The association between dyadic emotional co-regulation and neurodevelopment in infants born preterm

[Master's Thesis]

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1.0. Abstract

Background: Preterm birth increases the risks of adverse cognitive, motor, and social development. It also increases the risks of impaired parent-child emotional co-regulation (mutual interactions). This study explored whether preterm birth is associated with lower dyadic emotional co-regulation and suboptimal neurodevelopment. Additionally, the association between dyadic emotional co-regulation and neurodevelopmental outcomes was determined.

Methods: 49 preterm infants and their parents were recruited through opportunity sampling. Data were collected from obstetric records, amnestic questionnaires, the universal Welch Emotional Connection Screen (uWECS), and Bayley Scales of Infant and Toddler Development (BSID). Five a-priori-defined linear regression analyses were conducted to examine the associations between gestational age (GA), dyadic emotional co-regulation, and neurodevelopment. Mother's schooling, language barriers, infant biological sex, and age at BSID assessment functioned as control variables.

Results: Higher GA was positively associated with motor development ($B=1.32$, $SE=0.60$, $\beta=0.30$, $p=0.034$), explaining 9.2% of motor score variance, but did not predict cognitive development. Emotional connection scores showed a marginally positive association with motor development ($B=2.85$, $SE=1.46$, $\beta=0.27$, $p=0.057$), but no significant link to cognitive development. No association was found between GA and emotional connection scores.

Conclusions: The significant association between GA and motor development supports that preterm infants are at risk for less optimal neurodevelopment. The marginally significant association between dyadic emotional connection and Bayley motor standard scores also supports a potential link between low emotional co-regulation and less optimal neurodevelopment. Further research with larger samples is needed to explore the dynamic interplay between dyadic emotional co-regulation and neurodevelopmental outcomes in preterm infants.

Keywords: Preterm birth; Dyadic emotional co-regulation; Neurodevelopment; Welch Emotional Connection Screen (uWECS); Bayley Scales of Infant and Toddler Development (BSID)

2.0. Introduction

Infants born before 37 weeks of gestation (GA) are defined as preterm (Howson et al., 2013). Currently, 15 million babies are born preterm each year (Howson et al., 2013) and 5-10% of all infants are born between weeks 32 and 36 of GA (Boyle et al., 2012). Due to improved neonatal care, survival rates have increased in recent years (Patel, 2016). However, prematurity is still the leading cause of long-term morbidity and mortality in infants (Howson et al., 2013). One in four extremely preterm infants (< 28 weeks' gestation) still dies during hospitalisation (Patel, 2016). Those who survive face many difficulties. Preterm birth is associated with altered brain development (Volpe, 2009) and smaller brain volume (Cheong et al., 2008). Additionally, alterations in the thalamic system (Ball et al., 2012) and cortical folding are possible (Kapellou et al., 2006). According to Ream and Lehwald (2018), altered brain development in preterm infants increases the risk of neurological impairments. These impairments typically correlate with social and cognitive difficulties later in life (Ream & Lehwald, 2018). Motor coordination and fine/gross motor skills are often impaired in preterm infants (Bos et al., 2013; Patel, 2016). However, according to Patel (2016), it is difficult to predict outcomes as not all preterm infants are similarly affected by preterm birth.

1.1.Cognitive difficulties

Many studies indicate that preterm birth negatively impacts cognitive development (Johnson et al., 2011; Quigley et al., 2012; Patel, 2016). For example, Jaekel, Baumann, and Wolke (2013) found considerably higher cognitive performance deficits in moderately and very preterm infants compared with infants born at term. They also found gradual cognitive deficits in late preterm infants compared with early term infants. Overall, they noted that developmental delays are typical for preterm infants and that the relationship between gestation, cognitive development, and task workload, is curvilinear: Very and moderately preterm infants have disproportionally more performance deficits, and performance deficits increase disproportionately the more cognitively demanding tasks become. So, it is not surprising that according to Volpe (2009), cognitive deficits currently represent the most common form of neurodevelopmental problems in preterm infants.

Cognitive problems tend to persist in preterm infants over time. Breeman et al. (2015), found, on average, lower IQ scores in very low birth weight and very preterm infants than in term-born peers. In their study, very preterm and term-born individuals were monitored from birth until the age of 26. From 20 months onwards, very preterm individuals consistently reached lower IQ scores. Also, Huening and Jaekel (2021) highlight the long-term developmental risk associated with preterm birth. They found that delayed school entry is significantly more common in very preterm individuals compared to term-born peers. In their study, 12.5% of very preterm and only 1.7% of term-born individuals faced delayed school entry.

Still, some preterm infants do better than others. For example, Oliviera et al. (2023) found that preterm infants achieve significantly lower cognitive scores than term-born infants. However, in their study, they detected a recovery capacity in preterm infants during the first year. They assessed both preterm and term-born infants at six and 12 months. Each time preterm infants gained lower cognitive scores, but there was a more pronounced improvement in preterm infants. Thus, early cognitive assessment is crucial for providing targeted support (Breeman et al., 2015; Oliviera et al., 2023). Huening and Jaekel (2023) also highlight that early identification of developmental delay in preterm infants is important. They note that early support prevents future educational challenges (Huening & Jaekel, 2023). Especially, children born very preterm (<32 weeks' gestation or 1500 g birthweight) have on average, poorer mathematical skills, attention and working memory (Wolke et al., 2015; Jäkel et al., 2021). These skills are particularly important for educational achievement (Jäkel et al., 2021).

1.2.Deficits in motor skills

Deficits in motor development should also be investigated further in preterm infants. Especially as the development of motor skills in preterm infants is critical for school readiness and daily life (Dathe et al., 2020). Dathe et al. (2020) found that very preterm infants are more likely to have deficits in fine motor and visual motor skills. In their study infants born very preterm had significantly more fine motor deficits before school entry. Also, Bos et al. (2013) state that 40% of preterm infants have mildly or moderately impaired gross and fine motor skills. In their study, both gross and fine motor skills were equally affected. This is substantially more than in term-born individuals (Bos et al., 2013).

Deficits in motor skills usually persist over time in preterm infants (Evensen et al., 2020). This finding was supported by a systematic review of studies on motor development in very preterm and very low birth-weight infants (Evensen et al., 2020). The study examined motor outcomes of individuals from childhood until adolescence and early adulthood, finding consistent challenges in motor functions. (Evensen et al., 2020). Also, Evensen et al. (2004) found that motor deficits persist into adulthood. In their study, one in four individuals, born with very low birth weight (< 1500 g), still had deficits in fine and gross motor skills when they were 14 years old. Although the mean difference compared to term-born individuals was small, similar proportions were found in studies examining motor impairment in childhood.

Still, there is individual variability in the degree of motor deficits among preterm infants. Baumann et al. (2020) note that only a subgroup of very preterm infants develops severe motor difficulties. They found that neonatal complications, long hospital stays, abnormal neurological status and poor relationships between parents and their children predict more severe difficulties in preterm infants. Also, Miquelote et al. (2012) detected a factor that impacts motor development in preterm infants. They found a significant positive association between home environment (the degree of activities and play materials at home) and gross motor skills in 9-month-olds. The same association was found with fine motor skills six months later. Therefore, early assessment and support for those in need is important to ensure better development of preterm infants.

