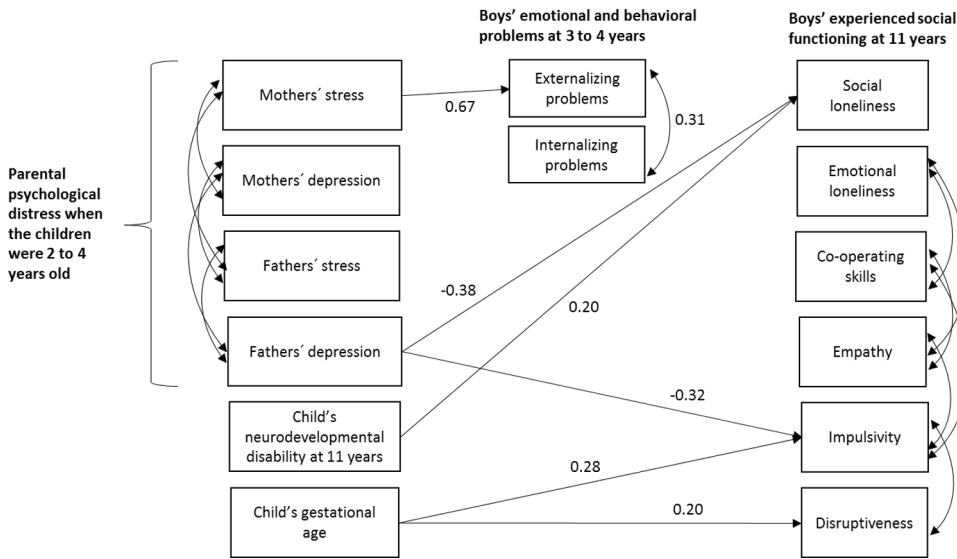


Figure 6. Associations between parental early psychological distress and a child's early mood and behavioral symptoms and experienced social functioning in 11-year-old boys born very preterm.

5.4 Associations between loneliness and the core executive functions

In the very preterm group, teacher-rated inhibition ($B = -0.05$, $t = 2.46$, $p = .015$) and shifting attention ($B = 0.06$, $t = 2.18$, $p = .031$) were significantly associated with experienced social loneliness, whereas teacher-rated working memory was not ($B = 0.02$, $t = 1.48$, $p = .40$). These significant associations remained even after adjusting for sex and FSIQ. The overall adjusted model was statistically significant, $F(5, 124) = 2.67$, $p = .024$, $R\text{-squared} = 0.06$. None of the core executive functions significantly predicted emotional loneliness before and after adjusting the model for sex and FSIQ. The overall adjusted model was deemed not statistically significant, $F(5, 125) = 1.57$, $p = .172$, $R\text{-squared} = 0.02$ (Study IV).

In term-born participants, neither social nor emotional loneliness were significantly associated with the core executive functions before and after controlling for sex.

Dropout analyses indicated that the mothers of preterm participants who remained in the sample had higher levels of education compared to those who dropped out ($p = 0.006$), and preterm participants who dropped out had significantly lower gestational age ($M = 27.60$, $SD = 3.04$) compared to those who remained in the study ($M = 28.98$, $SD = 2.71$), $t(253) = 3.66$, $p < .001$). The term-born participants did not differ from the term-born dropouts.

Table 3. Associations between the core executive functions and social and emotional loneliness in 11-year-old children born very preterm and term before and after controlling the selected background variables.

