Influence of Gestational Age and Parental Education on Executive Functions of Children Born Very Preterm

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Abstract

Background: Children born very preterm (<32 weeks’ gestational age; VPT) and/or very low birth weight (<1500 g; VLBW) are at high risk of deficits in executive functions, namely inhibition, working memory, and shifting. Both, gestational age and socioeconomic factors, such as parental education, are known to influence executive functions, with children born at lower gestational age and with lower educated parents displaying worse executive skills. This study aimed to investigate if parental and paternal education moderated the relationship between gestational age and executive functions in VPT/LBW children aged 8-12 years. It was hypothesised that the disadvantageous effect of low gestational age could be buffered more easily in families with higher educational background.

Methods: Sixty VPT/LBW children born in the cohort of 1998-2003 were recruited. All children completed executive function tasks (inhibition, working memory, and shifting).

Results: There was a significant dose-response-relationship between gestational age and inhibition, with children being born at earlier gestational age showing worse inhibition. However, neither maternal nor paternal education moderated the relationship between gestational age and executive functions significantly.

Conclusion: Findings suggest that gestational age was more determining for executive functions of VPT/LBW children than parental education. The disadvantageous effect of low gestational age was equal in children with higher and lower educated parents. However, the impact of gestational age and parental education on executive functions may differ depending on the socioeconomic spectrum of the study sample.

Keywords: Children born very preterm; Parental education; Inhibition; Working memory; Shifting

Abbreviations: VPT/LBW: Very Preterm or Very Low Birth Weight

Introduction

Children born very preterm (<32 weeks of gestation; VPT) and/or with a very low birth weight (<1500 g; VLBW) are at high risk of deficits in executive functions [1]. Executive functions refer to cognitive processes that are important for purposeful and self-regulated behaviour [2], namely inhibition, working memory, and shifting [3]. Inhibition is defined as the ability to suppress prepotent responses or ongoing processes and avoid cognitive interference [3]. Working memory is considered as the capacity to maintain and process information during a short period of time [4]. Shifting refers to the ability to deliberately shift between mental tasks or sets [3]. In school-aged children, difficulties in inhibition, working memory, and shifting relate to problems in mathematics [5], reading and writing skills [6], VPT/LBW children at ages 8 to 12 years are shown to perform worse than full-term controls in inhibition, working memory, and shifting [7,8]. Furthermore, low gestational age and/or high rates of severe neonatal complications (e.g. haemorrhage, periventricular leukomalacia) are associated with poor inhibition, working memory, and shifting [9-11], with children being born at lower gestational age and/or exhibiting many complications displaying more executive problems later in life [1,7,11].

During the third trimester of pregnancy, the foetus’ brain develops dramatically. Total brain volume increases 2.7-fold, cortical grey matter increases 4-fold, white matter increases 5-fold [12] and the cerebral cortex becomes folded [13]. Decreased cortical volume, less myelination [14] and reduced cortical surface area [15] have been observed in VPT/LBW infants at term compared to same-aged full-term infants. The alterations in structural brain development were increased with reduced gestational age [16], suggesting a dose-response relationship between the degree of prematurity and the alteration in structural brain maturation.

The emergence of executive functions has been linked to the maturation of the prefrontal cortex [17], which exhibits a protracted period of postnatal maturation [18]. A peak in grey matter maturation in the prefrontal cortex occurs between the ages of 11 and 12 years, which corresponds to the age window where executive functions become increasingly specialised [19]. Executive functions are the latest maturing brain functions during development [20], therefore offering socioeconomic factors a large window of plasticity to affect the structural differentiation and functional capability of the prefrontal cortex [21]. Socioeconomic factors have been shown to relate to executive functions in healthy [20] and preterm-born children [1], with children from families with higher socioeconomic position performing better in executive functions. Some studies reported the influence of parental socioeconomic position on cognitive

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development to decline when children entered school [22], whereas 
other studies established a stable influence across childhood [23]. The 
socioeconomic position usually is measured as parental education, 
income or occupational status [23]. Of these three indicators, parental 
education is shown to be the best predictor of the children's cognitive 
outcome [24], possibly because it tends to be the most stable aspect 
of one's socioeconomic position over time [23]. In general, parental 
education may affect the extent to which parents can provide resources 
to their children (e.g., books and learning materials, monitoring of 
the child’s activities, complexity of speech and vocabulary) or manage to 
recruit supporting social networks (i.e., social capital) [25].