1.3. Social impairments

Social impairments have also been detected in preterm infants. Several studies support that brain areas responsible for face processing, emotion evaluation, and detection of social cues can be altered in preterm infants (Montagna & Nosarti, 2016; Hack & Taylor, 2000). Preterm infants struggle to maintain social interactions and to orient themselves to social stimuli (Field, 1979; Barratt, Roach & Leavitt, 1992). They also show less positive affect when orienting toward faces (De Schuymer et al., 2012). These social deficits persist until adulthood, especially in extremely preterm infants (Linsell et al., 2019).

The neonatal intensive-care unit (NICU) experience, where incubator care limits contact between parents and their newborns, might further strain parent-child interactions (Feldman & Eidelman, 2007; Muller-Nix et al., 2004). Therefore, Ludwig and Welch (2020) argue that preterm birth can disrupt parent-child relationships. However, they also highlight that although the NICU experience poses a risk for parent-child interactions, parents can influence the outcome. Also, according to Jaekel and Wolke (2014), parental behaviour has a substantial impact on child development. Positive parent-child interactions help preterm infants catch up with their term-born peers (Jaekel & Wolke, 2014). This explains why even though adverse neurodevelopment and parent-child interactions are typical for preterm infants, some preterm infants do better than others.

1.4. Dyadic emotional co-regulation and uWECS

Ludwig and Welch (2020) propose that the behaviours observed between mother and infant are not inherited but are the result of autonomic co-conditioning (Ludwig & Welch,2020). Mothers and infants are co-regulated when they display approach behaviours (Ludwig & Welch 2022). During this process, a reflex arc, a neural pathway controlling reflex actions (Saladin, 2015), allows infants to adapt to both their external environment and their internal milieu (Conley et al., 2017). Dyadic emotional co-regulation leads to better mutual parent-child interactions via functional Pavlovian conditioning (Ludwig & Welch, 2020).

Considering this and the importance of good dyadic emotional co-regulation between parents and their children, the Welch Emotional Connection Screen (uWECS) was developed (Goddard et al., 2021). This validated screen assesses parent-child interactions, like sensitivity, facial communication, attraction, and vocal communication (Goddard et al., 2021). By assessing these parent-child interactions it aims to detect disrupted emotional co-regulation reliably and early (Goddard et al., 2021). The uWECS screen was first validated in 2019 (Hane et al., 2019), and according to a study conducted by Jaekel et al. (2024), it assesses dyadic emotional co-regulation reliably irrespective of language and culture. In their study, Jaekel et al. (2024) assessed parent-child interactions of 3–68-month-old infants and their parents with a multilingual team. They gained consistent findings among Finnish and German raters, irrespective of whether the language was understood.

Early assessment of parent-child interactions is important. The quality of dyadic emotional co-regulation between parents and their children has far-reaching consequences into adulthood. Welch et al. (2015) found that better-bonded infants show better neurodevelopment. Also, according to Jaekel et al. (2015), maternal sensitivity is associated with good academic outcomes. Impaired parent-child interactions, again, lead to less optimal neurodevelopment which has further negative consequences for academic success. Jaekel et al. (2015) note that infants born with very low and low birth weight are especially susceptible to negative parenting. In their study, negative parent-child interactions had a severely negative impact on academic success. Negative parent-child interactions also predict more severe motor difficulties in preterm and neonatal at-risk infants (Baumann et al., 2020).

So, several studies support that parent-child interactions influence cognitive development, motor development and academic success. This highlights the importance of dyadic emotional co-regulation when considering possible interventions for preterm infants. Instead, computerised interventions aimed at improving academic success, mathematical skills or executive functions yielded mixed results with either only short-lasting influence on academic outcomes or no improvement at all (Aarnoudse-Moens et al., 2018; van Houdt et al., 2021; Jaekel et al., 2021). So, even though academic support is beneficial, dyadic emotional co-regulation between parent and child might even have a larger impact on academic achievement.

1.5.Taking everything together

In conclusion, research suggests that preterm infants have an increased risk of cognitive, motor and social deficits, i.e., there is a positive association between higher GA at birth and neurodevelopmental outcomes (Bos et al., 2013; Ream & Lehwald, 2018). These deficits typically don’t ease off but are consistently detectable until adulthood (Breeman et al., 2015; Evensen et al., 2020). Social deficits and the NICU experience have further negative consequences on parent-child interactions which might lead to impaired emotional co-regulation (Ludwig & Welch, 2020). Impaired dyadic emotional co-regulation, again, is associated with less optimal neurodevelopment and academic success in preterm infants (Jaekel & Wolke, 2014; Jaekel et al., 2015; Welch et al., 2015). Poor parent-child interactions even predict a higher degree of complications after preterm birth (Baumann et al., 2020).

This highlights the importance of parent-child interactions and dyadic emotional co-regulation. It also explains why computerized interventions mainly have a short-lasting impact on academic outcomes (Aarnoudse-Moens et al., 2018; van Houdt et al., 2021; Jaekel et al., 2021), while parent-child interactions have a long-lasting impact on academic outcomes (Jaekel et al., 2015; Welch et al., 2015). So, lower GA is associated with less optimal neurodevelopment and lower dyadic emotional co-regulation, which again is linked to less optimal neurodevelopment. See Figure 1 for an illustration of the relationships between preterm birth and its potential consequences, including cognitive, motor, and social deficits, lower dyadic emotional co-regulation, and less optimal neurodevelopment. Considering these links the following hypotheses were formulated:

1. Lower gestational age is associated with lower dyadic emotional co-regulation.
2. Lower gestational age is associated with less optimal neurodevelopment.
3. Lower dyadic emotional co-regulation is associated with less optimal neurodevelopment.

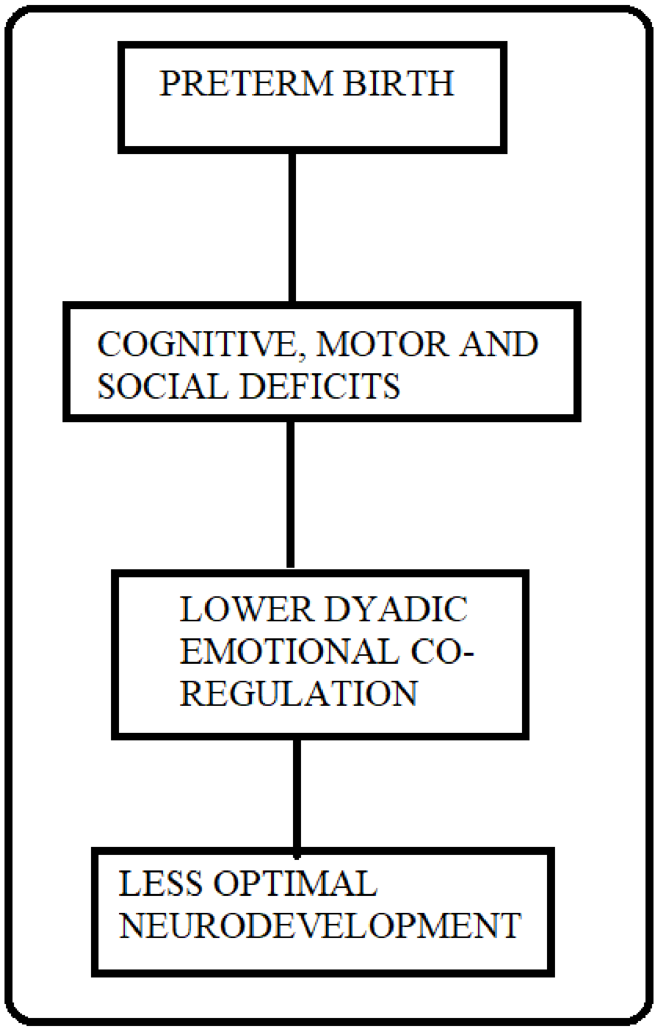

Figure 1: illustrating the connection between preterm birth, neurodevelopment, and dyadic emotional co-regulation.

