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Impacts of premature birth and low birthweight on the development of language and executive function

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The increasing rate of survival of preterm newborns raises many questions given that preterm and low-birthweight children are at risk for impaired development of various cognitive abilities. The purpose of this article is to summarise the research evidence concerning the outcomes of language and executive function development in this risk group. The authors will discuss what influences neonatal factors and early neurological injuries have on the late outcomes of these high-risk children from the perspective of potential protective factors and intervention.

Keywords: premature birth, low birthweight, perinatal complications, executive functions, language development

Introduction

Preterm birth and low birthweight are the most frequent perinatal risks endangering a child's development. Normally 37 to 43 weeks in length, the gestational period spans the time between fertilisation and birth. An infant born before the thirty-seventh week is considered premature. In 2019, the frequency of preterm birth was 8.3 % in Hungary. The degree of risk depends on how immature and tiny the baby is. Both gestational age and birthweight are used as a basis for classification of preterm neonates. According to maturity, the preterm birth categories are the following: extremely early (<28 weeks of gestation); very early (28-32 weeks), and moderate to late (32-37 weeks). The percentages of preterms falling to each of the above categories are 4.9%; 10.6%; 84.5%, respectively (KSH 2021).

Concerning birthweight, infants are born with extremely low birthweight (<1000 g); very low birthweight (1000-1499 g), and low birthweight (1500-2499 g). The percentages in each category are the following: 7.4%; 8.7%; 82.9% (KSH 2021). Complications associated with premature birth are the fourth leading cause of infant mortality. A wide variety of factors underlie premature birth including physical illness or psychosocial hazards affecting the mother, organic anomalies or disorders of the uterus, twin (multiple) pregnancies, maternal age (below 16 or over 35), or multiple prior abortions. Fetal factors may be infections as well as various impediments of development, including excess amniotic fluid. The development of children born prematurely or with low birthweights may deviate from the norms, therefore it is essential to follow the progress of these infants with a mind to their individual developmental paces.

Perinatal complications and development of the central nervous system (CNS)

The immature organism is more vulnerable to diseases affecting the respiratory organs (respiratory distress-syndrome, RDS), the central nervous system, and the sensory systems. The prevalence of intraventricular haemorrhage (IVH) among the ELBW and the VLBW infants is 50% and 20%, respectively (Balla & Szabó, 2013). The more immature the baby is, the more severe IVH tends to be. Among ELBW, the prevalence of mild IVH (stages I and II) is 21.3%, and severe IVH (stages III and IV) is 12.6% (Bolisetty et al., 2014).

Periventricular leukomalacia (PVL) is a typical white-matter injury in preterm infants which, along with the more severe degrees of IVH, may cause cerebral paresis and the loss of oligodendroglial cells (Mulder et al., 2009).

Bronchopulmonary dysplasia (BPD), a chronic lung disease, is also a common concomitant of premature birth and occurs in more than 40% of ELBW preterms (Glass et al., 2015). Ventilatory therapy and oxygen toxicity may cause diffuse damage of alveoli and serious pulmonary fibrosis (Hargitai & Marton, 2018). Ventilatory therapy (mostly by hyperoxia) may cause an abnormal vascular proliferation of the immature retina too, leading to an ocular disease called retinopathy of prematurity (ROP) (Behrman & Butter, 2007).

The development of the central nervous system in preterm infants deviates from that found in their full-term counterparts. The gyrification occurs between 26-40 weeks of gestation, therefore in very immature preterms the brain surface is nearly flat. Before the thirty-second week of gestation, oligodendrocytes are in their early stage of development and are very sensitive to harmful environment. Disturbances of brain maturation may cause axon and astrocyte death (Back, 2015). Anomalies are often found in the structure of both the white and the grey matter. The entorhinal cortex and the corpus callosum can be thinner (Feldman et al., 2012) and the volume of the hippocampus as well as that of the cerebellum can be smaller than in term newborns (de Kieviet et al., 2012). Among low-risk preterm infants, no significant differences in the volume of the dorsal prefrontal and the orbitofrontal lobe were found (Peterson et al., 2000). The effects of prematurity on the central nervous system development seem to differ across the brain regions. One region may be affected severely while others may remain intact, and there are compensatory processes, such as plasticity, reorganisation processes, and environment factors (e.g., cognitive stimulation), which influence the development of the CNS.