Group	Variable	Emotional loneliness						Social loneliness					
		Unadjusted model			Adjusted model			Unadjusted model			Adjusted model		
		B	95% CI ^a	p	B	95% CI ^a	p	B	95% CI ^a	p	B	95% CI ^a	p
Preterm	Inhibition	0.00	-0.04, 0.04	0.9	0.00	-0.04, 0.04	0.9	-0.06	-0.10, -0.02	0.005^b	-0.05	-0.10, -0.01	0.013^b
	Shifting	0.03	-0.02, 0.09	0.3	0.03	-0.03, 0.08	0.3	0.06	0.01, 0.12	0.025^b	0.06	0.01, 0.12	0.026^b
	Working Memory	-0.01	-0.05, 0.03	0.5	-0.02	-0.06, 0.02	0.3	0.03	-0.01, 0.07	0.2	0.02	-0.02, 0.06	0.4
	Sex (Girl)				-0.68	-1.5, 0.12	0.095				0.33	-0.46, 1.1	0.4
	FSIQ				-0.03	-0.06, 0.00	0.081				-0.02	-0.06, 0.01	0.15
Full Term	Inhibition	0.00	-0.06, 0.07	0.9	0.00	-0.06, 0.07	0.9	-0.04	-0.10, 0.02	0.2	-0.04	-0.10, 0.02	0.2
	Shifting	-0.03	-0.09, 0.04	0.4	-0.01	-0.07, 0.06	0.8	-0.01	-0.07, 0.05	0.7	-0.01	-0.07, 0.05	0.8
	Working Memory	-0.02	-0.09, 0.06	0.6	-0.04	-0.11, 0.03	0.3	0.04	-0.03, 0.10	0.3	0.03	-0.03, 0.10	0.3
	Sex (girl)				1.5	0.57, 2.5	0.002^b				0.21	-0.66, 1.1	0.6

Note: FSIQ = full-scale intelligence quotient

a: confidence interval

b: statistically significant ($p < .05$)

6 Discussion

This dissertation examined experienced social functioning and associated risk factors of social functioning in 11-year-old children born very preterm and full-term. The focus was on young adolescents born very preterm. It was aimed to identify factors that, when considered, could support the social functioning of young adolescents born very preterm in the future during the sensitive period of adolescence.

In Study I, it was identified profiles of experienced social functioning including social and emotional loneliness and social competence (co-operating skills, empathy, impulsivity, disruptiveness) in young adolescents born very preterm and full-term. Experienced social functioning of boys and girls born very preterm was compared to social functioning of same-sex peers born full-term. It was hypothesized that young adolescents born very preterm report lower social functioning compared to their full-term controls. Furthermore, earlier gestational weeks, lower cognitive performance and lower parental education as potential risk factors for low social functioning in young adolescents born very preterm were studied.

In Study II, associations between loneliness (social and emotional) and social competence (co-operating skills, empathy, impulsivity, disruptiveness), and regional brain volumes in young adolescents born very preterm and full-term were investigated. It was hypothesized that loneliness and social competence are more closely related to brain volumes in young adolescents born very preterm than in those born full-term.

In Study III, the long-term associations between parental psychological distress (stress and depression) when the child was 2 to 4 years old, the child's mood and behavioral symptoms (internalizing and externalizing) at 3 to 4 years, and experienced social functioning at 11 years in boys and girls born very preterm were assessed. It was hypothesized that a higher level of parental psychological distress and a child's mood and behavioral symptoms during early childhood are associated with a lower level of experienced social functioning in young adolescents born very preterm, especially in girls.

In Study IV, associations between the core executive functions (inhibition, shifting attention, and working memory) manifested at school, and experienced

social and emotional loneliness was examined in young adolescents born very preterm and at term. The core executive functions were hypothesized to be more related to loneliness in young adolescents born very preterm than those born at term. Furthermore, the study examined whether sex in both groups and general cognitive performance (FSIQ) in the very preterm group modulated the associations between the core executive functions and experienced social and emotional loneliness. An overview of the studies that comprise this dissertation is presented in **Table 4**.

Table 4. Overview of the Studies I – IV.

	Aims	Participants & methods	Key findings
<p>Study I ”Social functioning questionnaires of adolescents born preterm show average profiles and attenuated sex differences”</p>	<p>To evaluate social competence and loneliness profiles in 11-year-old girls and boys born very preterm and full-term. To determine how gestational age, cognitive performance and parental education were associated with social competence and loneliness in preterm-born young adolescents.</p>	<p>172 young adolescents born very preterm (<32 weeks of gestation and/or ≤1500 grams birth weight) and 134 young adolescents born full-term. The Peer Network and Dyadic Loneliness Scale (PNDLS) at 11 years of age. The Multisource Assessment of Children’s Social Competence Scale (MASCS) at 11 years of age. The Wechsler’s Intelligence Scale for Children (WISC-IV) (4th edition) at 11 years of age.</p>	<p>Young adolescents born very preterm most frequently reported average social functioning. Differences between the sexes were attenuated in the very preterm–born group. Boys born very preterm reported low social functioning less frequently, while girls born very preterm reported high social functioning less frequently than same-sex term-born peers. A good working memory and high levels of maternal education were associated with high levels of social functioning (i.e., low levels of loneliness and high levels of social competence) in young adolescents born very preterm.</p>
<p>Study II “Brain volumes in relation to loneliness and social competence in preadolescents born very preterm”</p>	<p>To assess how regional brain volumes are associated with experienced loneliness and social competence in young adolescents born very preterm and full term.</p>	<p>34 young adolescents born very preterm (<32 weeks of gestation and/or ≤1500 grams birth weight), and 31 young adolescents born full term. A brain MRI at term age and at 12 years of age. The PNDLS and the MASCS at 11 years of age.</p>	<p>The brain volumes were associated with emotional loneliness in the very preterm group, but not in the full-term group. Brain volumes and social competence were associated to a greater degree in the very preterm group than in the full-term group.</p>

