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Delay of gratification and time comprehension is impaired in very preterm children at the age of 4 years

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ABSTRACT

Background: Very preterm infants more likely exhibit deficient executive functions than term born controls. Delay of gratification, as part of the executive functions, allows for rejecting an immediate in favor of a greater future reward. Time comprehension might help to delay gratification.

Aims: We hypothesized that delay of gratification and time comprehension is less developed in preterm children and that time comprehension is associated with the ability to wait for a greater reward.

Study design: Very preterm children (< 32 weeks' gestation) and term born controls were tested for receptive language skills, time comprehension and delay of gratification at the (corrected) age of 4 years.

Subjects: 25 preterm subjects (12 female; median: gestational age (GA) 28.3 weeks, corrected age 4 years, 22 days) and 26 controls (16 female, median GA: 40.0 weeks, age 4 years, 25 days) participated.

Outcome measures: Correct answers in the time comprehension and receptive language task, waiting time in the delay-of-gratification task were measured.

Results: Preterm subjects had less time comprehension than controls (43% vs. 53%, $p = 0.017$, one-tailed) but receptive language skills were similar. Waiting time in the delay-of-gratification task was 3:42 min in preterm subjects, versus 10:09 min in controls ($p = 0.043$, one-tailed). Even after controlling for language skills, waiting time correlated positively with time comprehension in both groups ($r = 0.399$, $p = 0.004$, two-tailed).

Conclusions: Preterm children's time comprehension and delay of gratification ability is impaired. Future research is warranted to investigate whether training in time comprehension increases the ability to delay gratification.

1. Introduction

Premature birth incorporates an increased risk for neurocognitive deficits, behavioral problems; attention deficit (hyperactivity) syndrome and autism spectrum disorders in future life [1–3]. Cognitive impairments comprise lower intelligence quotient (IQ) in former preterm infants as well as poorer performance in executive function tasks compared to controls [4–6]. Deficits persist into adulthood [6,7] and are considered responsible for lower educational qualifications and net income [8,9]. Executive functions have been described as key factors for lower academic achievement and behavioral problems [10,11], and are influenced by gestational age (GA), birth weight and morbidities deriving from the perinatal period [12,13].

According to Diamond there are three core executive functions: inhibitory control, working memory and cognitive flexibility, that develop at different paces from infancy to adulthood. For example, inhibitory control is far more difficult for young children than for adults [7,14].

Inhibitory control describes the ability to resist temptations or control impulsive reactions and to modulate emotional expressions. Inhibitory control in early childhood predicts life perspectives (physical and mental health, personal finances, addiction to substances, delinquency and crime) [15]. Thus, developing inhibitory control abilities is vital for children in order to navigate through their social environment.

In preterm infants, Jaekel et al. described a correlation of low GA at birth with lower inhibitory control in childhood. Low inhibitory control was predictive for lower attention regulation and academic

Abbreviations: GA, gestational age; IQ, intelligence quotient; MRI, magnetic resonance imaging; yrs, years

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achievement at the age of 8 years [16]. Therefore it is important to identify children with poor inhibitory control as much as it is crucial to reveal possible starting points for training programs to promote those children at highest risk.

A reliable method of measuring inhibitory control is the delay-of-gratification task [17,18]. It has been shown that children's ability to wait for a greater reward in the delay-of-gratification task develops between the age of 3–4 years and correlates with children's understanding of temporal terms (e.g. “tomorrow” or “before”) [19,20]. Few studies, however, relate the ability to delay gratification to time perception [21] during childhood [22,23] and adolescence [24], suggesting that children's concept of time develops in synchrony with their ability to refrain from acting on impulse. A general misconception of time intervals might lead individuals with low inhibitory control to overestimate the waiting period in relation to the value of the additional reward. To our knowledge the development of time comprehension in very preterm infants and its relation to inhibitory control abilities has not been investigated to date.

In the present study, the first hypothesis was that very preterm children fall behind term children in their ability to delay gratification and in their time comprehension. The second hypothesis was that delay of gratification correlates with time comprehension independent of the GA at birth. It was furthermore conceivable that understanding of temporal terms might also be based on linguistic capacities. Thus, the third hypothesis was that the correlation of both functions remains valid after controlling for receptive language skills.

