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Implicit Learning Abilities in Adolescents Born Very Preterm

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ABSTRACT

Very preterm birth is associated with neurodevelopmental impairments and outcomes have not improved over the last decades. Insight in learning processes is important for the development of effective interventions. Implicit learning is of particular interest because of its independence from working memory processes that are affected by preterm birth. This study examined implicit learning abilities in 49 very preterm and 61 full-term 13-year-old adolescents. The degree of implicit learning was not different between groups. This indicates intact implicit learning abilities in adolescents born very preterm. Implicit learning strategies may be beneficial for skill learning in very preterm born children.

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Very preterm birth has long-term consequences for functioning in a wide range of domains, including cognitive, motor, and academic abilities (Allotey et al., 2018; De Kieviet, Piek, Aarnoudse-Moens, & Oosterlaan, 2009; Twilhaar, De Kieviet, Aarnoudse-Moens, Van Elburg, & Oosterlaan, 2018; Twilhaar et al., 2018). Despite advances in neonatal health care, a meta-analysis showed no significant improvement of cognitive outcomes in very preterm born children between 1990 and 2008 (Twilhaar et al., 2018). Moreover, academic impairments observed at school entry have been shown to remain stable throughout primary school, regardless of the increased provision of educational assistance to very preterm born children (Twilhaar, De Kieviet, Van Elburg, & Oosterlaan, 2018). There is little evidence in support of interventions to improve neurodevelopmental outcomes after very preterm birth. Effects of early intervention programs were found to be small at most and were not sustained into school age (Spittle, Orton, Anderson, Boyd, & Doyle, 2015). Similarly, cognitive training (i.e. working memory training) at school age was not found to enhance academic and neurocognitive functioning 24 months after training (Anderson et al., 2018). These findings indicate the lack of intervention programs that may induce meaningful improvements of functional outcomes after very preterm birth.

A domain that has received little attention in the study of outcomes after very preterm birth is learning. However, the limited efficacy of available interventions to improve neurodevelopmental outcomes in very preterm born children may be related to possibly suboptimal learning processes that may prevent these children to fully benefit from the interventions. Insight in learning mechanisms in very preterm born children is therefore crucial for the development of effective interventions. Learning involves both explicit and implicit processes. Implicit learning may be defined as

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a fundamental ability to extract regularities from the environment without conscious awareness or the intention to do so (Jiménez, 2003) and has been found to support the acquisition of linguistic, motor, and social skills (Conway & Pisoni, 2008; Lieberman, 2000; Masters & Maxwell, 2004). Explicit learning is characterized by hypothesis testing to formulate declarative rules to guide performance and thereby requires working memory (Unsworth & Engle, 2005), a neurocognitive function that has frequently been found to be comprised in very preterm born children (Aarnoudse-Moens, Weisglas-Kuperus, van Goudoever, & Oosterlaan, 2009; Luu, Ment, Allan, Schneider, & Vohr, 2011). In contrast, implicit learning is generally found to be independent of working memory and executive control processes and intelligence (Janacsek & Nemeth, 2013; Kaufman et al., 2010; Reber, Walkenfeld, & Hernstadt, 1991; Unsworth & Engle, 2005).

The limited evidence available on learning in very preterm born children shows mixed findings. Omizzolo et al. (2014) reported impaired learning of both verbal and visuospatial information in 7-years-old very preterm born children relative to full-term born peers. In a sample of 11-years-old children born with extremely low birth weight, Taylor, Klein, Minich, and Hack (2000) found impaired learning of verbal information compared to controls. In both studies, learning was explicit. In a recent study, Jongbloed-Pereboom, Janssen, Steiner, Steenbergen, and Nijhuis-van der Sanden (2017) assessed both explicit and implicit learning of a sequence based on visuospatial cues using the Serial Reaction Time (SRT) task (Nissen & Bullemer, 1987). The researchers compared the performance of 20 very preterm born children with motor problems, 20 without motor problems, and 20 full-term children at school age and found no negative effects of very preterm birth on both explicit and implicit sequence learning. However, 7.5% of the very preterm and 30% of the full-term born children showed awareness of the sequence in the implicit condition of the task. As a consequence, implicit learning processes may have been contaminated by explicit knowledge of the sequence. Hence, replication of the findings in different samples is warranted.