Aims	Participants & methods	Key findings
<p>Study III “Longitudinal associations between parental early psychological distress and children’s emotional and behavioural problems during early childhood and self-reported social functioning in 11-year-old children born very preterm”</p>	<p>To evaluate how maternal and paternal stress and depression and children’s internalizing and externalizing problems during early childhood are linked to experienced loneliness and social competence in 11-year-old girls and boys born very preterm.</p>	<p>In girls, higher levels of early maternal depression were associated with higher levels of emotional loneliness in early adolescence. Higher levels of early maternal stress were associated with higher levels of girls’ early externalizing problems, which were associated with lower levels of empathy behavior in early adolescence.</p> <p>In boys, higher levels of early paternal depression were associated with lower levels of social loneliness and lower levels of impulsive behavior in early adolescence.</p>
<p>Study IV “Associations between executive functions and loneliness in young adolescents born very preterm”</p>	<p>To examine the associations between the core executive functions (inhibition, working memory, and shifting attention) and social and emotional loneliness in early adolescence.</p>	<p>In young adolescents born very preterm, higher levels of problems in shifting attention were associated with higher levels of social loneliness. Higher levels of problems in inhibition associated with lower levels of social loneliness. The associations remained statistically significant after adjusting for sex and FSIQ.</p> <p>In young adolescents born full term, no associations were found between the core executive functions and loneliness.</p>

6.1 Profiles of social functioning in young adolescents born very preterm

Three types of experienced social functioning in early adolescence – high, average, and low – were identified. Most young adolescents born very preterm reported average social functioning (i.e., average social competence and average loneliness) irrespective of their biological sex. In girls born very preterm, the next most commonly reported social functioning profile was a high social functioning profile (i.e., high social competence and low loneliness), which was the most frequently reported profile among term-born girls. In boys born very preterm, the next most commonly reported social functioning profile was the low social functioning profile (i.e., low social competence and average loneliness), which was the most frequently reported profile among term-born boys.

Girls born very preterm reported a high social functioning profile less frequently than girls born full term, whereas boys born very preterm reported a low social functioning profile less frequently than boys born full term. A good working memory and high maternal education were associated with a high social functioning profile in young adolescents born very preterm.

The main finding that very preterm birth had an effect on experienced social functioning in early adolescence is consistent with previous literature demonstrating that preterm birth has long-lasting effects on social functioning (Bilgin et al., 2021; Ritchie et al., 2015; van der Pal-de Bruin et al., 2015; Taylor, 2020). This supports the idea of prematurity as a chronic state (Raju et al., 2017). Preterm birth has been shown to alter the development of the brain and increase vulnerability to environmental stressors (Cheong et al., 2020; Montagna & Nosarti, 2016). This explains its long-term effects on socioemotional development (Taylor, 2020).

The finding that girls born very preterm reported a high social functioning profile less frequently than girls born full term is consistent with our hypothesis and previous literature demonstrating impaired social functioning in children and adolescents born very preterm (Ritchie et al., 2015; Taylor, 2020). The tendency of girls born very preterm to report higher levels of loneliness and lower social competence, including reduced levels of prosocial behaviors compared to term-born girls, may result in withdrawn and internalizing behaviors commonly observed in preterm populations from childhood to adulthood (Mathewson et al., 2017; van der Pal-de Bruin et al., 2015; Taylor, 2020). However, contrary to the hypothesis, boys born very preterm reported low social functioning less frequently compared to full-term boys. Preterm-born boys' tendency to report less impulsive and disruptive behavior compared to term-born boys may be related to a lower risk for hyperactive, oppositional, and externalizing behaviors reported by adolescents and adults born very preterm (Mathewson et al., 2017; Pyhälä et al., 2017). In general, most young adolescents born very preterm reported average to high social functioning in this

study; this aligns with previous findings indicating that the majority of children and young adolescents born very preterm have low levels of behavioral problems (van Houdt et al., 2020).