2. Material and methods

2.1. Participants

Preterm participants were recruited from 89 surviving very preterm born infants admitted between April 2010 and March 2012 to the Neonatology department of the University Hospital Essen, University of Duisburg-Essen, Germany. Inclusion criteria were: preterm birth < 32 weeks' gestation and corrected age of 48–50 month. Exclusion criteria were severe disabilities and insufficient German language skills. For comparison 30 healthy term born children (> 37 weeks' gestation) were enrolled. They were either peers of preterm participants or recruited in daycare centers or by advertisement on the hospital website and newsletter. One preterm and three term participants had to be excluded due to experimenter error, (n = 3) and insufficient language skills (n = 1). Table 1 presents characteristics of the 25 very preterm and 26 term born participants.

The study was approved by the local ethical committee of the University of Duisburg-Essen, Germany (13-5461_BO). The experiments were performed in accordance with the Declaration of Helsinki. One of the legal representatives gave informed written consent prior to participation.

2.2. Experimental setting

The study was performed in a specifically designed room (2.0 × 2.5 m), empty of distractions, with a one-way mirror and furnished only with a child-sized table, two child-sized chairs, and an extra chair for one parent. A camera for video recording was placed near the ceiling in a corner of the room enabling panoramic observation of the setting (see Fig. 1).

2.3. Design & procedure

All participants completed three different tasks in a randomized order: a receptive-language-test (SETK 3-5, German language development test for 3 to 5 year olds, [25]), a time-comprehension-task (hourglass-test [26]), and a delay-of-gratification task [18]. The investigator was blinded to the medical history of preterm children. Tasks started after a short interval of warming-up where children were offered to draw a picture with the investigator. Parents were allowed to stay in the room during warm up, language- and time-comprehension-tasks. Furthermore, parents were asked to complete a questionnaire on socio-economic status and parental education. Perinatal data were taken from Germany's official documentation of healthcare visits, birth charts or hospital records.

Table 1
Clinical characteristics of participating children.

	Prenatal children (n = 25)	Control children (n = 26)
Demographic characteristics		
Age in yrs. and d – mean (range)	4, 27 (4, 1–4, 57)	4, 28 (4, 8–4, 58)
Sex – male/female – n	12/13	16/10
Parental education (maternal; paternal)[a]		
Level 0 – n (%)	1(4%); 0 (0%)	0 (0%); 0 (0%)
Level I – n (%)	2 (8%); 3 (12%)	0 (0%); 2 (7.7%)
Level II – n (%)	4 (16%); 9 (36.0%)	1 (3.8%); 1 (3.8%)
Level III – n (%)	18 (72%); 12 (48%)	25 (96.2%); 23 (88.5%)
Perinatal characteristics		
Gestational age at birth in weeks – median (range)	28.29 (24.0–31.43)	40.0 (37.14–42.14)
Birth weight in grams – median (range)	1060 (590–1850)	3337 (2430–4280)
Small for gestational age (< 10th centile) – n (%)	3 (12%)	0 (0%)
5-min APGAR score – median (range)	8 (4–10)	10 (9–10)
10-min APGAR score – median (range)	9 (7–10)	10 (9–10)
Umbilical artery pH – median (range)	7.35 (7.13–7.43)	7.31 (7.15–7.43)
AIS – no/yes/unknown – n	18/5/2	0/0/0
Antenatal steroids – no/yes/unknown – n	2/21/2	26/0/0
Bronchopulmonal dysplasia – n (%)	2 (8)	n.a.
Retinopathia praematuorum > grade 2 – n (%)	6 (24)	n.a.
Persistent ductus arteriosus – n (%)	17 (68)	n.a.
Postnatal characteristics	**n = 23**	**n = 26**
Proven sepsis – no/yes/unknown – n	17/6/2	0/0/0
Postnatal steroids – no/yes/unknown – n	20/3/2	0/0/0
Cerebral ultrasonography (postnatal period)	**n = 24**	
Intraventricular hemorrhage[b] – n (%)	4 (16.7%)	n.a.
Grade I – n	3 (12.5%)	n.a.
Grade II – n	1 (4.2%)	n.a.
Periventricular leukomalacia at TEA – n	0 (0%)	n.a.
Cerebral MRI at term equivalent age	**n = 24**	
Intraventricular hemorrhage[b] – n/(%)	7 (29%)	n.a.
Grade I – n (%)	5 (21%)	n.a.
Grade II – n (%)	2 (8.3%)	n.a.
Ventricular dilatation[c] – n (%)	17 (70.8%)	n.a.
Yes, mild – n (%)	9 (37.5%)	n.a.
Yes, moderate – n (%)	8 (33,3%)	n.a.
Yes, severe – n (%)	0 (0%)	
Punctate cerebral lesions[c] – n (%)	3 (12.5%)	n.a.
Delayed myelination[c] – n (%)	3 (12.5%)	n.a.
Bayley Scales of Infant Development II at 2 yrs corrected age		
MDI – median (range)/unknown	101 (80–122)/2	n.d.
PDI – median (range)/unknown	95 (72–125)/8	n.d.