3.0. Methods

3.1. Ethical Statement

This study was conducted as part of standard neonatal follow-up care in the context of preterm birth at Essen University Hospital. Parents agreed to have their infants' data used anonymously in research. Therefore, individualised informed consent was not required. However, parents were informed about the new dyadic interaction behaviour observation approach, verbally and with information brochures. Additionally, a consent form was provided for the video recordings. Data was pseudonymised and participants had the right to withdraw their participation before and during data collection. The Helsinki and Oviedo Conventions were followed, and the ethical boards of Essen University Hospital and Utrecht University granted ethical approval for the analyses performed in this study.

3.2. Participants

49 mothers/fathers and their preterm infants participated in this study. All infants were 11-38 months old at the BSID assessment. The sampling method was based on opportunity sampling. Demographic and psychosocial background information such as mother’s schooling (low-medium vs high), language barriers (yes/no), child age at BSID assessment, and infant sex (female/male) were additionally controlled for in analyses.

3.3. Measures

3.3.1. Biological and demographic variables

Obstetric records were used to determine gestational age (GA) in weeks, infant biological sex, and age at assessment (chronological age in months corrected for GA at birth). The mother's schooling and language barriers were determined using anamnestic questionnaires at follow-up. Mother's schooling was based on years of education and classified as low-medium (fewer than 10 years) and high (more than 10 years). Language barriers were operationalised in the form of a self-report of mothers not understanding or speaking German, the majority language.

3.3.2. Neurodevelopmental assessment

The third edition of the Bayley Scales of Infant and Toddler Development (BSID) was used to assess infant neurodevelopment (Bayley, 2006; Macha & Petermann, 2015). This screening test is a standardised and valid tool (Bayley, 2006). It is frequently used in the context of preterm birth and takes 30-70 minutes to complete (Bayley, 2006; Macha & Petermann, 2015). Required materials include booklets, record forms, answer sheets, manuals, a manipulative set, and an observation checklist (Bayley, 2006; Macha & Petermann, 2015). The BSID measures behavioural, motor, linguistic, cognitive, and social-emotional milestones (Bayley, 2006; Macha & Petermann, 2015). For the analysis of this study, individual assessments were scheduled for each family and conducted in a quiet environment. A video camera was set up on a tripod to capture a clear view of the child. Sounds and speech were recorded using an integrated microphone. The assessments were administered by trained professionals and conducted following standardised procedures. Raw scores for the cognitive and motor domain subscale were summed up and converted to age-normed standard scores (mean = 100). All data and recordings were entered into a secure database, and scores/recordings were reviewed for completeness and accuracy. Any discrepancies were resolved by re-evaluating the recordings, the data and/or the scoring.

3.3.3. Assessment of emotional co-regulation

Emotional co-regulation was assessed with the universal Welch Emotional Connection Screen (uWECS). This validated standardised behaviour observation paradigm is based on a numerical rating (1.0 – 3.0, Likert scale with 0.25-point steps) and four parameters (Sensitivity/Reciprocity, Facial Communication, Attraction, and Vocal Communication) (Goddard et al., 2021; Hane et al., 2019). For the recordings, parents were asked to hold their child on their lap to ensure good eye contact. They were instructed to interact with their child as they typically would, speaking in their native language. The use of any objects, pacifiers, toys, or food was not allowed. A video camera was set up on a tripod to capture a clear view of the child's and the parent's faces. Sounds and speech were recorded using an integrated microphone. During the observation period, the dyad was left alone in the room, but a staff member remained nearby, within auditory contact. Three-minute videos of parent-child interactions were recorded and rated to compute the uWECS scores. Researchers rated the videos, separately for each parameter (Sensitivity/Reciprocity, Facial Communication, Attraction, and Vocal Communication) (see Appendix A1). Thereafter, the scores were summed up, and a final continuous emotional connection score was obtained (possible range 4-12).

3.4. Statistical Analysis

Gestational age (GA), the uWECS final emotional connection score, and the BSID motor and cognitive standard scores were used for the statistical analysis of this study. A set of five linear regression analyses was performed to determine (1.) whether low GA is associated with low emotional connection scores, (2.) whether low GA is associated with low motor and cognitive standard scores, and (3.) whether low emotional connection scores are associated with low motor and cognitive standard scores. The analysis was performed with SPSS v. 29. Mothers’ schooling, language barriers, infant sex, and age at BSID assessment were included as control variables.

4.0. Results

4.1. Descriptive Statistics

The total sample comprised 77 dyads of which 49 infants were tested with the BSID, and only these infants with complete data on the explanatory variables of interest were included. Accordingly, the final sample comprised 49 dyads. Due to incomplete control variable data, the sample sizes for control analyses varied. The mean GA was 30.41 (SD = 4.43, min = 23, max = 41), and uWECS scores reached a mean of 6.49 (SD = 1.85, min = 4, max = 10). Bayley motor standard scores reached 92.59 (SD = 19.27, min = 45, max = 134) and Bayley cognitive standard scores reached a mean of 93.57 (SD = 21.55, min = 55, max = 145). Additionally, 49% of the infants were female, and the mean age at BSID assessment was 23.12 months (SD = 10.13, min = 11, max = 38). 71.4% of mothers had completed secondary school education (i.e., >10 years of schooling), and 4.1% did not speak German at all (See Table 1). Normal distribution, homoscedasticity and the residuals were examined for all analyses, and all model assumptions were met, except for the uWECS combined total score output, which was not normally distributed (Shapiro-Wilk W = .92, p = .003).

	Total sample (N=49)
Child sex [female, n (%)]	24 (49%)
Gestational age [weeks, M (SD)]	30.41 (4.43)
Age at BSID assessment [months, M (SD)]	23.14 (10.13)
uWECS score [M (SD)]	6.49 (1.85)
Bayley motor standard score [M (SD)]	92.59 (19.28)
Bayley cognitive standard score [M (SD)]	93.57 (21.55)
*Mother's schooling [high, n (%)]	35 (71.4%)
*Mother's language barrier [yes, n (%)]	2 (4.1%)

*Please note that only a subsample of n=40 was assessed

Table 1: Descriptive statistics table including uWECS scores, GA, Bayley motor and cognitive standard scores, and demographic information.

4.2. Hypothesis 1

4.2.1. The association between GA and dyadic emotional co-regulation

When determining the association between GA and dyadic emotional co-regulation the linear regression analysis revealed a statistically insignificant model (B = 0.06, SE = 0.06, β = 0.15, t = 1.06, p = .295) (see Appendix A2), with an R^2 of .023. This finding suggests that GA accounts for approximately 2.3% of the variance in uWECS scores. Including the control variables reduced the sample to n=40. This did not change the estimates of the explanatory variable of interest. However, age at BSID assessment was significantly associated with dyadic emotional co-regulation (See Appendix A3). Figure 2 depicts a scatter plot showing the relationship between gestational age at birth (in weeks) and the uWECS combined total score (on a scale from 4 to 10), which measures dyadic emotional co-regulation across four dimensions (Sensitivity/Reciprocity, Facial Communication, Attraction, and Vocal Communication). Each dot represents one individual data point corresponding to a specific gestational age and score. The x-axis represents GA, and the y-axis shows the uWECS combined total score (see Figure 2).