Better working memory and higher levels of maternal education were associated with a high social functioning profile in young adolescents born very preterm. The literature has also previously identified positive associations between social functioning and general cognitive performance (Heuser et al., 2018; Linsell et al., 2019), executive function (Alduncin et al., 2014; Schnider et al., 2020), and parental education (van Houdt et al., 2019) in very preterm-born populations. Furthermore, worse working memory and lower levels of parental education have been identified as risk factors that accompany decreased general cognitive performance and inhibitory control among children and adolescents born very preterm, who also exhibit a wide range of behavioral problems (van Houdt et al., 2020).

6.2 Neurological correlates of social functioning in young adolescents born very preterm

Emotional loneliness in young adolescents born very preterm was associated with smaller volumes of the right and left hippocampi as well as larger volumes of total cerebral white matter volume. Furthermore, impulsivity was associated with larger right cerebellar white matter and smaller right parietal lobe volume. Disruptiveness was also associated with a smaller volume in the right parietal lobe. The only statistically significant association in the full-term group involved disruptiveness and smaller left fusiform gyrus volume.

The main finding was that elements of social functioning were associated with a greater degree with regional brain volumes in young adolescents born very preterm than those born full term. This finding supports previous evidence of altered development of the brain underlying long-term social outcomes in preterm-born populations (Healy et al., 2013; Taylor, 2020). However, past research on specific associations between regional brain volumes and loneliness, as well as associations between brain volumes and social competence in young adolescents born very preterm, is limited.

Emotional loneliness was associated with smaller volumes of right and left hippocampi in young adolescents born very preterm, partly aligning with a previous study finding that smaller hippocampal volumes at term equivalent age predict peer problems at five years of age in girls born very preterm. (Rogers et al., 2012). Furthermore, smaller right parietal lobe volume was associated with higher levels of impulsivity and disruptiveness in young adolescents born very preterm. These findings are in line with previously discovered associations between smaller parietal cortex volume and increase inattention and hyperactivity and poorer psychosocial

functioning in adolescents born with very low birth weights (Botellero et al., 2017). Reduced total and regional brain volumes have been frequently reported in populations born very preterm (de Kieviet et al., 2012; Kelly et al., 2023). In contrast, the findings that emotional loneliness was associated with larger total cerebral white matter volume and that impulsivity was associated with larger cerebellar white matter volume in the preterm group were unexpected. However, subjects with autism spectrum disorder have found to have increased total brain volume (Pagnozzi et al., 2018) and increased cerebellar volume (Traut et al., 2018), which suggests a link between larger white matter volumes and social problems, including impaired self-regulation.

6.3 Early parental psychological distress, mood and behavioral problems, and social functioning in young adolescents born very preterm

This study identified distinct trajectories for boys and girls born very preterm in relation to early parental psychological distress, the child's early mood and behavioral symptoms, and social functioning in early adolescence. In girls, higher levels of maternal stress when the child was 2–4 years old were associated with higher levels of the child externalizing problems at 3–4 years old, which, in turn, were associated with less empathetic behavior at 11 years old. Furthermore, higher levels of maternal depression when girls are 2–4 years old were associated with social and emotional loneliness at 11 years. In boys, a higher level of early paternal depression was associated with a lower level of social loneliness and a lower level of impulsive behavior at 11 years.

In line with previous literature, early parental psychological distress was found in this study to have a long-term effect on social functioning in young adolescents born very preterm (Hosozawa et al., 2021; Montagna & Nosarti, 2016). In particular, exposure to maternal psychological distress during one's early years has been associated the long-term risk of lowering children's social functioning (Hosozawa et al., 2021; Huhtala et al., 2014), inducing poorer socioemotional development (Fredriksen et al., 2019) in very preterm and community samples.