Further insight in learning mechanisms that do not, or to a minimal extent, rely on working memory processes and general cognitive abilities (i.e. implicit learning) are of particular interest in the study of outcomes after very preterm birth. Because of the deficits in working memory and intelligence observed after very preterm birth, interventions including explicit learning strategies that place high demands on these capacities may be less beneficial for very preterm born children. However, if implicit learning processes are intact in very preterm born children, these may provide alternative approaches for intervention in this population. The present study, therefore, aimed to examine implicit learning abilities in very preterm and full-term born adolescents. As opposed to the deterministic sequence structure in the SRT, as used by Jongbloed-Pereboom et al. (2017), the present study used the Alternating SRT (ASRT; Howard Jr & Howard, 1997) task to assess implicit learning of a sequence with a probabilistic structure. Because of the probabilistic sequence structure in this task, participants do not report explicit knowledge of the sequence even after prolonged practice (Howard et al., 2004).

Methods

Participants

Participants were recruited from a cohort of very preterm (<32 weeks' gestation) and/or very low birth weight (<1500 grams) infants who were admitted to the level III neonatal intensive care unit of the Vrije Universiteit Medical Center in Amsterdam between September 2001 and July 2003. The initial cohort comprised 102 infants who were enrolled in a randomized controlled trial on the effects of enteral glutamine supplementation in the first month after birth (Van den Berg, Van Elburg, Twisk, & Fetter, 2004). The inclusion and randomization process has been described in detail elsewhere (Van den Berg, Van Elburg, Westerbeek, Twisk, & Fetter, 2005). We previously showed no differences between very preterm born children in the intervention and placebo group on academic, neurocognitive, motor, and behavioral functioning at 13 years (Twilhaar, De Kieviet, Oosterlaan, & Van Elburg, 2018). The present study treated the very preterm born participants as one sample after the absence of intervention effects on implicit learning was confirmed (Supplement). At one year of age, 88 children were alive and eligible for

Table 1. Perinatal characteristics of very preterm born children who participated in the study and those lost to follow up.

	Participants (*n* = 49)	Non-participants (*n* = 39)	*p* -value
Sex, *n* (%) boys	25 (51)	19 (49)	.83[a]
Gestational age, weeks, *M* (*SD*)	29.30 (1.56)	28.95 (2.09)	.36[b]
Birth weight, grams, *M* (*SD*)	1273.78 (360.16)	1078.21 (305.20)	.01[b]
Small for gestational age[c], *n* (%)	12 (24)	12 (31)	.51[a]
Caesarean section, *n* (%)	28 (57)	21 (54)	.76[a]
Bronchopulmonary dysplasia[e], *n* (%)	14 (29)	13 (33)	.63[a]
Intraventricular hemorrhage grade I/II, *n* (%)	7 (14)	14 (36)	.02[a]
Intraventricular hemorrhage grade III/IV, *n* (%)	1 (2)	2 (5)	.58[d]
Periventricular leukomalacia, *n* (%)	1 (2)	5 (13)	.08[d]
Patent ductus arteriosus, *n* (%)	7 (14)	7 (18)	.64[a]
Retinopathy of prematurity, *n* (%)	4 (8)	4 (10)	1.00[d]
Necrotizing enterocolitis, *n* (%)	0 (0)	2 (5)	.19[d]
≥1 serious infection[f], *n* (%)	30 (61)	26 (67)	.60[a]

Note. *M* = mean, *SD* = standard deviation. [a]chi-square test. [b]t-test. [c]birth weight <10th percentile. [d]Fisher's exact test. [e]oxygen requirement at 36 weeks postmenstrual age. [f]sepsis, pneumonia, meningitis, pyelonephritis, or arthritis diagnosed based on a combination of clinical signs and positive culture.