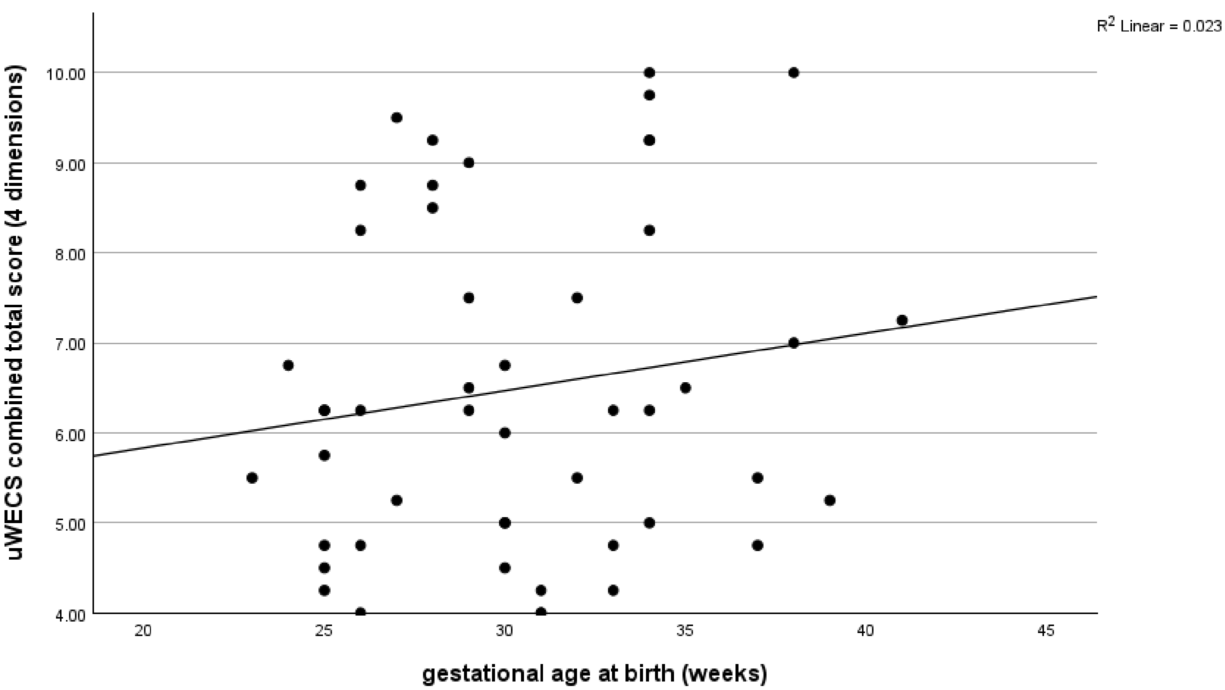

Figure 2: The association between GA and uWECS scores

4.3. Hypothesis 2

4.3.1. The association between GA and Bayley cognitive standard scores

When determining the association between GA and Bayley cognitive standard scores the linear regression analysis revealed a statistically insignificant model (B = 0.66, SE = 0.70, β = 0.14, t = 0.94, p = .352) (see Appendix B1), with an R^2 of .018. This finding suggests that GA accounts for approximately 1.8% of the variance in Bayley cognitive standard scores. Including the control variables reduced the sample to n=40. This did not change the estimates of the explanatory variable of interest. Figure 3 depicts a scatter plot showing the relationship between gestational age at birth (in weeks) and the most recent Bayley cognitive standard score (ranging from 55 to 145). Each dot represents one individual data point corresponding to a specific gestational age and score. The x-axis represents GA, and the y-axis represents the Bayley cognitive standard score (see Figure 3).

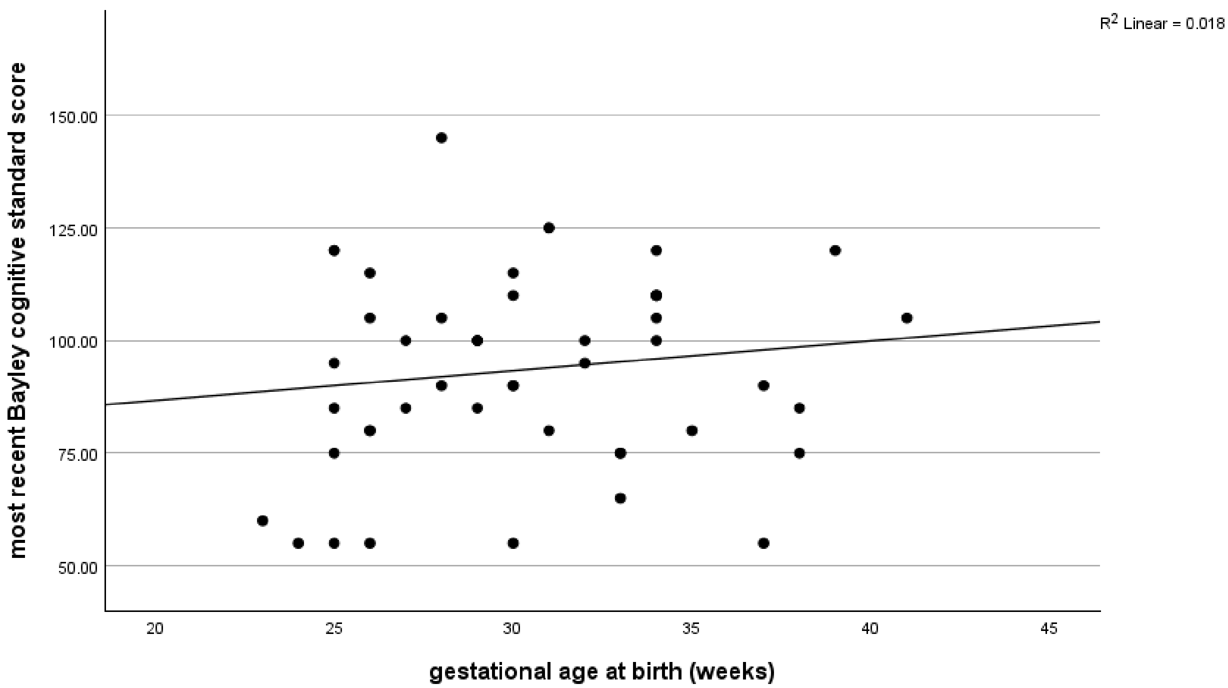

Figure 3: The association between GA and Bayley cognitive standard scores

4.3.2. The association between GA and Bayley motor standard scores

When determining the association between GA and Bayley motor standard scores the linear regression analysis revealed a statistically significant positive effect (B = 1.32, SE = 0.60, β = 0.30, t = 2.18, p = .034) (see Appendix B2), with an R^2 of .092. This finding suggests that GA accounts for approximately 9.2% of the variance in Bayley motor standard scores. However, the association became insignificant when control variables were included (B = 0.74, SE = 0.71, β = 0.18, t = 1.04, p = .305) (See Appendix B3). Including the control variables reduced the sample to n=40. Figure 4 depicts a scatter plot showing the relationship between gestational age at birth (in weeks) and the most recent Bayley motor standard score (ranging from 45 to 134). Each dot represents one individual data point corresponding to a specific gestational age and score. The x-axis represents GA, and the y-axis represents the Bayley motor standard score (see Figure 4).