Girls born very preterm were more susceptible to the longitudinal effects of their mothers' psychological distress during early childhood compared to boys. Previous findings from community samples have suggested interesting links between maternal psychological distress and girls' social functioning. Shared genetic factors may explain vulnerability to similar socioemotional outcomes (Harold et al., 2017). Prenatal exposure to maternal stress has been found to have more pronounced effects on girls' emotional reactivity in infancy compared to boys (Nolvi et al., 2019). In

early adolescence, mothers' loneliness has been identified to predict girls' social loneliness, whereas fathers' loneliness tends to predict boys' social loneliness (Salo et al., 2020).

Contrary to the hypothesis proposed in this paper, an association between a higher level of early paternal depression and a lower level of experienced loneliness and impulsivity in 11-year-old boys born very preterm was found. This may have been the result of co-parenting in the family and the child's stage of development. Sensitive maternal parenting has been demonstrated to enhance a child's long-term resilience (Faure et al., 2017) and to predict more sensitive parenting by fathers (Scott et al., 2018). It is possible that when the father is depressed, the mother's sensitive parenting acts as a buffer against the potential negative effects of the father's depression on his parenting and on a child's social functioning. It has also been shown that mothers' parenting may have a greater influence on the development of the child during the early years, while the influence of paternal parenting increases as the child grows older (Scott et al., 2018). Earlier in this study cohort, maternal depression (but not paternal depression) was associated with higher levels of social, behavioral, and functional problems at five years of age (Huhtala et al., 2014).

6.4 Associations between executive function at school and social functioning in young adolescents born very preterm

In young adolescents born very preterm, a higher level of problems in shifting attention was associated with a higher level of social loneliness. However, higher levels of problems in inhibition were associated with a lower level of social loneliness. These associations remained statistically significant after adjusting for sex and FSIQ. No associations were found between the core executive functions and emotional loneliness in the preterm-born group or between executive function and either type of loneliness in the term-born group.

The main finding was that social loneliness was associated with the elements of executive functions in young adolescents born very preterm but not in young adolescents born full-term. Previous literature has suggested that impaired executive function plays a more central role in the social functioning of children, adolescents, and adults born very preterm than those born full-term (Alduncin et al., 2014; Kroll et al., 2017; Schnider et al., 2020; Twilhaar et al., 2019). In contrast, one study reported similar associations between self-control skills and socio-emotional functioning in children and adolescents born very preterm and at term (Bilgin et al., 2022). In general, various cognitive, social, and behavioral problems have been shown to have stronger associations in children born very preterm compared to

children born full-term (Leoni et al., 2023), and a wide range of behavioral problems have been shown to accumulate in the same children born very preterm (van Houdt et al., 2020). This finding, building on previous literature, suggests that elements of executive function may have a predictive role on social functioning in very preterm-born populations.

As hypothesized in this study, a higher level of problems with shifting attention at school was associated with higher levels of reported social loneliness in young adolescents born very preterm. There is some evidence that slowness in shifting attention can be detected as early as 12 months of age in infants born very preterm with average intelligence (Downes et al., 2018), and problems persist from childhood into early adolescence, interfering with performance, especially in complex and cognitively demanding situations (Ritter et al., 2014; Wehrle et al., 2016). Adolescence is a sensitive period for social development marked by an increase in the need for peer relations and heightened sensitivity to social cues (Laursen & Veenstra, 2021; Orben et al., 2020), coinciding with the growing demands of a social environment that requires more sophisticated skills (Junge et al., 2020). Although most children born very preterm have been reported to have few behavioral problems (van Houdt et al., 2020), my finding suggests that those with problems in shifting attention, even without cognitive disabilities, may find it challenging to join or belong to peer groups and may be at increased risk for social loneliness in early adolescence.

In contrast to my hypothesis, a higher level of problems in inhibition at school was associated with lower levels of experienced social loneliness in young adolescents born very preterm. In line with the finding, social problems have been found to be more strongly associated with internalizing symptoms and attention deficits than with impulsive and externalizing behavior in very preterm-born populations. (Taylor, 2020) A higher level of inhibitory control in infancy has been found to predict a higher level of social withdrawal during childhood in a community sample; this, in turn, has been shown to predict higher levels of loneliness in adolescence (Verhagen et al., 2023). Considering the relatedness of internalizing behavior and social problems in very preterm born populations, the findings of the study may indicate that young adolescents born very preterm who behave more impulsively at school tend to have less prematurity-related internalizing symptoms and thus experience less social loneliness.