Cognitive development in preterm children

Intelligence

It is apparent that the neurodevelopmental consequences of premature birth affect the development of cognitive functions and academic abilities, although the bulk of research evidence is not consistent. The IQs of the VLBW/ELBW preterm children as a group were found to fall into the average (Grunewaldt et al., 2013; Nagy et al., 2021) or low-average zone (StÅlnacke et al., 2019). However, according to a recent meta-analysis reviewing 71 studies, the IQ's of the very preterm children significantly lagged behind those of term comparison groups (Twilhaar et al., 2018). The authors of the meta-analysis also noted the heterogeneity of results across studies. The IQ of an individual is a composite measure which reflects the levels of a host of various cognitive abilities which are differentially affected by the neurodevelopmental sequelae of prematurity.

IQ per se does not give much information about the difficulties risk children encounter in their academic progress. If the aim is to understand and, ultimately, remediate the delays and disorders of cognitive development in preterm children it is far more fruitful to focus on specific abilities. Language and executive functions are among the abilities of paramount importance for both academic achievement and managing everyday life.

Do premature birth and low birthweight have a negative impact on children's learning and linguistic development?

Researchers have established four separate categories of infants based on the predominant development trends:

- spontaneous development
- development gap – predominantly motor development problems
- minor neurological deficits and/or mild learning problems
- profound central nervous system dysfunctions (disabilities) serious problems with living skills

A study of that included care of premature infants with birthweights of less than 1000 grams found the following (Müller-Rieckmann, 2001):

- one fifth of these premature babies had profound central nervous system deficits resulting in intellectual disabilities and serious difficulties with living skills
- few cases displayed mild neurological deficits and/or slight learning impairments
- for about 50 percent, deficits in motor development, particularly in gross motor skills, were clearly demonstrable
- good spontaneous development was observed for half of the children in this group

A vast number of research projects have begun to ascertain the developmental abilities of premature and low birthweight babies and the results are quite diverse. A series of domestic and international studies have found that if even extremely low weight preemies do not have serious neurological deficits, they will be normal in intelligence if raised and socialised in an appropriate family environment. By the time they are ready for school, they can catch up to their peers who were born with normal birthweights. Another significant domestic research project (Ittzésné Nagy et al., 1991), involved formerly premature babies (who were an average of 9.6 years old at the time of the study). Based on parental information, they found three typical behaviour patterns that were significant: extremes in activeness, mood swings and demanding behaviour.

Henry Truby began researching the phenomenon of fetal language in 1975, at which time he linked the development of speech initiative and preverbal abilities and reported that language development was underway before birth (Lengyel, 1981). According to Truby, a fetus is not merely a passive recipient of the patterns of maternal speech but also a ‘practitioner’ of the motor abilities needed to emit sound as a premature infant or a full-term neonate. Truby’s research raised a number of issues that went far beyond his immediate research: the roots of a communication deficit which go back to the pre-birth development phase. The analytical school of modern Hungarian psychological literature (relationship analysis) investigates active communication between fetus and mother. This body of literature urges us to move beyond the concept that the first nine months of life in the womb are a low-stimulus period.

There are many factors that go into determining the development of preverbal abilities. All congenital deficits and injuries in the initial weeks and months of life will affect the child’s development, including his/her preverbal and language skills. The deficits can be transitional in that they interrupt development for only brief periods. The child can bridge the gap that results from the consequence of the deficit as he/she gets older. However, sometimes processes are irreversible: when left to his or her own devices, the child will be unable to compensate, as can be seen by the many children who require some form of assistance or development therapy.

Throughout over forty years of investigation, researchers have been unable to offer a clear and acceptable answer. Several studies have pointed out that when the linguistic development of these children is compared to that of children born at term and with normal weight, they show a delay. Other researchers have drawn exactly the opposite conclusion, finding that delayed language development was no more common among preemies than among full-term babies, or if there were early differences, they could be made to disappear from the age of 2 or 3 on if diagnosed in a timely manner.

According to empiric Hungarian data, studies of speech perception and speech comprehension that were carried out when examining children to determine their readiness for school found that very low birthweight babies were worse performers than children born at term and with normal weight. Perception and comprehension were found to be related to intelligence test outcomes which suggested that speech development was a good predictor of later cognitive performance (Beke et al., 2001).