follow-up, of whom 55 agreed to participate in all assessments of the current 13-years follow-up. Measurements of six very preterm born adolescents were unsuccessful because of time constraints (*n* = 2), motor problems that prevented handling of the response box (*n* = 3) or behavioral difficulties (*n* = 1). Perinatal characteristics of the very preterm born sample are presented in Table 1, along with characteristics of those lost to follow-up. Controls were classmates of the very preterm participants or recruited from schools located in the surroundings of Amsterdam, born at term (≥37 weeks of gestation), and free of developmental, behavioral, or learning disorders. A total of 61 full-term born adolescents participated. Table 2 presents the demographic characteristics and general functioning of both the very preterm and full-term samples.

Alternating serial reaction time task

The task design of the ASRT is depicted in Figure 1. A row of four squares was presented on a black background on a computer screen. In each trial, one of the squares turned yellow which required a press on the corresponding response button. Adolescents were instructed to let four fingers of their dominant hand rest on the response buttons. The inter-stimulus interval was 120 ms. The next trial only appeared after a correct response. The stimuli constituted an eight-element sequence (3R1R2R4R), in which the location of the first, third, fifth, and seventh element were determined by a fixed sequence (indicated by digits) and alternated with elements that appeared at a random location (indicated by R). Stimuli were presented in test blocks that each started with five random trials followed by ten repetitions of the eight-element sequence, resulting in 85 trials per block. The test included a practice block of 16 random trials followed by 15 test blocks. In line with previous

Table 2. Characteristics of the very preterm and full-term sample.

	Very preterm (*n* = 49)	Full-term (*n* = 61)	*p* -value
Age at assessment, *M* (*SD*)	13.31 (0.32)	13.27 (0.53)	.55[a, b]
Sex, *n* (%) boys	25 (51)	34 (56)	.62[c]
Parental education, *n* (%) ≥bachelor degree or equivalent	31 (63)	38 (62)	.92[c]
Estimated full-scale IQ, *M* (*SD*)	99.94 (15.26)	110.54 (10.71)	<.001[a]
Motor impairment[d], *n* (%)	15 (31)	5 (8)	.002[c]
Special educational support[e], *n* (%)	11 (22)	3 (5)	.006[c]

[a]independent samples t-test. [b]degrees of freedom (100.48) were adjusted because of violation of the assumption of homogeneity of variance. [c]χ^2 test. [d]Movement Assessment Battery for Children (2[nd] edition) total test score ≤5th percentile of the normative population. [e]this includes both schools for special education and special educational assistance within regular classes.