6.5 Possible mechanisms for explaining social functioning in young adolescents born very preterm

Although this dissertation does not allow for the determination of causal relationships between experienced social functioning in young adolescents born very preterm and associated factors, the findings provide an opportunity to speculate on its potential underlying mechanisms.

First, prematurity may impact social functioning by altering the structure and functional connectivity of socioemotional and cognitive brain networks, which increases one's neurobiological susceptibility to environmental stressors and protective factors (Healy et al., 2013; Montagna & Nosarti, 2016). Prematurity may interfere with brain development through various biological mechanisms, such as disrupting the natural maturation process, exposing the infant to health complications, and increasing exposure to stress due to neonatal pain and increased parental distress (Montagna & Nosarti, 2016). Pre- and postnatal environments have been suggested to alter neurodevelopment and behavioral outcomes via epigenetic mechanisms, such as affecting stress regulation by altering the functioning of stress-related genes (Provenzi et al., 2018; Tien et al., 2020). Alterations in the endocrine system, especially the functioning of the stress-related hypothalamic–pituitary–adrenal (HPA) axis (Taylor, 2020; Tien et al., 2020), as well as alterations in the immune system and the functioning of the microbiome–gut–brain axis (Li et al., 2024; Napolini et al., 2024) have also been suggested to mediate the effects of the pre- and postnatal environment on behavioral outcomes. This dissertation does not address the pre- and postnatal mechanisms affecting the social functioning of very preterm infants. However, prematurity attenuated the effects of biological sex—another strong biological predictor—on social functioning. Additionally, elements of social functioning were more often related to brain volumes in young adolescents born very preterm than those born full term, even when brain injury, developmental impairments, sex, age at assessment, and total intracranial brain volume were considered. It is possible that minor alterations in early-life brain development underlie these findings.

Second, parental characteristics may either buffer or exacerbate the adverse effects of very preterm birth on socioemotional development (Richie et al., 2015; Montagna & Nosarti, 2026; Taylor, 2020). Developing socioemotional brain networks requires tactile, auditory, and visual input with emotional valence from birth (Ciarrusta et al., 2020). Thus, positive, sensitive parenting, and good parental mental health during infancy and early childhood longitudinally shape neurodevelopment in preterm-born infants (Cheong et al., 2020). Although prematurity does not necessarily turn parenting less sensitive (Bilgin & Wolke, 2015; Doiron et al., 2022), an elevated amount of psychological distress associated with

infant's very preterm birth (Mendelson et al., 2017; Treyvaud, 2014) may affect a child's socioemotional development by altering parenting behavior into becoming less sensitive, less involved, and more loaded with negative affective states (Korja et al., 2008; Neri et al., 2015; Neuhauser, 2018). Similar alterations in parenting behavior may originate from a parent's disadvantageous socioeconomic status, which has also been shown to accentuate the effects of stress on parenting behaviors (Doiron et al., 2022), pointing to the cumulative impact of adverse environmental factors. On the other hand, higher parental education may protect the social development of the child by altering parenting behavior into behavior that is more sensitive and involved (Neuhauser, 2018; Doiron et al., 2022). More educated parents may also possess greater knowledge and financial resources to create an environment that supports social development. According to our findings, higher maternal education can be considered a protective factor for social functioning, although its mechanisms remain unexplored in this study. According to our findings, maternal depression during the early years of the child may be a risk factor for loneliness in girls born very preterm. Although, again, causality cannot be addressed, it is possible that mothers who are still depressed after two years are genetically more vulnerable to internalizing behavior. In most cases, prematurity-related parental distress has been shown to decrease over time (Treyvaud et al., 2014). Shared genetic factors may also explain the link between early maternal depression and increased loneliness in daughters (Harold et al., 2017). Lastly, maternal depression may be a sign of the accumulation of multiple risk factors affecting social development, such as a lack of social support.