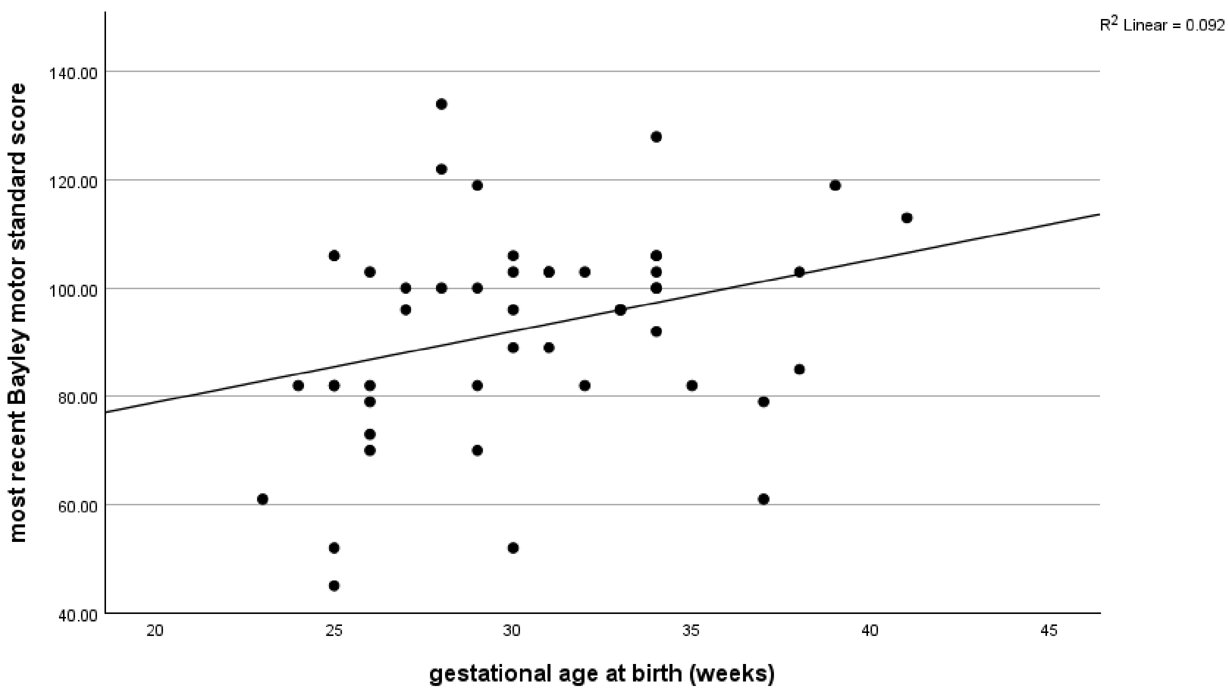

Figure 4: The association between GA and Bayley motor standard scores

4.4. Hypothesis 3

4.4.1. The association between dyadic emotional co-regulation and Bayley cognitive standard scores

When determining the association between dyadic emotional co-regulation and Bayley cognitive standard scores the linear regression analysis revealed a statistically insignificant model (B = 2.27, SE = 1.67, β = 0.195, t = 1.36, p = .179) (see Appendix C1), with an R^2 of .038. This finding suggests that dyadic emotional co-regulation accounts for approximately 3.8% of the variance in Bayley cognitive standard scores. Including the control variables reduced the sample to n=40. This did not change the estimates of the explanatory variable of interest. Figure 5 depicts a scatter plot showing the relationship between the uWECS combined total score (on a scale from 4 to 10) and the most recent Bayley cognitive standard score (ranging from 55 to 145). Each dot represents one individual data point corresponding to specific scores. The x-axis represents the uWECS combined total score, and the y-axis represents the Bayley cognitive standard score (see Figure 5).

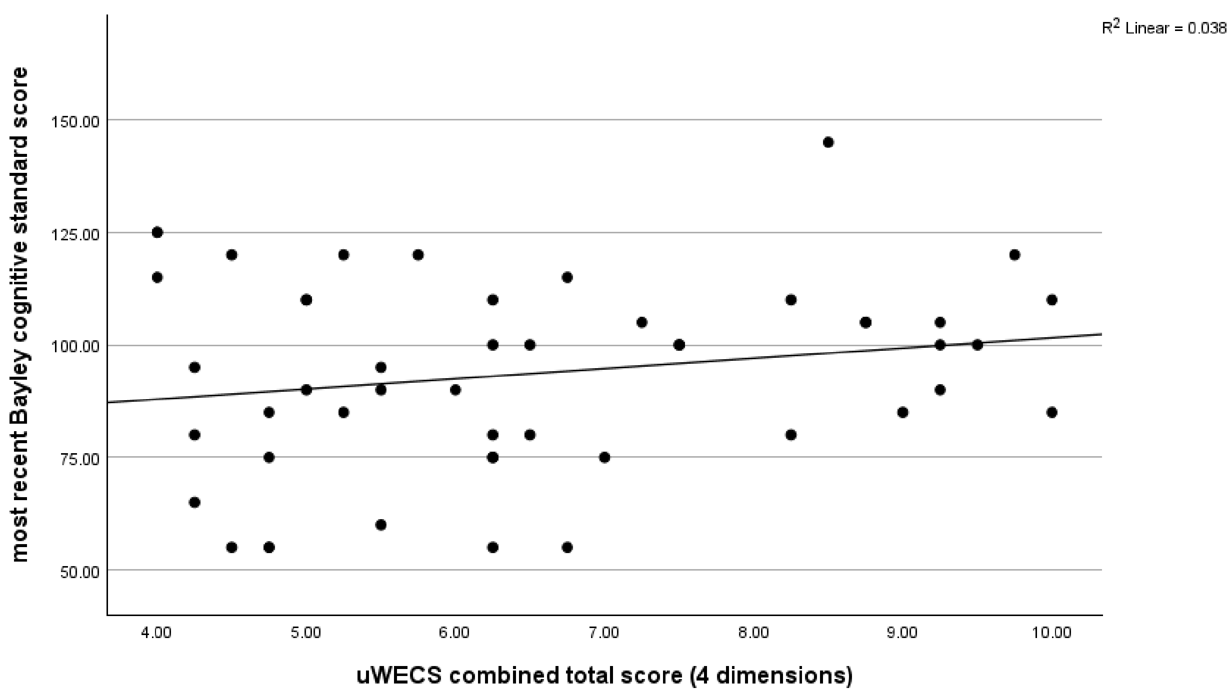

Figure 5: The association between uWECS scores and Bayley cognitive standard scores

4.4.2. The association between dyadic emotional co-regulation and Bayley motor standard scores

When determining the association between dyadic emotional co-regulation and Bayley motor standard scores the linear regression analysis revealed a marginally significant positive effect (B = 2.85, SE = 1.46, β = 0.27, t = 1.95, p = .057) (see Appendix C2), with an R^2 of .075. This finding suggests that dyadic emotional co-regulation accounts for approximately 7.5% of the variance in Bayley motor standard scores. The model became insignificant when control variables were included (B = 1.96, SE = 1.56, β = 0.21, t = 1.25, p = .218) (see Appendix C3). Including the control variables reduced the sample to n=40. Figure 6 depicts a scatter plot showing the relationship between the uWECS combined total score (on a scale from 4 to 10) and the most recent Bayley motor standard score (ranging from 45 to 134). Each dot represents one individual data point corresponding to specific scores. The x-axis represents the uWECS combined total score, and the y-axis represents the Bayley motor standard score (see Figure 6).