The present study investigated whether maternal and paternal 
education moderated the relationship between gestational age and 
executive functions in VPT/VLBW children. It was hypothesised that 
the disadvantageous effect of early gestational age could be buffered 
more easily in families with higher educational background. The 
moderator effect was tested on a sample of VPT/VLBW children with 
no or mild neonatal cerebral lesions, as these children represent the 
majority of the preterm population [70%] [26].

Methods

This study reports on a subset of data from the NEMO (NEuropsychology und meMOry) research project at the Children's 
University Hospital in Bern, Switzerland. The NEMO project examines cognitive development and the effect of cognitive training in 
VPT/VLBW children and has been approved by the ethics committee 
of the Children's University Hospital in Bern. All children and 
caregivers provided informed written consent prior to participation, 
consistent with the Code of Ethics of the World Medical Association 
(Declaration of Helsinki).

Participants

The medical records of all VPT/VLBW children (<32 weeks 
gestational age and/or <1500 g birth weight) born in the cohort of 1998 
to 2003 at the Children's University Hospital in Bern, Switzerland, 
were reviewed. Inclusion criteria were: (a) aged between 8 and 12 
years; (b) maximal haemorrhage grade II; (c) maximal periventricular 
leukomalacia grade II; (d) no chronic illness potentially influencing 
development (e.g., congenital defects, cerebral palsy or epilepsy); (e) 
no medical problems potentially influencing development (e.g., 
meningitis, encephalopathy, traumatic brain injury); (f) no pervasive 
developmental disorders (e.g., autism). As this study is part of a large 
clinical trial examining the effect of cognitive training in VPT/VLBW 
children, only children with IQ>85 were included in order to avoid 
cognitive heterogeneity. According to their medical records, 247 
children (92.5%) fulfilled the inclusion criteria. They were contacted 
by a letter including an information booklet for parents and children. 
After obtaining written consent from the caregivers, children were 
assessed individually by a trained neuropsychologist (B.R. or R.E.). Sixty-three children (25.50%) completed the neuropsychological 
assessment, but 3 children had to be excluded because IQ<85 (n=2; 
3.17%) or refusal at assessment (n=1; 1.58%). Finally, 60 VPT/VLBW 
children, 27 girls (45%) and 33 boys (55%) were included in the 
analyses.

Assessment

To assess cognitive functions, well-known and standardised 
neuropsychological tests were employed. Raw scores were transformed 
to age-corrected scaled scores or index scores according to the 
respective test manual, with high scores reflecting better performance.

Inhibition was assessed using the first (colour naming task) and 
third condition (interference task) of the D-KEFS' Colour-Word 
Interference Test (Delis-Kaplan Executive Function System, D-KEFS 
[27]. In the colour naming task, the child was asked to name colour 
patches as fast as possible (no inhibitory load). In the interference task, 
the child had to name the ink colours of words printed in an incongruent 
ink as fast as possible (high inhibitory load). The measure of inhibition 
was the difference between the colour naming and interference tasks.

Working memory was assessed using the digit span backwards task of 
the German version of the Wechsler intelligence scale for children 
(WISC-IV) [28]. The variable of interest was the maximum backward 
span attained. Shifting was assessed using the forth condition of 
the D-KEFS Trail Making Test (number-letter-switching; D-KEFS) [27]. 
The child was asked to connect numbers (1 to 16) and letters (A to 
P) by switching between connecting numbers in correct order as 
fast as possible (i.e. 1-A-2-B-3-C et cetera). General intelligence was 
assessed using the short form of the WISC-IV [28,29]. Full-scale IQ 
and index scores were calculated from scores on seven subtests of 
the original WISC-IV [29]. Processing speed and verbal comprehension 
was assessed to control for possible confounder variables. Processing 
speed was assessed using the processing speed index score of the short 
form of the WISC-IV [28,29]. Verbal comprehension was assessed 
using the verbal comprehension index score of the short form of the 
German version of the Wechsler intelligence scale for children [28,29]. 