yrs = years; d = days; AIS = amnion infection syndrome; APGAR = method to score the postnatal adaptation of a newborn; TEA = term equivalent age; n = number; n.a. = not applicable; n.d. = not done.

[a] The German school system has three levels of graduation. Level III qualifies for university entrance and Level 0 represents no graduation.

[b] Intraventricular hemorrhage was graded according to Papile et al. [42].

[c] White matter injury (ventricular dilatation, punctate or cystic lesions and delayed myelination) were graded according to Kidokoro et al. [43].

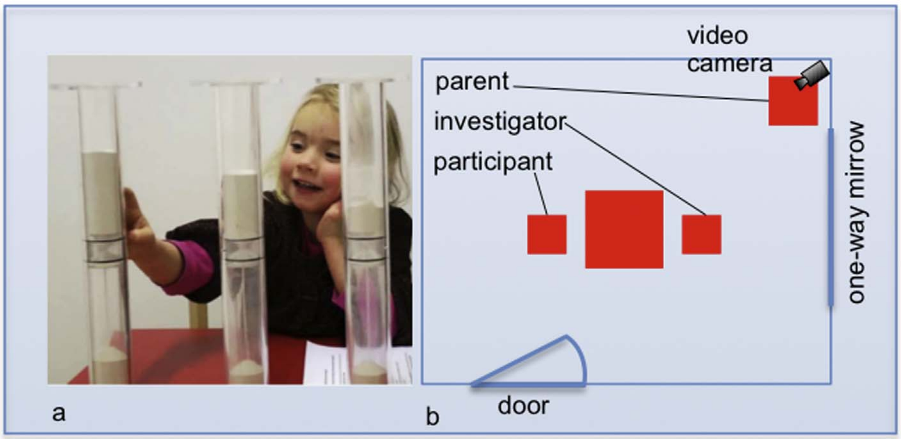

Fig. 1. Experimental setting: (a) time comprehension was tested in the hourglass task with three different hourglasses operating. (b) Outline of the specifically designed room (furnishing, technical equipment and seating arrangements).

2.4. SETK 3-5

Receptive language was tested with the subtest of the SETK 3-5 test in order to ensure that verbal instructions in the following tasks were understood. Children had to follow 15 instructions to point out or perform short activities with different materials (e.g. bag, red and blue pencil, box, picture book). Verbal instructions increased in grammatical complexity.

2.5. Hourglass-test

Time comprehension was tested by comparison of three different hourglasses (5, 4 and 3 min) as was previously described by Zmyj et al. [27]. Briefly said, the hourglasses were turned simultaneously after an introduction to the mechanism. While the hourglasses were operating, children had to predict which one would finish first/last and why. After the hourglasses had run out of sand and were switched to different random positions on the table, the children had to recall the running time of each hourglass.

2.6. Delay-of-gratification task

Children's ability to refrain from receiving a small amount of treats immediately in favor of receiving a larger amount of treats in the future was tested using a modification of the delay-of-gratification task [18]. At first, the investigator presented the child with a bar of chocolate. Then the child was told that the investigator had to leave the room for some minutes. Before leaving the room the investigator gave the child the following choice. The researcher told the child that it could eat the treat, but if it waited for the investigator to return without having eaten the chocolate bar it would receive a second treat. If the child could not resist the temptation and ate the chocolate bar or rang the bell to call the researcher back immediately it would not be allowed a second treat.