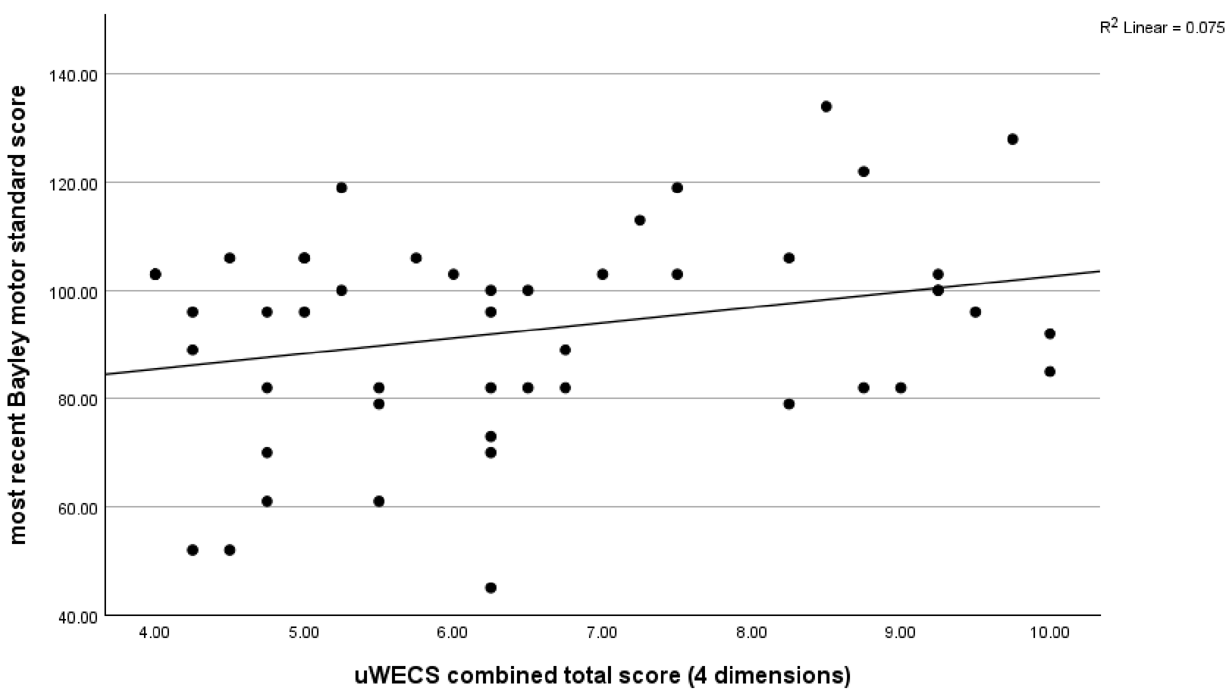

Figure 6: The association between uWECS scores and Bayley motor standard score

5.0. Discussion

This study examined the associations between gestational age (GA), dyadic emotional co-regulation, and neurodevelopmental outcomes in preterm infants. Infant GA ranged from 23 to 41 weeks, as the sample included 6 term-born infants with other neonatal risks such as asphyxia. Three a-priori-defined hypotheses examined (1) whether low GA is associated with lower dyadic emotional co-regulation, (2) whether low GA is associated with less optimal neurodevelopment, and (3) whether lower dyadic emotional co-regulation is associated with less optimal neurodevelopment.

5.1. Key findings

5.1.1. Hypothesis 1

The first hypothesis proposed that low GA is associated with low dyadic emotional co-regulation (measured with uWECS). The results revealed no statistically significant association between GA and dyadic emotional co-regulation. GA accounted for only 2.3% of the variance in uWECS scores. This finding implies that prematurity is not a strong predictor of dyadic emotional co-regulation. Instead, age at BSID assessment was significantly associated with dyadic emotional co-regulation, suggesting a potential influence of infant age, i.e., maturity, on dyadic emotional co-regulation.

However, this finding contrasts with previous research indicating that preterm birth negatively impacts parent-child interactions (Feldman & Eidelman, 2007; Muller-Nix et al., 2004). Possibly the small sample size led to a Type II error, where the study failed to detect meaningful associations that might exist. This conclusion is supported by the slope of the regression line, which suggests a positive trend between GA and dyadic emotional co-regulation. However, it is also possible that other factors influenced the results. For example, the parent-centred care provided at Essen University Hospital, including music therapy and kangaroo mother care, might have mitigated the impact of prematurity on dyadic emotional co-regulation. Receipt of these therapies was not documented in the available data and could therefore not be controlled for in analyses.

5.1.2. Hypothesis 2

The second hypothesis proposed that lower GA is associated with less optimal neurodevelopment, specifically lower BSID motor and cognitive standard scores. The analysis found a statistically significant association between GA and Bayley motor standard scores, with GA explaining 9.2% of the variance. Additionally, the slope of the regression line did indicate a positive association between GA and motor standard scores. This suggests that GA has an impact on motor development. This is consistent with existing literature highlighting delayed motor development in preterm infants (Cheong et al., 2008; Dathe et al., 2020). Therefore, the positive association between GA and motor development was not surprising.

When control variables were included, the association between GA and Bayley motor standard scores became insignificant. This suggests that factors such as the mother’s schooling and language barriers as well as infant age at assessment may play a more crucial role in motor development than GA alone. Although none of the control variables gained significance individually, their combined influence might be substantial, potentially overshadowing the effect of GA. The interplay of various socio-demographic factors and the holistic developmental environment might be critical in shaping functional neurodevelopmental outcomes.

No statistically significant association between GA and Bayley cognitive standard scores was found, accounting for only 1.8% of the variance. This suggests that GA might not be a reliable predictor of cognitive development. Instead, other developmental or environmental factors might influence cognitive development. This result is surprising as many studies focus on cognitive deficits in preterm infants. For example, Volpe (2009) highlights that cognitive deficits represent the most common form of neurodevelopmental problems in preterm infants. Also, several other studies found significantly more cognitive deficits in preterm infants compared to term-born peers (Johnson et al., 2011; Quigley et al., 2012; Jaekel, Baumann & Wolke, 2013; Patel, 2016).

The different results might be due to differing methodologies as not all cited studies examining the association between GA and cognitive development, used the BSID for assessments. However, the small sample size increased the risk for Type II error, and the slope of the regression line suggests a positive trend between GA and cognitive standard scores. So, the link between GA and cognitive neurodevelopment might become more visible and significant if a greater sample size was applied.

Also, the large distribution of age at the BSID assessment might have impacted the results. Additionally, the distribution between cognitive standard scores was larger than the distribution between motor standard scores. So, there was greater variability in cognitive performance among infants. Greater variability can make it more challenging to detect significant associations as the data points are spread out. This might explain why no significant association between GA and cognitive standard scores was reached, while GA and motor standard scores were significantly associated.

There was also a substantial proportion of mothers with a more than 10 years of school education. This might have mitigated the negative impact of prematurity on neurodevelopment. Higher maternal educational levels support child development due to better nutrition, more stimulating home environments, and greater access to resources (Bradley & Corwyn, 2002). Particularly the stimulating home environment typically provided by mothers with longer schooling has been linked to better neurodevelopment (Miquelote et al., 2012). So, the positive impact of these benefits might have mitigated the negative impact of preterm birth and thereby improved BSID outcomes.