Thirdly, a child's cognitive resources may facilitate or interfere his/her interaction with his/her social environment, thus affecting his/her social functioning. Improved general cognitive capacity allows for faster and more fluid reasoning, which facilitates adaptation, especially in new and constantly changing environments. Better executive function facilitates adaptation by enhancing behavioral and emotional regulation and enabling more deliberate responses to environmental cues. In the present study, better working memory, a common component of general cognitive capacity and executive function, was associated with better social functioning in young adolescents born very preterm. Furthermore, problems with shifting attention (in other words, lower cognitive flexibility), were associated with a higher level of experienced social loneliness in young adolescents born very preterm, even when general cognitive performance level and sex were taken into account. A common feature of working memory and attention shifting is that they both enhance the efficiency of processing a large amount of information simultaneously. Higher working memory assists in the short-term processing and updating of information in the mind, while better attention shifting facilitates the collection of additional information by flexibly shifting attention from one thing to

another. Although causality cannot be established based on this study, our findings suggest that a limited capacity to process a large number of social cues simultaneously may be a key factor in impairing social functioning in young adolescents born very preterm without major cognitive impairments. In line with this finding, deficits in executive function have been shown to predict poor behavioral performance better than intelligence quotients can (van Houdt et al., 2019). Better self-regulation skills in childhood have been shown to predict heightened social functioning in childhood and adolescence in very preterm- and term-born populations (Bilgin et al., 2022, Alduncin et al., 2014). It is possible that even if executive function skills are not clinically impaired, they may develop later in the preterm-born population (Ritter et al., 2013), impairing social development, especially during the crucial early adolescence period, which is important for social development. Since social interaction involves a vast amount of simultaneous, rapidly changing, and multisensory information, minor deficits in processing this information may lead to problems in social functioning. Thus, even adolescents born very preterm who have difficulties with executive function only in complex situations (Wehrle et al., 2016) may be at risk of impaired social functioning.

6.6 Strengths and limitations of the study

The major strengths of this study include its bringing forth the experiences of young adolescents born very preterm at a clinically relevant developmental stage as well as the quality of its data. Social functioning was assessed in early adolescence—the onset of a sensitive period for social development. Validated and ecologically valid measurements were used, and the questionnaires used were returned at a high rate. The effect of biological sex was systematically accounted for, allowing for the identification of separate profiles and developmental trajectories for boys and girls born very preterm (Studies I and III). In addition, the prospective design in Study III allowed for the examination of longitudinal trajectories. In Studies II and IV, well-defined study groups allowed for the identification of prematurity-related specific neurodevelopmental and cognitive characteristics by comparing very preterm- and full-term groups.

A major limitation of this study was that social competence was only assessed from the perspective of young adolescents. A multi-source approach would have provided a more comprehensive view on social competence in early adolescence and allowed for the detection of discrepancies between different informants. Although assessments by different informants (self, parent, teacher, and peers) have been found to be correlated (Junttila et al., 2006), several studies have indicated that adolescents born very preterm may perceive their social functioning more positively than people in their immediate social environment (Twilhaar et al., 2019).

Nevertheless, given its highly subjective nature, self-assessment remains the most effective method for evaluating loneliness. In Study II, the limited size of the study groups may have restricted the findings to only the most significant ones. However, given the novelty of this approach in exploring neural correlates of social functioning, including loneliness, this is acceptable. In Study III, values from the questionnaires collected at two consecutive age points during early childhood were aggregated into a mean score, with the aim of simplifying the statistical models. This may have led to certain age-related associations going unnoticed. The assessment of core executive functions and social loneliness at the same time-point restricted the findings in Study IV to correlations. Conducting the same assessments at consecutive time points would have allowed for the evaluation of bidirectional developmental trajectories, as reported in recent studies (Ben-asher et al., 2023; Verhagen et al., 2023).

7 Conclusions

In conclusion, the majority of young adolescents born very preterm perceived their social functioning to be average or high. Differences in social functioning between the biological sexes were less pronounced in young adolescents born very preterm compared to their full-term peers. Girls born very preterm were likelier to report lower social functioning compared to girls born full term, whereas boys born very preterm were likelier to report higher social functioning compared to boys born full term.

Brain development was more related to social functioning in young adolescents born very preterm than those born full term. Experienced emotional loneliness, self-rated impulsivity, and self-rated disruptiveness were associated with several regional brain volumes in young adolescents born very preterm. In young adolescents born full term, only disruptiveness was associated with left fusiform gyrus volume.

Parental psychological distress during early childhood was found to have longitudinal associations with social functioning in early adolescence in the very preterm–born group. These associations were modulated by sex. In particular, girls' social functioning in early adolescence appeared to be particularly sensitive to the long-term negative effects of maternal psychological distress during early childhood.