In 1998, Tanya M. Gallagher and Kenneth L. Watkin published an article (Gallagher et al., 1998) in which they concluded that numerous language difficulties are not apparent among children born prematurely, for possible impacts on the nervous system are not generally manifest until language development reaches the expression level.

When studying parental empathy and its impacts on the child's communication development, researchers found that the communicative attitudes of mothers and fathers – in combination with their emotional communication abilities (empathy levels) – do influence the socio-cognitive skills of the children including the development of linguistic communication. In her investigations conducted in 2001, Júlia Kádár-Sugár (Kádár-Sugár, 2001) found that, when combined with the parent's emotional communication, interactions involving the child's activities and desire to communicate determine 'vocal' communication and speech development. Thus, it was possible to demonstrate the defining role of the early social roots to speech development and the role the continuity of speech development plays in socio-cognitive development.

The object of our research was to compare the preverbal development levels of six- to eighteen-month-old children who were born preterm but with satisfactory birthweights or born prematurely with very low (including extremely low) birthweights. This study was conducted while focusing on both the productive and the receptive sides. (Nagy & Szanati, 2008) We found no correlations between duration of gestation, birthweight and the development level of preverbal abilities, nor did we find significant gender differences in the children's performances. As regards the order of birth, we found that the communication abilities of first children were farther behind those of second children. We have verified that possible deficits in the preverbal abilities of children born prematurely (with normal, quite low, and extremely low birthweights) can be discovered at a very early age, in infancy. We did not verify that low birthweight and the shorter gestation period have primary influences on the level of linguistic development among children born prematurely. We did not find difference between results of speech production and speech comprehension and results of toddlers (aged twelve to eighteen months) better than infants aged six to eleven months. It appears that qualification of mothers determines preverbal abilities of children. Children with extremely low birthweights achievement are not equalised.

It has been described in the literature that early exposure to the extrauterine environment can be advantageous for neurodevelopment. The emphasis mostly lies on the fact that preterm birth may have an unfavourable effect on numerous aspects of development such as cognition, language, and behaviour. Various studies reported atypical language development in preterm born children in the preschool years but also in school-aged children and adolescents. This review gives an overview of the course of language development and examines how prematurity can lead to atypical linguistic performances. They mainly focus on environmental and neurophysiological factors influencing preterm infant neuroplasticity with potential short- and long-term effects on language development. According to the discussed research, it can be concluded that during the first years of life, a period that is crucial for gaining adequate social and adaptive skills, language development can be affected by preterm birth. Altered brain maturation, leading to atypical functional organization and structural changes, was associated with abiding language impairments. In addition, environmental factors such as a long stay in a NICU with underexposure to significant auditory stimuli and nonoptimal infant-caregiver interactions have been associated with weaker language outcomes. Several intervention methods have proven useful in promoting the parent-child relationship, resulting in better interactions which have positive effects on cognitive and language development of children born preterm (Vandormael et al., 2019).

The aim of another research project was to study whether prematurity, associated with prenatal and neonatal risk factors, affects specific literacy skills among school children born at a very low gestational age of <32 weeks (VLGA). The study group comprised 76 followed VLGA children born and 51 term controls. The conclusion was that very low gestational age school children performed poorer in reading comprehension and spelling than term children. In addition, poor fetal growth in VLGA children was associated with literacy problems. (Heikkinen et al., 2020)

Very low birth weight, preterm infants have a higher rate of language impairments compared to children who were born full term. The early identification of those preterm infants who are at risk of language delay is essential to guide early intervention during the period of optimal neuroplasticity. This study examined near-term structural brain magnetic resonance imaging (MRI) and white matter microstructure assessed on diffusion tensor imaging (DTI) in relation to early language development in children born very preterm. A total of 102 very low birth weight neonates (birthweight≤1500g, gestational age ≤32-weeks) were recruited to participate. Language development was assessed using the Bayley Scales of Infant-Toddler Development-III at 18 to 22 months adjusted age. Children with cerebellar asymmetry had lower receptive language subscores. Infants at high risk for language impairments were predicted based on regional white matter microstructure on DTI with high accuracy (sensitivity, specificity) for composite, expressive, and receptive language. The conclusion was reached that multivariate models of near-term structural MRI and white matter microstructure on DTI may assist in identification of preterm infants at risk for language impairment, thereby guiding early intervention (Vassar et al., 2020).