Three questions were used to ensure that children understood the rules correctly: "How many chocolate bars will you get if you wait until I come back?", "If you want me to come back, what do you do?", How many chocolate bars will you get if you ring the bell?". If one question was answered incorrectly, further explanations followed until all three questions were answered correctly. The investigator then left the room and observed the experiment via a one-way mirror. Maximum waiting time was 15 min.

2.7. Coding and data analysis

In the SETK-3-5, a correct action was scored with "1"; all other actions were scored with "0" and the sum score was transformed into a *T*-score. In the hourglass-task, each correct answer was scored with "1", incorrect/no answers as "0" as described previously [27]. A sum score was calculated from all 14 questions and correct answers were calculated in % of total questions. In the delay-of-gratification-task, the duration children waited until they rang the bell or ate the chocolate bar was measured in minutes and seconds. Analyses were performed with SPSS 24.0 (SPSS, Chicago, IL, USA).

Some variables were asymmetrically distributed and were thus analyzed non-parametrically with Mann-Whitney-*U* test and Spearman rank correlations, respectively. The alpha error level was 0.05.

3. Results

In the SETK-3-5, there was no evidence for a difference in receptive language abilities between the preterm and the term population (*Median* = 50 in both groups, $U = 260.5$, $p = 0.220$). As predicted in hypothesis 1, very preterm born children (*Median* = 43% correct answers) performed worse in the hourglass-task than term children (*Median* = 54% correct answers, $U = 213$, $p = 0.017$, one-tailed). Likewise, in the delay-of-gratification task, former preterm children (*Median* = 3 min 42 s) waited for significantly shorter periods of time in comparison to term born children (*Median* = 10 min 9 s, $U = 236$, $p = 0.043$, one-tailed).

There was a correlation between the time all children waited in the delay-of-gratification task and the percentage of correct answers in the hourglass-task ($r = 0.399$, $p = 0.004$, hypothesis 2). This was the case for preterm born children ($r = 0.461$, $p = 0.021$) and with a smaller effect size but not statistically significant for term born controls ($r = 0.307$, $p = 0.127$).

The correlation between the time children waited in the delay-of-gratification task and the percentage of correct answers in the hourglass-task remained statistically significant after controlling for receptive language abilities as measured by the SETK-3-5 ($r = 0.324$, $p = 0.022$, hypothesis 3). The effect size was analogous in preterm and term subjects, separately, but not statistically significant ($r = 0.314$, $p = 0.135$, and $r = 0.312$, $p = 0.129$).

There was a difference in the level of maternal and paternal educations (see Table 1; $U = 245.0$, $p = 0.017$, and $U = 199.5$, $p = 0.007$, respectively). There was a relationship between maternal and paternal education level and children's percentage of correct answers in the hourglass task ($r = 0.367$, $p = 0.008$, and $r = 0.308$, $p = 0.030$, respectively). However, there was no relationship between maternal and paternal level of education and children's waiting time ($r = 0.135$, $p = 0.346$, and $r = 0.164$, $p = 0.256$, respectively). The correlation between the time children waited in the delay-of-gratification task and the percentage of correct answers in the hourglass-task remained statistically significant after controlling for maternal and paternal level of education ($r = 0.380$, $p = 0.008$, and $r = 0.374$, $p = 0.008$, respectively).

4. Discussion

Former preterm children showed a lower ability to delay gratification and a lower comprehension of time compared to term born controls. Furthermore, the better children estimated and remembered running times of hourglasses, the longer they could wait for gratification. This correlation remained statistically significant after controlling for receptive language ability.

This study adds more evidence to various reports on very preterm children's deficits in executive functions in general and inhibitory control in particular [7,12,28]. Delay tasks in preterm toddlers and children of different ages revealed difficulties with inhibitory control and linked these deficits to problems in their learning and attention regulation at the age of 6 and 8 years [16,29].

This work suggests a new component contributing to the ability of inhibitory control: time comprehension. In 4-year-old term born children, that waiting time in the same delay task correlated with the correct estimation and remembrance of duration of hourglasses [23]. The present study confirms this correlation. However, it also documents that preterm subjects performed disproportionally worse in both tasks compared to controls.