Executive functions assessed by teachers were associated with experienced social loneliness in young adolescents born very preterm but not in young adolescents born full term. Increased difficulty with shifting attention may indicate an increased risk of experiencing social loneliness in young adolescents born very preterm, irrespective of general cognitive performance.

8 Clinical Implications and Future Studies

Very preterm birth is an important background factor for assessing social functioning in early adolescence. As such, it does not always result in impaired social functioning. However, if a young adolescent born very preterm has social problems, the underlying mechanisms seem to be different than those in full-term populations. Inquiring about very preterm birth as part of the psychological and psychiatric clinical interviews expands the current understanding of potential comorbidities and the background factors of impaired social functioning.

This study indicated that the self-ratings of loneliness and social competence are applicable for assessing experienced social functioning in young adolescents born very preterm. Although PNDLS and MASCS have been mainly used in scientific studies, they could also be used in clinical settings. Children and adolescents completing them with healthcare professionals could serve as a basis for discussions on the difficult topics of loneliness and social difficulties, thus helping to identify young adolescents who need support. In addition, directly asking about difficulties and empathetically listening to the answers may support mental well-being.

From the perspective of cognitive abilities, problems in the social functioning of young adolescents born very preterm seem to be related to difficulties in flexibly processing large amounts of rapidly changing information. Thus, strategies to decrease the volume of simultaneously processed information in social situations may support the social functioning of young adolescents born very preterm and heighten their feelings of belonging to peer groups. Small-group settings at school and in hobbies, clear structure and purpose in group situations, and sufficient time to act and react in social situations may be beneficial for them. When targeting very preterm-born young adolescents at risk of experiencing social and academic difficulties, it may be useful and cost-effective to include teachers' evaluation of behavioral executive functions (BRIEF) at the end of primary school and conduct a follow-up protocol of young adolescents born very preterm. (Nyman et al., 2019) The transition to lower secondary school can be socially challenging as new classes are formed and as teaching groups and teachers change based on school subjects.

This may be an optimal time to support social functioning in young adolescents born very preterm who are at risk for social difficulties.

From a family background perspective, early maternal depression is a longitudinal risk factor for girls born very preterm, and low maternal education may be an additional risk factor. The findings of this study, together with previous findings (Crump, 2020; Raju et al., 2017), indicate that the follow-up of preterm-born infants should be continued after two years of corrected age and should also include assessments of parental mental health. The BDI is widely used, has cut-off scores for depression, and is quick to complete. Thus, it may be a good candidate for inclusion in follow-up protocols for children born very preterm aimed at identifying at-risk families.

This study highlights two main gaps in previous knowledge that warrant further attention from researchers. In the literature on very preterm infants, little effort has been made to examine the role of biological sex in social functioning. However, this study and previous findings from community samples (Junttila & Vauras, 2009; Junttila et al., 2006; A. Salo et al., 2020) indicate that biological sex modulates social functioning and its risks. Future studies assessing longitudinal trajectories from potential risk and protective factors to social functioning separately for boys and girls are necessary.

Second, although social difficulties have been extensively studied in very preterm-born populations, subjective feelings of loneliness have received little attention. Given that loneliness is an extremely distressing feeling (Mansfield et al., 2021) that, when chronic, is relatively stable (Junttila et al., 2009; Mund et al., 2020) and predicts a variety of negative outcomes (Hawkley & Cacioppo, 2010), additional studies using validated assessments of loneliness are needed to support very preterm-born populations.

Abbreviations

BDI	Beck Depression Inventory
BRIEF	Behavior Rating Inventory of Executive Function
CBCL	Child Behavior Checklist
CFI	Comparative fit index
FSIQ	Full-scale intelligence quotient
IQ	Intelligence quotient
MASCS	Multisource Assessment of Children's Social Competence Scale
MRI	Magnetic resonance imaging
NDI	Neurodevelopmental impairment
PIPARI	PIeniPAinoisten RIskilasten käyttäytyminen ja toimintakyky imeväisiästä kouluikään
PNDLS	Peer Network and Dyadic Loneliness Scale
PRI	Perceptual reasoning
PSI	Processing speed
RMSEA	Root mean square error of approximation
SGA	Small for gestational age
SRMR	Standardized root mean square residual
TLI	Tucker–Lewis index
WHO	World Health Organization
WMI	Working memory index
VCI	Verbal reasoning index

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