The question remains of whether preterm infants have a higher risk of language delay throughout childhood. The ability to integrate audiovisual speech information is associated with language acquisition in term infants; however, the relation is still unclear in preterm infant. Imafoku et al. found that preterm infants did not clearly show visual preference for the congruent audiovisual display at any age, whereas term infants looked at the congruent audiovisual display longer than the incongruent audiovisual display at six and eighteen months. Preterm infants' receptive and expressive vocabulary scores were lower than those of term infants at twelve and eighteen months. Furthermore, the proportion of looking time toward the congruent audiovisual display at six months was positively correlated with receptive vocabulary scores at twelve and eighteen months for both groups. These findings suggest that better audiovisual speech perception abilities are one factor that results in better language acquisition in preterm as well as term infants. Early identification of behaviours associated with later language in preterm infants may contribute to planning intervention for developmental problems (Imafoku et al., 2019).

Children born VP had language difficulties that were not expected from their significantly higher VIQ and vocabulary knowledge. Clinicians assessing these children should be aware of possible language issues which cannot be detected by means of a simple vocabulary task. Stipdonk et al findings provide evidence of the need for adequate language assessments by a speech-language pathologist in children born VP, especially in those with VIQ scores in the low average range. Highlights of this study include that language scores are worse than verbal IQ and vocabulary in children born VP (very preterm). At the same time, language scores are significantly associated with verbal IQ, parent's vocabulary knowledge is a stronger predictor than parent's educational level, meaning that a follow-up test conducted by a speech language pathologist or, better yet, a multi-disciplinary team is advised (Stipdonk et al., 2020).

These results call attention to the psychological consequences of the medical intervention needed by premature and low birthweight infants. Neonates born under these conditions often spend a lengthy period of time separated from their mothers. Often their first experience following birth is that of separation. By the time the infant has the chance to get to know its mother in an uninterrupted manner, it is no longer a neonate. Until that time, the more often the parents visit, and fewer the specialist interventions on the part of doctors and nurses, the greater the chance for parents and child to bond. We also have to realise that, among these parents, tension in their relationship can occur, either as an outcome of overprotection or emotional rejection of the child. These factors all influence communication with the child and therefore of the preverbal and language-skills development of the infant.

Why are the executive functions in preterm children worthy of interest?

Research interest in executive functions (EFs) – which is an umbrella term encompassing conscious, goal-directed, problem-solving thinking and the higher-order control processes (Lee et al., 2013; Zelazo et al., 2008) – is relatively recent. A universally accepted theoretical model of EF is not yet available, but cognitive flexibility (shifting), updating/working memory, and inhibition have been generally regarded as its core components (Diamond, 2016; Józsa & Józsa, 2018; Miyake et al., 2000; Miyake & Friedman,2012). The higher-order executive functions (thinking, problem-solving, and planning) are built upon these core components (Diamond, 2016). Similar to the maturation of the prefrontal lobe, the development of the EFs is a long process and lasts until adolescence (Csépe, 2005). The various components mature in different rates, then start to decline in time (Diamond, 2016).

In light of the majority of research evidence, executive function is more sensitive to the biological risk involved by prematurity than the elementary cognitive abilities assessed by the IQ test. Four-year-old, preterm children performed more poorly than the term comparison group in direct measures of EF, and their teachers reported that they had more difficulties with inhibition, working memory, planning/organisational skills, and self-control (O'Meagher et al., 2017). School-age ELBW/VLBW preterms scored more poorly compared to their non-risk counterparts in tasks requiring inhibition, working memory, and shifting (i.e., cognitive flexibility) (Aarnoudse-Moens, 2012; Ford et al., 2011; Stålnacke et al., 2019). In the study by Ritter et al. (2013), eight- to ten-year-old VLBW children performed significantly more poorly than the control group in inhibition, working memory, and shifting, whereas ten- to thirteen-year-old VLBW children reached the same level as the control group in all three EFs. The authors concluded that the poor performances of the younger VLBW children might reflect a delay rather than a deficit. The catch-up tendency presumably stems from the plasticity of function and organisation of the human brain (Ford et al., 2013). A study by Costa et al (2017) calls attention to the variety of developmental trends of executive functions in ELBW children. In the majority of their subjects, the EFs remained stable between eight and eighteen years of age, with more than half of them scoring in the typical range and 15% performing persistently low. However, the EF performances of about one quarter of the subjects changed markedly, with late-onset difficulties and remitting trends occurring in equal proportions.