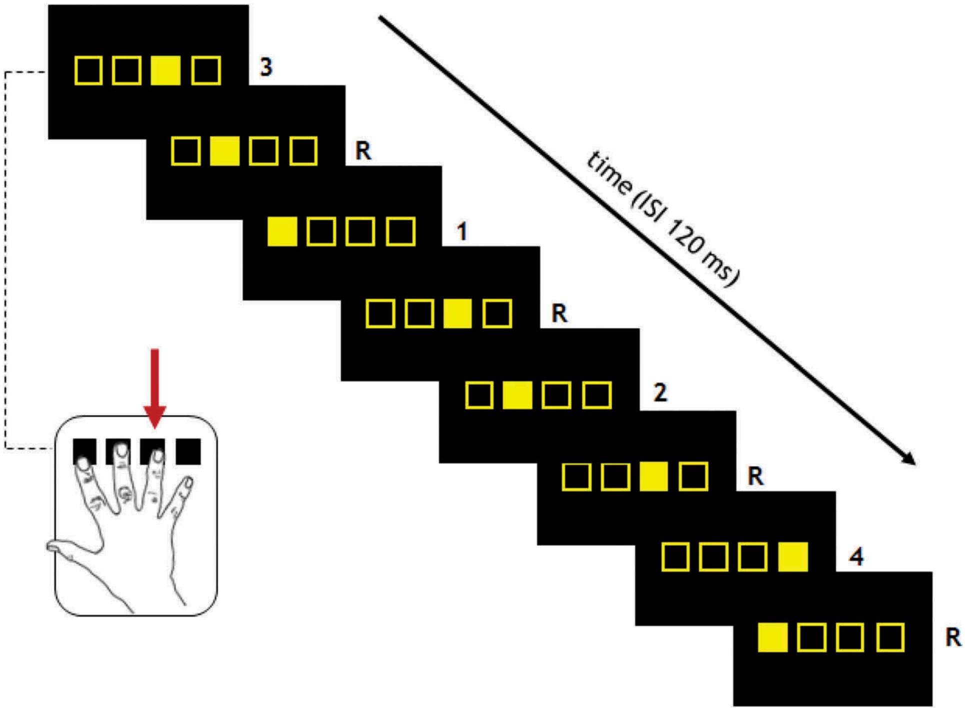

Figure 1. Design of the alternating serial reaction time task in which consecutive trials form an eight-element sequence of which the location of the first, third, fifth, and seventh element are fixed (3, 1, 2, 4) and alternated with elements with a random location (R). Each trial requires a press on the button that corresponds with the location of the yellow square on the screen. The inter-stimulus interval (ISI) was 120 ms.

studies, adolescents were instructed to respond as fast as possible while maintaining an accuracy rate of ~92%. This was supported by differential feedback after each block prompting participants to focus more on accuracy if the accuracy rate was <91% and more on speed if the accuracy rate was >93%. If the accuracy rate was 91–93%, participants were encouraged to continue the same way. This strategy has previously been shown to minimize the effects of different response strategies across participants or groups (Negash, Howard, Japikse, & Howard Jr, 2003). After completion of the task, awareness of the sequence was evaluated using increasingly specific questions about the pattern. None of the adolescents reported explicit awareness of the sequence.

As a result of the fixed sequence, some combinations of three elements (triplets) occur more frequently than others. Given the above sequence, the triplet 341 occurs with a high frequency, because 3 and 1 are fixed elements of the sequence, whereas the triplet 421 occurs with a low frequency as 4 and 1 are random elements. Triplets including repetitions (e.g. 111) or trills (e.g. 313) were excluded from the analyses as responses to these triplets were found to be influenced by preexisting response tendencies (Howard et al., 2004). Reaction time (RT) and accuracy (%) for high- versus low-frequency triplets were used as measures of implicit sequence learning. General skill learning is reflected in the decrease in RT with task progression irrespective of triplet type, while sequence-specific learning is reflected by faster RTs and higher accuracy for high- relative to low-frequency triplets (Howard & Howard, 1997). RTs and accuracy rates were averaged in five epochs of three blocks each to facilitate data processing.

Visuospatial working memory and intelligence

In order to test the assumption that implicit learning is mostly independent of working memory and intelligence, a spatial span task (Nutley, Söderqvist, Bryde, Humphreys, & Klingberg, 2009) was used to assess visuospatial working memory and intelligence was assessed using a short form of the Wechsler Intelligence Scale for Children, third edition (WISC-III; Wechsler, 1991).

In the spatial span task, a 4 × 4 grid was presented on a touch screen in which a sequence of stimuli (yellow dots) of increasing length appeared. Sequences had to be reproduced in reversed order by tapping on the screen. Difficulty was determined by sequence length, path crossing, and distance between stimuli. Each difficulty level consisted of two trials. If none of both trials could be reproduced the task was terminated. The highest completed difficulty level multiplied by the number of correct trials was used as a measure of working memory (Nutley et al., 2009).

The Vocabulary and Block design subtests of the WISC-III were used to estimate the intelligence level. This short form correlates strongly ($r > .90$) with full-scale IQ (Sattler, 2008).

Procedure

The study was conducted according to the principles of the Declaration of Helsinki (2013) and approved by the local research ethics committee. Informed consent was signed by parents and adolescents. Tests were individually administered in a quiet room by trained testers using standardized instructions. The tasks described in this study were administered as part of a 4-hour assessment (including breaks).