Socioeconomic status was defined as maternal and paternal education 
level at the time when the neuropsychological assessment took place. 
No graduation was coded as 1, college as 2, college of higher education 
as 3, and university degree as 4. Information about the gestational age 
was collected from the children's neonatal medical records. It was 
measured in weeks and days based on the date of the last menstrual 
period and a prenatal ultrasound scan.

Statistical analyses

To test the study hypothesis, the moderator effect of maternal 
and paternal education on the relationship between gestational age 
and executive functions was analysed by means of hierarchical 
multiple regression using the Statistical Package for Social Sciences 
software for Windows, version 17 (SPSS, Chicago, Illinois). Statistical 
assumptions to conduct a moderator analyses with hierarchical 
regression are (a) normal distribution of the dependent variables 
and (b) the absence of multicollinearity effects [30]. In a sample of as 
many as 60 subjects, normal distribution of the dependent variables 
(i.e. executive functions performance) can be expected [31]. To 

| Variable                      | Mean  | SD   | Min  | Max  |
|-------------------------------|-------|------|------|------|
| Age at assessment             | 10.01 | 1.50 | 8.03 | 12.97|
| Maternal education1           | 2.33  | 0.60 | 2    | 4    |
| Paternal education1           | 2.57  | 0.79 | 2    | 4    |
| Number of siblings            | 1.60  | 1.10 | 0    | 4    |
| Gestational age (weeks)       | 29.80 | 2.20 | 24.71| 33.71|
| Birth weight (grams)          | 1238.25| 354.16| 570  | 2060 |
| IQ2                           | 100.75| 10.03| 85   | 122  |
| Processing speed2             | 99.48 | 13.08| 66   | 134  |
| Verbal comprehension2         | 102.20| 9.64 | 87   | 124  |
| Inhibition3                   | 9.57  | 2.70 | 2    | 16   |
| Working memory3               | 9.70  | 1.10 | 7    | 12   |
| Shifting3                     | 8.74  | 3.55 | 2    | 14   |

Note. 1. Scale of education: 1=no graduation, 2=college, 3=college of higher 
education, 4=university degree; 2. WISC-IV, short form (M=100, SD=15); 3. Scaled 
score (M=10, SD=3); 4. a high scaled score indicates that the child exhibited good 
inhibition, good working memory or good shifting ability.

Table 1: Descriptive Data.
1. Age -
2. Maternal education -0.13 -
3. Paternal education -0.03 0.41** -
4. Number of siblings 0.01 0.02 0.04 -
5. Gestational Age 0.01 0.06 0.03 0.11 -
6. Birth weight -0.03 0.09 -0.05 0.15 0.64** -
7. IQ 0.23 0.08 0.36** -0.24 0.12 0.05 -
8. Processing speed 0.34** 0.06 0.09 -0.13 0.07 0.02 0.66** -
9. Verbal comprehension 0.03 -0.02 0.47** -0.27* 0.32* 0.01 0.66** 0.14 -
10. Inhibition -0.17 0.01 -0.03 0.14 0.32* 0.20 -0.19 0.04 -0.26* -
11. Working Memory -0.25 -0.02 -0.15 -0.09 -0.03 -0.12 0.39** 0.19 0.20 -0.31* -
12. Shifting 0.29* 0.08 0.24 0.05 0.24 0.17 0.55** 0.58** 0.17 0.10 0.05 -

Table 2: Pearson correlations coefficients (r) between all variables.