A comprehensive concept of time is a prerequisite of future-oriented thinking which allows children to organize motives in a temporal order and to resist immediate temptation in favor of an additional reward in the future. This flexible management of motives promotes an independent behavior in the future, regardless of current impulses. Without inhibitory control, actions would be driven by impulses and environmental stimuli [14]. Considering time as a relevant factor in action planning might help individuals to refrain from acting on impulses [23]. One way to verify this presumed causal relationship could be to test whether training of children's concept of time improves their inhibitory control in the delay-of-gratification task.

Deficits in delay of gratification and time comprehension in preterm participants may be explained by alterations in underlying cerebral networks. Frontostriatal circuits are proposed as neural substrates of delay of gratification with differences in activation patterns depending on subjects' age and ability to control their impulses [30–32]. Using a fibre-tracking approach, Achterberg et al. revealed that the maturational increase to delay gratification between childhood and young adulthood was significantly dependent on frontostriatal white matter integrity [33].

The comparatively long developmental trajectory and highly branched networks of the frontal lobes increase their vulnerability during the last trimester of pregnancy and early postnatal life. Advanced imaging techniques revealed reduced white matter microstructural integrity in current populations of preterm infants, e.g. paucity of white matter with enlarged ventricles and signal abnormalities on MRI [34,35]. Additional research described alterations in resting state and tasked based connectivity with auxiliary networks in former preterm infants [36]. Other studies suggested that “network integrity” is essential to enable sufficient executive functioning [37] and that preterm birth alters executive control networks [36].

A limitation of this study is, that neither functional nor advanced imaging was performed at the time of testing. Thus potential differences in underlying networks need to be addressed in future studies. However, in all but one preterm participant, routine (conventional) brain magnetic resonance images (MRI) was performed at term equivalent (neonatal) age in addition to postnatal serial ultrasound screenings. Scans revealed diffuse white matter abnormalities with enlarged ventricles in 70.8%, focal signal abnormalities and a delay in myelination, each in 3 infants. (see Table 1) which implicates impaired integrity among preterm participants with greater probability.

Due to the correlational design of the study, it is difficult to identify the causal relationship between time comprehension and delay of gratification.

First, children's time comprehensions correlated with parental levels of education. We assume that the children's IQ as one linking factor, assuming that children of intelligent and highly educated parents could have higher levels of IQ which, in turn, helped children to find the correct answer in the time comprehension task.

Second although we controlled for receptive language, other third variables could moderate the relationship, such as intelligence: It is reasonable to presume that the higher the children's IQ, the better they can solve both, the time-comprehension-task and the delay-of-gratification task. Due to time constraints for a single session, we were unable to implement simultaneous IQ testing in the current study, which remains to be acknowledged in future research. However, at least all but two participants were routinely tested at the corrected age of 24 month with Bayley Scales of Infant Development II, showing developmental indices within normal ranges (n = 18) or with only mild impairments (n = 5) (see Table 1). All participants attended a regular kindergarten. Apart from controlling other third variables, another avenue for future studies suggested by our interpretation, is to experimentally manipulate children's concept of time.

Executive functions affect many aspects of life: Mental and physical health, quality of life, school and job success, marital harmony and law-abidance [14]. However executive functions can be trained and those with the lowest functions benefit the most [38,39].

The correlation of inhibitory control and time comprehension may open a new perspective for cognitive intervention in this patient group. This correlation might also be moderated by children's future-oriented thinking, an ability that depends on time comprehension that significantly improves at the age of 4 years [40]. Daniel et al. provide first evidence for such training: Overweight children at the age of 9 to 14 years were able to control their eating behavior better when they performed episodic future-oriented thinking in contrast to thinking of the past before the eating task began [41]. The ability to think about the future might enable children to imagine the future event in which the gratification is fulfilled [40]. Future studies will have to provide more evidence for the effectiveness of future-oriented thinking to improve inhibitory control. Furthermore, it has to be demonstrated that these training effects are transferred into daily life.

Early identification of children with poor executive functions and specific training may reduce long-term complications of preterm children.

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Patient Identification: The parents of the participant whose photograph was used in Fig. 1 gave a signed statement of informed consent. The family had the opportunity to see the manuscript prior to submission.

Data statement: The datasets analyzed during the current study (except individual videos) are available from the corresponding author on reasonable request.

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