Statistical analysis

Statistical analyses were performed using SPSS version 25 (IBM Inc. Armonk, New York). Group differences on perinatal and demographic variables and general functioning were evaluated using independent samples *t*-test and χ^2-test. A 2 × 2 × 5 mixed-effects ANOVA was conducted, with group (very preterm, full-term) as between-subjects variable and triplet type (high-frequency, low-frequency) and epoch (1–5) as within-subjects variables. The triplet type × epoch interaction was additionally tested for both groups separately, to verify that implicit learning occurred in the very preterm and full-term born group. Moreover, the triplet type × group interaction was also analyzed per epoch to assess the degree of learning at the different phases of practice. Very preterm born children generally show slower processing speed (Hutchinson, De Luca, Doyle, Roberts, & Anderson, 2013; Mulder, Pitchford, & Marlow, 2011). To account for possible differences in baseline speed between groups that may affect the room for improvement, analysis of general skill learning (i.e. decrease in RT with task progression irrespective of triplet type) was adjusted for median RT for epoch 1. To control for baseline speed in the analyses of implicit learning, implicit learning proportional to baseline speed was calculated as (RT low-frequency – high-frequency)/low-frequency triplets (Barnes et al., 2008). This proportional measure of learning was used as the outcome in a 2 × 5 mixed-effects ANOVA, with group as between-subjects variable and epoch as within-subjects variable. Effect size benchmarks for partial η^2 were .01 (*small*), .06 (*medium*), and .14 (*large*; Cohen, 1992). The relation between implicit learning and visuospatial working memory was tested using Pearson's correlation.

Results

Compared to adolescents who were lost to follow-up, adolescents participating in the current study had higher birth weight and there was a lower prevalence of mild intraventricular hemorrhage in this group (Table 1). Comparison of very preterm and full-term born adolescents showed no differences between groups in age, sex, and level of parental education (Table 2). Adolescents born very preterm had significantly lower intelligence levels and a larger proportion showed motor impairments and special educational needs, compared to adolescents born at term (Table 2).

General skill learning

Figures 2 and 3 present the reaction times and accuracy rates, respectively, for low- and high-frequency triplets with task progression for both groups. Very preterm born adolescents exhibited slower RTs than full-term born adolescents (main effect group: $F(1, 108) = 6.31$, $p = .01$, $\eta_p^2 = 0.06$). The overall accuracy (%) of very preterm born adolescents (M= 91.46, SE= 0.46) was not different from full-term controls ($M = 90.57$, $SE = 0.41$; $F(1, 108) = 2.10$, $p = .15$, $\eta_p^2 = 0.02$). These percentages are close to 92%, showing that the provided differential feedback was effective for both groups.

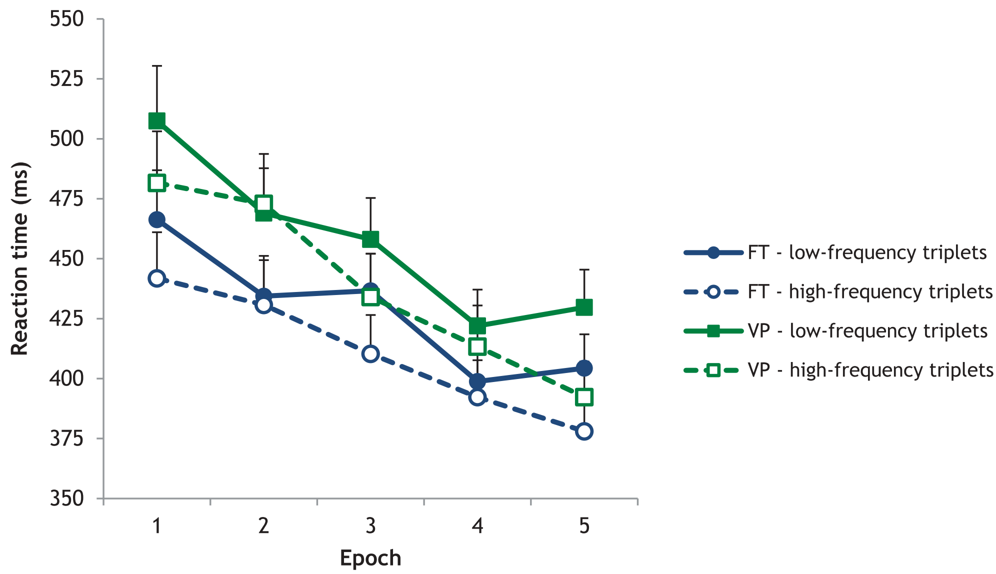

Figure 2. Median reaction time with 95% confidence intervals per epoch for low-frequency (solid lines) and high-frequency (dashed lines) triplets for the very preterm (VP) and full-term (FT) born group.