5.1.3. Hypothesis 3

The third hypothesis proposed that low dyadic emotional co-regulation is associated with less optimal neurodevelopment, specifically lower Bayley motor and cognitive standard scores. The results indicated a marginally significant association between dyadic emotional co-regulation and Bayley motor standard scores, explaining 7.5% of the variance. Additionally, the slope of the regression line indicated a positive trend between dyadic emotional co-regulation and motor standard scores. So, this is a preliminary indication that emotional co-regulation plays a role in motor development. This is not surprising as previous research found a link between parent-child interactions and neurodevelopment (Jaekel & Wolke, 2014; Ludwig & Welch, 2020).

Nonetheless, the association became insignificant when control variables were considered, implying that factors like maternal education and language barriers might exert a stronger influence on motor development than dyadic emotional co-regulation alone. Although none of the control variables were individually significant, their combined impact could be considerable. The interaction of various socio-demographic factors and the overall developmental environment may play a crucial role in shaping neurodevelopmental outcomes.

No significant association was found between dyadic emotional co-regulation and Bayley cognitive standard scores. So, the impact of emotional co-regulation on cognitive development was less clear. Still, previous research emphasized the importance of parent-child interactions for neurodevelopment (Jaekel & Wolke, 2014; Ludwig & Welch, 2020). Better bonded infants and maternal sensitivity was linked to better neurodevelopment and more positive academic outcomes (Jaekel et al., 2015; Welch et al., 2015). Conversely, impaired parent-child interactions were linked to suboptimal neurodevelopment (Jaekel et al., 2015).

It is possible that the small sample size led to a Type II error. Therefore, future studies with larger sample sizes are necessary to clarify the relationship between emotional co-regulation and neurodevelopment. Especially, as the slope of the regression line indicated a positive trend between dyadic emotional co-regulation and cognitive standard scores. Also, the greater variability in cognitive performance among infants, coupled with a wide age range at BSID assessment, may have masked potential associations, and the high maternal educational level may have played a protective role. Longer maternal education supports child development through better nutrition, stimulating environments, and greater access to resources (Bradley & Corwyn, 2002).

5.2. Future Research and Clinical Implications

The significant association between GA and motor development indicates that preterm infants are at risk for less optimal neurodevelopment and thus need further support. Additionally, the marginally significant association between dyadic emotional co-regulation and Bayley motor standard scores supports that dyadic emotional co-regulation may be linked to less optimal neurodevelopment. This highlights the need for further research with larger sample sizes, to support these findings. Additionally, it is crucial to determine which factors predict less optimal neurodevelopment so that appropriate interventions and support can be provided. Randomized controlled trials would be particularly beneficial for establishing such causal conclusions. Future research should also determine which interventions are most effective in maximising developmental outcomes. The best way to examine the benefit of different interventions would be via longitudinal studies.

So far, computerized interventions aimed at improving academic success, mathematical skills or executive functions have mainly yielded short-term academic improvement or no improvement at all (Aarnoudse-Moens et al., 2018; Jaekel et al., 2021; van Houdt et al., 2021). Instead, parent-child interactions are strongly linked to academic success and neurodevelopment in preterm infants (Jaekel et al., 2015; Welch et al., 2015). Positive parenting is not only linked to better academic success in preterm infants, but preterm infants are also particularly susceptible to negative parenting, yielding particularly negative academic outcomes (Jaekel et al., 2015).

So, instead of targeting cognitive skills directly, evidence-based interventions that improve parent-child interactions are needed. Figure 7 shows the possible consequences of preterm birth and suggests that interventions tackling dyadic emotional co-regulation could improve the outcomes. Apart from music therapy and kangaroo mother care, the Family Nurture Intervention (FNI) shows promise in improving dyadic emotional co-regulation by strengthening parent-child interactions via Pavlovian co-conditioning (US/CRs) of the autonomic nervous system (ANS) (Ludwig & Welch, 2019). This underscores the potential value of early interventions that focus on enhancing parent-child interactions rather than solely addressing cognitive skills.

Future research should investigate the link between dyadic emotional co-regulation and neurodevelopment further by combining uWECS assessments with the FNI intervention as part of randomized-controlled trials. In a longitudinal study, uWECS assessments and BSID assessments could be followed by an intensive period of FNI interventions versus treatment as usual, and regular uWECS and BSID follow-ups. This would make it possible to determine a possible long-term benefit of the FNI intervention.

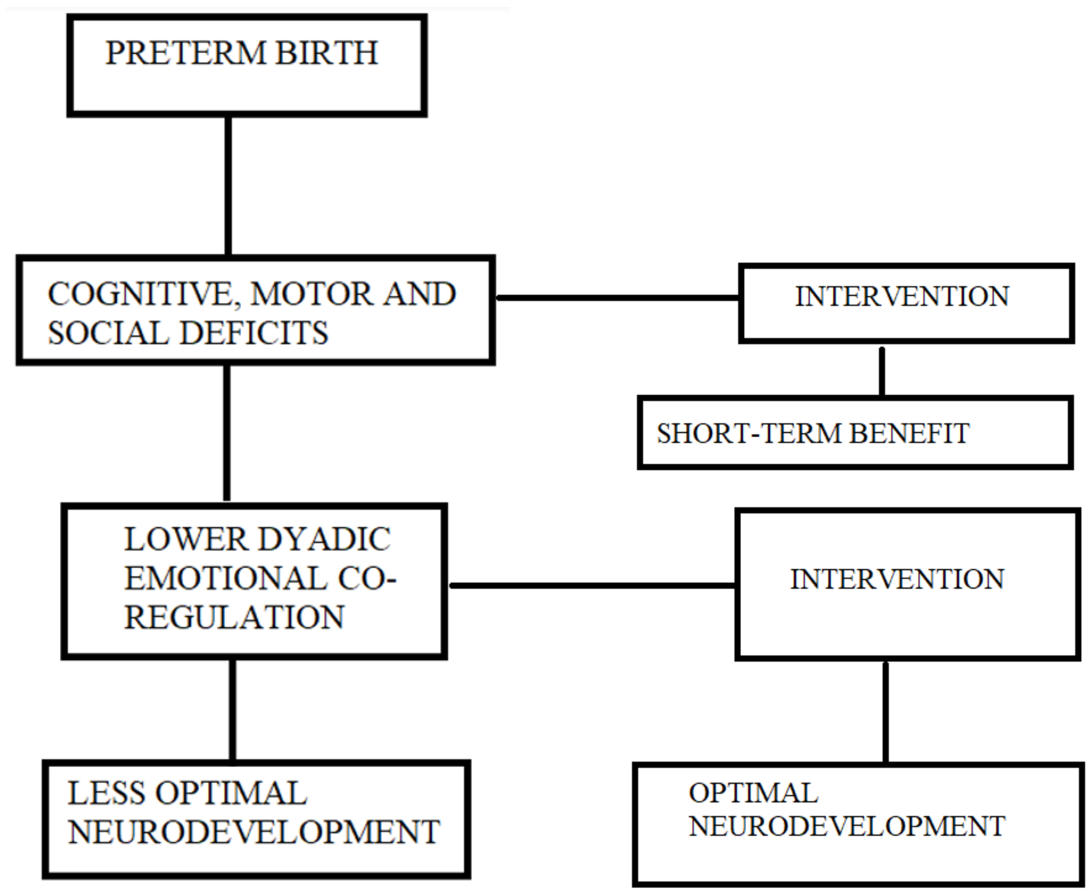

Figure 7: indicating possible ways to improve neurodevelopmental outcomes

5.3. Limitations

This study had several limitations. The generalizability of the findings was limited due to the small and selective sample size. The use of opportunity sampling might have introduced selection bias yielding no representative sample of the general population - there was a substantial proportion of mothers with more than ten years of schooling. Additionally, the study design, even though longitudinal, did not allow for the determination of causality. Future research should replicate these findings with randomised controlled trials and larger samples. Longitudinal studies would also be beneficial for understanding the long-term impact of GA on dyadic emotional co-regulation and neurodevelopmental outcomes, as well as the impact of dyadic emotional co-regulation on neurodevelopmental outcomes. Also, additional control variables, such as parental mental health and socioeconomic status, could provide more comprehensive results.