Diamond et al. (2013) reported a strong correlation between the processing speed and the updating/working memory and interpreted it as the processing speed having a crucial role in executive function. Lee et al. (2013) also emphasised the importance of processing speed, claiming that the development of response inhibition and working memory was mediated by the development of processing speed. Our study conducted with nine- to ten-year-old preterm children and a full-term comparison group (Nagy, 2019) supported the link between the processing speed and the updating/working memory only among the VLBW preterms. Among the ELBW preterms, the assessments of the IQ test (full-scale IQ, working memory, processing speed) were related to cognitive flexibility, hence corroborating the claim by Rose et al. (2011) that there is a direct link between birth status and cognitive flexibility. In this study, the effect of processing speed was significant for all three core components of executive function, but preterm birth had an independent impact on cognitive flexibility. The authors have yet to explain this phenomenon but assume that perseveration might be independent of processing speed.

Background of the development of executive functions in preterm children:

One of the most remarkable findings of our own study was the massive scattering of the individual scores falling below the group means; some of the preterm children, even a few born with extremely low birthweights, had chances for developmental outcomes comparable to the non-risk, full-term children (Nagy, 2019; Nagy et al., 2021). The substantial inter-individual variations within the performances as well as the variety of developmental trends of the executive functions (Costa et al., 2017) among the preterm children underline the issue of prediction, the prerequisite of which is to reveal the factors explaining these variances.

Research evidence suggests that the most powerful covariates for the preterms' development are gestational age (Mulder et al., 2009; O'Meagher et al., 2017; Stålnacke et al., 2019; Nagy, 2019; Nagy et al., 2021) and birthweight (Ford et al., 2011; Twilhaar et al., 2018). Perinatal complications, disturbed maturation, and injuries to the CNS have untoward effects on cognitive development, including executive functions (Arhan et al., 2017; Loe et al., 2018; Iwata et al., 2012; Nagy, 2019; Nagy et al., 2021). Gender also seems to have a role: within the groups of EP/ELBW and VP/VLBW, female preterms performed better on IQ tests and EF tasks than their male counterparts (Aarnoudse-Moens et al., 2012; Baron et al., 2009; O'Meagher et al., 2017; Nagy, 2019; Nagy et al., 2021).

When attempting to explain why the lag between the EF performances of VLBW children and those of the normative group was not found at later ages, Ritter et al. (2013) argued for the potential remedial effects of environmental factors. O'Meagher et al. (2017) reported that social risks and particularly low maternal education were the strongest associates of impaired EF outcomes while the perinatal variables had no predictive power. A study by Ford et al. (2011) provided a more complex picture of the background of the development of the EF and revealed interactions between the neurobiological risk factors and maternal education in ELBW children. In accordance with the phenomenon described above, a cluster analysis of our data corroborated the substantial effects of biological risks, yet also suggested the power of protective factors, including maternal education, which made it possible for even a few ELBW preterms to qualify for the top cluster (Nagy, 2019; Nagy et al., 2021). A recent eighteen-year longitudinal study by Stålnacke et al. (2018) revealed a complex mechanism underlying the development of EFs by using a serial multiple mediator model. The results showed a remarkable stability in both working memory and cognitive flexibility from ages five-and-a-half to eighteen years. Parental education had direct effect on both EF measures for children aged 5.5 years, while perinatal medical complications and intrauterine growth had direct effects on cognitive flexibility at eighteen years. In addition, mental development at ten months of age mediated the influences of perinatal variables and gender by having direct relation to the EF measures for children aged 5.5.

Conclusions

Drawing an association between early neurological hazards and developmental handicaps is statistically strong but not necessary as this parallel does not apply to each, individual case. The prediction of the outcome at the individual level is very uncertain, therefore conducting a long-term follow-up assessment of preterm and low birthweight children is essential. This follow-up assessment should be interdisciplinary and consist of a team of experts in neonatology, child neurology, ophtalmology, otolaryngology, child psychology, somatotherapy, speech therapy, special education, social work, etc. The adverse effects of neurobiological risks can be compensated (whether fully or at least partially) by favourable social backgrounds while early developmental training can either correct the adverse effects or attenuate the severity. Research can provide information on the protective factors families and professionals can utilise in creating optimal conditions for the children's development. Theoretically grounded and empirical evidence-based intervention can contribute substantially to the favourable outcomes of children born at perinatal risk (Beke et al., 2004).

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