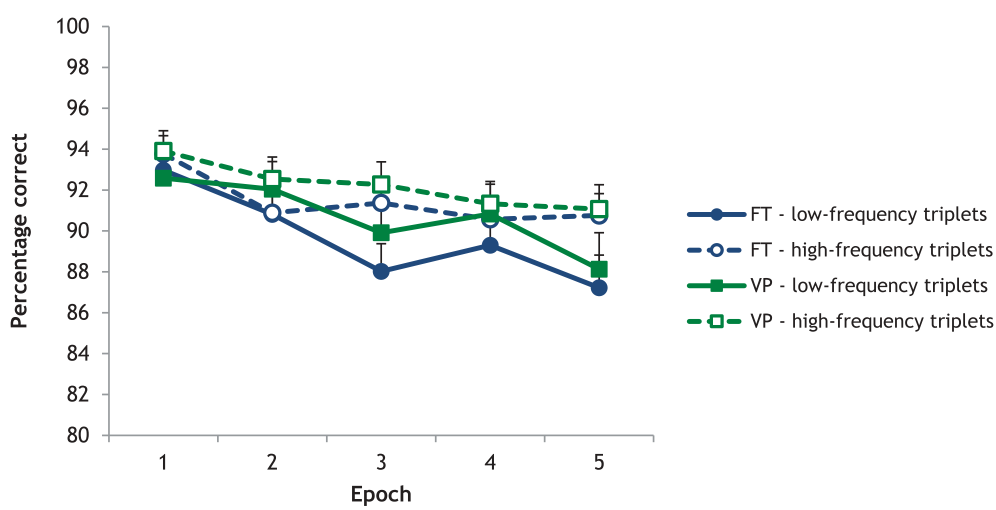

Figure 3. Mean percentage of correct trials with 95% confidence intervals per epoch for low-frequency (solid lines) and high-frequency (dashed lines) triplets in the very preterm (VP) and full-term (FT) born sample.

General skill learning was indicated by a significant decrease in RT with task progression, irrespective of triplet type (main effect epoch: $F(2.30, 247.82) = 159.97$, $p < .001$, $\eta_p^2 = 0.60$). There was a significant group × epoch interaction ($F(2.30, 247.82) = 4.16$, $p = .01$, $\eta_p^2 = 0.04$). Planned contrast analysis revealed a larger decrease in RT in very preterm than full-term adolescents between epoch 2–3 ($F(1, 108) = 8.03$, $p = .01$, $\eta_p^2 = 0.07$) and epoch 4–5 ($F(1, 108) = 4.67$, $p = .03$, $\eta_p^2 = 0.04$). A similar but non-significant trend was found between epoch 3–4 ($F(1, 108) = 2.91$, $p = .09$, $\eta_p^2 = 0.03$). However, when adjusted for baseline speed (i.e. RT in the first epoch), no significant group × epoch interaction was found ($F(3.25, 347.47) = 0.82$, $p = .49$, $\eta_p^2 = 0.01$), which indicates that the larger decrease in RT in the very preterm sample can be attributed to their slower RT at baseline compared to controls. Accuracy decreased during task progression (main effect epoch: $F(3.39, 366.05) = 32.79$, $p < .001$, $\eta_p^2 = 0.23$).