5.4. Conclusion

This study explored the relationships between GA, dyadic emotional co-regulation, and neurodevelopmental outcomes in preterm infants. Results showed that GA was significantly associated with motor development. Additionally, dyadic emotional co-regulation showed a marginally significant association with motor development. So, lower GA and lower dyadic emotional co-regulation were linked to less optimal motor development. However, the small sample size and the substantial proportion of long school education among mothers might have rendered the significant associations insignificant when control variables were included. Also, possibly due to the small sample size and the large distribution between cognitive standard scores, cognitive development was not significantly associated with GA and dyadic emotional co-regulation.

Even though future studies should investigate the link between GA, dyadic emotional co-regulation, and cognitive development with larger sample sizes, the results of the present study support that preterm infants are at greater risk for adverse motor development. There was also a preliminary indication that stronger dyadic emotional co-regulation is beneficial for neurodevelopmental outcomes. Interventions that foster better parent-child interactions are needed for preterm infants. This might mitigate the negative impact preterm birth has on neurodevelopment.

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8.0. Appendix

Appendix A1: uWECS Score Sheet

V.1

uWECS SCORE SHEET

GERMAN - DEUTSCH

Universal Welch Emotional Connection Screen - clear explicit language

Kind auf dem Schoß des Elternteils, sie sehen einander an, 3 Minuten lang.
Keine Gegenstände, Spielzeuge, Lebensmittel.

1

Mama und Kind wollen beide sehr nah sein

1	1.25	1.5	1.75	2	2.25	2.5	2.75	3

2

Mama und Kind wollen einander beide etwas sagen.
Mama will wissen was Kind sagen will. Kind will wissen was Mama sagen will.

1	1.25	1.5	1.75	2	2.25	2.5	2.75	3

3

Mama und Kind sehen einander ins Gesicht.
Mama will wissen was Kind fühlt. Kind will wissen was Mama fühlt.

1	1.25	1.5	1.75	2	2.25	2.5	2.75	3

4

Mama weiß immer was Kind fühlt. Kind weiß immer was Mama fühlt.

1	1.25	1.5	1.75	2	2.25	2.5	2.75	3

Fühlen Mama und Kind beide etwas sehr Gutes weil sie zusammen sind?

☐ **Nein** ☐ **Ja**

Appendix A2: Hypothesis 1, SPSS output

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.153[a]	.023	.002	1.84857	.023	1.120	1	47	.295

a. Predictors: (Constant), gestational age at birth (weeks)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	4.559	1.849		2.466	.017
	gestational age at birth (weeks)	.064	.060	.153	1.058	.295

a. Dependent Variable: uWECS combined total score (4 dimensions)

Appendix A3: Hypothesis 1, SPSS output with control variables

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.468[a]	.219	.105	1.76259	.219	1.911	5	34	.118

a. Predictors: (Constant), age_Bayley, child sex, mother's schooling, Mother's language barrier, gestational age at birth (weeks)

b. Dependent Variable: uWECS combined total score (4 dimensions)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.934	3.432		.564	.577
	gestational age at birth (weeks)	.024	.071	.054	.332	.742
	child sex	.870	.600	.235	1.451	.156
	mother's schooling	.333	.799	.065	.417	.679
	Mother's language barrier	-1.399	1.858	-.119	-.753	.457
	age_Bayley	.074	.030	.388	2.470	.019

a. Dependent Variable: uWECS combined total score (4 dimensions)

Appendix B1: Hypothesis 2, SPSS output, cognitive

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics: R Square Change	F Change	df1	df2	Sig. F Change
1	.136[a]	.018	-.002	21.58014	.018	.885	1	47	.352

a. Predictors: (Constant), gestational age at birth (weeks)

Coefficients[a]

Model		Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	73.481	21.581		3.405	.001
	gestational age at birth (weeks)	.661	.702	.136	.941	.352

a. Dependent Variable: most recent Bayley cognitive standard score

Appendix B2: Hypothesis 2, SPSS output, motor

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.303[a]	.092	.072	18.56504	.092	4.743	1	47	.034

a. Predictors: (Constant), gestational age at birth (weeks)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	52.572	18.566		2.832	.007
	gestational age at birth (weeks)	1.316	.604	.303	2.178	.034

a. Dependent Variable: most recent Bayley motor standard score

Appendix B3: Hypothesis 2, SPSS output, motor with control variables

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.237[a]	.056	-.083	17.84537	.056	.403	5	34	.843

a. Predictors: (Constant), age_Bayley, child sex, mother's schooling, Mother's language barrier, gestational age at birth (weeks)

b. Dependent Variable: most recent Bayley motor standard score

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	70.708	34.749		2.035	.050
	gestational age at birth (weeks)	.676	.721	.169	.938	.355
	child sex	2.624	6.070	.077	.432	.668
	mother's schooling	-2.052	8.090	-.043	-.254	.801
	Mother's language barrier	-6.938	18.816	-.064	-.369	.715
	age_Bayley	.186	.302	.106	.616	.542

a. Dependent Variable: most recent Bayley motor standard score

Appendix C1: Hypothesis 3, SPSS output, cognitive

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics: R Square Change	F Change	df1	df2	Sig. F Change
1	.195[a]	.038	.018	21.36418	.038	1.858	1	47	.179

a. Predictors: (Constant), uWECS combined total score (4 dimensions)

Coefficients[a]

Model		Unstandardized Coefficients: B	Std. Error	Standardized Coefficients: Beta	t	Sig.
1	(Constant)	78.823	11.243		7.011	<,001
	uWECS combined total score (4 dimensions)	2.271	1.666	.195	1.363	.179

a. Dependent Variable: most recent Bayley cognitive standard score

Appendix C2: Hypothesis 3, SPSS output, motor

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics: R Square Change	F Change	df1	df2	Sig. F Change
1	.274[a]	.075	.055	18.73485	.075	3.809	1	47	.057

a. Predictors: (Constant), uWECS combined total score (4 dimensions)

Coefficients[a]

Model		Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	74.071	9.859		7.513	<,001
	uWECS combined total score (4 dimensions)	2.852	1.461	.274	1.952	.057

a. Dependent Variable: most recent Bayley motor standard score

Appendix C3: Hypothesis 3, SPSS output, motor with control variables

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.246[a]	.060	-.078	17.80322	.060	.438	5	34	.819

a. Predictors: (Constant), uWECS combined total score (4 dimensions), mother's schooling, Mother's language barrier, child sex, age_Bayley

b. Dependent Variable: most recent Bayley motor standard score

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	88.225	25.703		3.433	.002
	child sex	-.401	5.985	-.012	-.067	.947
	mother's schooling	-2.602	8.092	-.055	-.322	.750
	Mother's language barrier	-7.115	18.710	-.066	-.380	.706
	age_Bayley	.092	.326	.052	.281	.780
	uWECS combined total score (4 dimensions)	1.768	1.729	.192	1.023	.314

a. Dependent Variable: most recent Bayley motor standard score