Note. Hierarchical multiple regression of the moderator analyses is presented. GA=gestational age; ME=maternal education; PE=paternal education; GA×ME=product term (interaction); B=unstandardised regression weight; SE=standard error of the unstandardised regression weight; B̂=standardised regression weight; p=level of exact significance; ΔR^2=explained variance of the predictors in the criterion; p of R^2 change=level of exact significance of the increase in explained variance; *=p<0.05, **=p<0.01

Table 3: Moderator analyses of maternal education (ME) and paternal education (PE). Eliminate multicollinearity effects, gestational age and maternal as well as paternal education were centred [30]. Then, gestational age and maternal as well as paternal education were multiplied together to create the interaction term. Finally, gestational age and maternal as well as paternal education were entered into a hierarchical multiple regression (step 1, direct effect), followed by the interaction (step 2, moderator effect). In the case of a moderator effect, adding the interaction term would significantly increase the explained variance in the dependent variable (ΔR^2), in contrast to the variance already explained by the predictor and the moderator entered in the first step.

Results

All parents of the VPT/VLBW children graduated from school (Table 1) (mothers: 44 (73.3%) college degree, 12 (20%) degree of college of higher education, 4 (6.7%) university degree; fathers: 41 (68.3%) college degree, 4 (6.7%) degree of college of higher education, 15 (25%) university degree). The mean IQ of the children and the mean executive functions were in the normative range. Maternal education correlated positively with paternal education (r=0.41, p<0.01) (Table 2). As expected, processing speed, verbal comprehension and working memory, correlated significantly with IQ (processing speed: r=0.66, p<0.01; verbal comprehension: r=0.66, p<0.01; working memory: r=0.39, p<0.01). With respect to executive functions, inhibition correlated significantly with gestational age (r=0.32, p<0.01), whereas neither working memory (r=0.03, p=0.84) nor shifting (r=0.24, p=0.07) correlated significantly with gestational age. None of the executive functions were significantly associated with maternal or paternal education (Table 2).

Moderator analyses with maternal and paternal education

Regarding inhibition, a total of 10% (p=0.05) of the variance in inhibition was explained by gestational age and maternal as well as paternal education (step 1, direct effect; Table 3). Gestational age predicted inhibition significantly (b=0.39, p<0.05), whereas there was no significant predictive value of maternal (b=0.04, p=0.94) or paternal education (b=-0.12, p=0.77) on inhibition. The prediction of gestational age remained significant even if confounder variables were taken into account: age (b=0.39, p<0.05); sex (b=0.38, p<0.05); IQ (b=0.42, p<0.05); processing speed (b=0.40, p<0.05); and verbal comprehension (b=0.42, p<0.01). Adding the interaction term between gestational age and maternal education (ΔR^2=0.01, p=0.42) and the interaction term between gestational age and paternal education (ΔR^2=0.02, p=0.35) did not increase the explained variance in inhibition significantly (step 2, moderator effect).

Regarding working memory, a total of 1% (p=0.97) of the variance in working memory was explained by gestational age and maternal as well as paternal education. Neither gestational age (b=0.01, p=0.86) nor maternal (b=-0.01, p=0.88) or paternal education (b=0.03, p=0.63) predicted working memory significantly. Adding the interaction term between gestational age and maternal education (ΔR^2=0.01, p=0.36) and the interaction term between gestational age and paternal education (ΔR^2=0.01, p=0.42) did not increase the explained variance in working memory significantly.

Regarding shifting, a total of 6% (p=0.17) of the variance in shifting was explained by gestational age and maternal education and a total of 11% (p<0.03) of the variance in shifting was explained by gestational age and paternal education. Neither gestational age (b=0.38, p=0.08) nor maternal (b=0.43, p=0.57) or paternal education (b=0.94, p=0.07) predicted shifting significantly. Adding the interaction term between gestational age and maternal education (ΔR^2=0.05, p=0.09) and the interaction term between gestational age and paternal education (ΔR^2=0.01, p=0.44) did not increase the explained variance in shifting significantly.
To summarize, neither maternal nor paternal education moderated the relationship between gestational age and executive functions, namely inhibition, working memory, and shifting (Table 3).

Discussion

The present study investigated whether maternal and paternal education moderated the relationship between gestational age and VPT/VLBW children's performance in inhibition, working memory, and shifting. Analyses revealed that gestational age predicted inhibition of VPT/VLBW children. Higher gestational age was significantly associated with better inhibition, even when possible confounder variables (age, sex, IQ, processing speed, and verbal comprehension) were taken into account. Being born at a higher gestational age seems to facilitate the emergence of inhibition, presumably because brain maturation is less affected by prematurity with increasing duration of pregnancy. This is plausible when considering the remarkable brain development in the last trimester of pregnancy [12]. Davis et al. [32] reported that even modest decreases in the duration of pregnancy can be associated with profound and lasting effects on neurodevelopment, indicating a dose-response-relationship between the degree of prematurity and changes in structural brain maturation [16].

Hence, the present data suggest that neither maternal nor paternal education were significant moderators on the relationship between gestational age and executive functions. Parental education had no statistically significant impact on executive functions of this VPT/VLBW sample. In contrast, research shows that VPT/VLBW children of less educated parents perform lower in cognitive tests than children of higher educated parents [33]. Carlson (2003) [34] suggested three parental factors to support a child's executive development: maternal sensitivity (responding adequately to the infant's signals), scaffolding (offering the child assist-tance in tasks beyond its current capability) and mind-mindedness (commenting on the child's thoughts and actions). Sensitive and mind-minded parents who support learning with scaffolding provide their child with experiences of successful interaction with the environment and effective self-regulation, which boosts executive development. Parents with low education are more likely to experience adverse social and physical conditions (e.g. crowded housing, pollution, high crime rates), daily problems as a consequence of occupational or material disadvantage and stressful life events (e.g. loss of employment, frequent household moves and lack of access to medical care) [25], all factors which substantially affect parent-child interactions in everyday life. The chronic stress associated with low socioeconomic position can lead to decreased quality of care-giving, for example reduced emotional warmth and sensitivity to a child's needs, harsh disciplinary style and sparse verbal communication [25]. However, in Switzerland, where the present data was collected, socioeconomic standards and education level are relatively high. Switzerland consists of a good welfare and health care system and a stable low unemployment rate (2.7-2.9%; State Secretariat for Economic Affairs SECO, July 2012). All parents of the reported VPT/VLBW children graduated from school, which is the case in about 92.7% of Swiss citizens (Swiss Federal Statistical Office, 2011). On the one hand, it might be that parental education did not influence the relationship between gestational age and executive functions in this sample because all VPT/VLBW children have relatively high educated parents and, therefore, the variance of socioeconomic background was rather small. Additionally, one could speculate that the influence of parental education on the child's executive functions may be weaker in Switzerland compared to countries with worse socioeconomic standards. On the other hand, the influence of parental education on children's cognitive performances can diminish during school age [22], since schooling might equalize the influence of socioeconomic differences across children. It might be that parental education did not relate to executive functions in the school-aged VPT/VLBW children of this study, because the time window where parental education has its strongest influence on children's executive functions has already passed.

As limitation, all parents of this study graduated from school, therefore representing the majority but not the whole educational spectrum of Switzerland. A second aspect is that education is a rather distal factor of the child's socio-familial environment. More proximal socioeconomic factors, such as the availability of stimulating materials, parental responsibility or complexity of speech, may explain more variance in the outcome than distal factors. Combining distal and proximal assessments of one's socioeconomic position may provide further insights into the fine mechanisms enabling socioeconomic factors to affect a child's cognitive development. Third, due to the restricted sample size (n=60) the power of the study decreases, whereas the chance of outliers increases [35]. To minimize these consequences, we used methodological (e.g., careful selection of sample, homogenous age groups concerning demographic and birth data) and statistical methods (e.g., centering the variables to avoid multicollinearity effects). However, studies with larger sample size are needed to give further insight into the relationship between socioeconomic status, gestational age and executive functions in VPT/VLBW children. A fourth aspect relates to the assessment of the three executive functions. Each of the three executive functions was measured using a single assessment task rather than a variety of tasks.

Findings suggest that gestational age was more determining for executive functions of the VPT/VLBW children than parental education. The disadvantageous effect of low gestational age was equal in children with higher and lower educated parents. However, the impact of gestational age and parental education on executive functions may differ dependent on the socioeconomic spectrum of the study sample.

Conflict of Interest

There are no conflicts of interest to declare.

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