Implicit sequence learning

RT was faster for high- than low-frequency triplets (main effect triplet type: $F(1, 108) = 169.13$, $p < .001$, $\eta_p^2 = 0.61$). The effect of triplet type was not different across groups (group × triplet type: $F(1, 108) = 0.12$, $p = .73$, $\eta_p^2 = 0.001$). Similarly, accuracy rates were higher for high- than for low-frequency triplets (main effect triplet type: $F(1, 108) = 58.03$, $p < .001$, $\eta_p^2 = 0.35$). This difference in accuracy between high- and low-frequency triplets was not different for very preterm and full-term born adolescents (group × triplet type: $F(1, 108) = 0.41$, $p = .52$, $\eta_p^2 = 0.004$).

Implicit sequence learning was reflected by a significant triplet type × epoch interaction for RT ($F(4, 432) = 34.21$, $p < .001$, $\eta_p^2 = 0.24$), which was present in both the very preterm ($F(4, 192) = 18.39$, $p < .001$, $\eta_p^2 = 0.28$) and full-term born sample ($F(4, 240) = 16.01$, $p < .001$, $\eta_p^2 = 0.21$), showing a larger decrease in RT for high- than low-frequency triplets with practice. No differences in implicit sequence learning were found between very preterm and full-term born adolescents, as indicated by the non-significant group × triplet type × epoch interaction ($F(3.85, 415.71) = 2.17$, $p = .07$, $\eta_p^2 = 0.02$; Figure 2). With respect to the accuracy, the significant triplet type × epoch interaction ($F(3.69, 398.77) = 10.49$, $p < .001$, $\eta_p^2 = 0.09$) indicated that the decrease in accuracy with task progression was mostly due to a decline in accuracy for low-frequency triplets and relatively stable accuracy rates for high-frequency triplets (Figure 3). Again, the group × triplet type × epoch interaction was not significant ($F(3.69, 398.77) = 0.78$, $p = .53$, $\eta_p^2 = 0.01$), indicating no differences in implicit sequence learning between very preterm and full-term born adolescents.

Testing the group × triplet type interaction per epoch revealed a significantly larger difference in RT between triplet types in very preterm than in full-term born adolescents at epoch 5 ($F(1, 108) = 5.95$, $p = .02$, $\eta_p^2 = 0.05$), while this was not found for epoch 1–4. This may be attributed to the slower overall RT and hence a larger room for improvement in very preterm born adolescents, which may be suggested by the larger decrease in RT in very preterm born adolescents compared to controls that was described above. Using implicit learning proportional to baseline speed as a measure of outcome, similar results were found. The group × epoch interaction was not significant ($F(4, 432) = 2.27$, $p = .06$, $\eta_p^2 = 0.02$). However, there was a significant difference in proportional learning between groups at epoch 5 only ($t(108) = -2.25$, $p = .03$, $d = 0.43$). This indicates increased sequence-specific learning in very preterm born adolescents during the last epoch compared to full-term born adolescents, which was not related to the observed slower overall RT in very preterm born adolescents.

Visuospatial working memory and intelligence

Adolescents born very preterm (M = 53.50, SD = 32.73) showed poorer visuospatial working memory than full-term born controls (M = 72.04, SD = 34.75; $F(1, 107) = 8.05$, $p = .01$, $\eta_p^2 = 0.07$). Implicit learning as indicated by the difference in RT between triplet types was neither correlated with visuospatial working memory ($r = 0.05$, $p = .64$) nor with intelligence ($r = -0.04$, $p = .71$).

Discussion

In the present study, we examined implicit sequence learning abilities in very preterm and full-term born adolescents at thirteen years of age. The ASRT allowed to differentiate between general skill learning and implicit sequence learning. Adolescents born very preterm exhibited slower overall RTs but also a larger decrease in RT with practice than full-term peers. However, when the difference in baseline speed was taken into account, a difference between groups in the decrease of RT with task progression was no longer observed, indicating no difference in general skill learning between very preterm and full-term born adolescents. Implicit sequence learning was inferred from both RT and accuracy data. The decrease in accuracy primarily for low-frequency triplets has previously been reported by a number of studies (e.g. Howard et al., 2004; Howard Jr, Howard, Japikse, & Eden, 2006; Takács et al., 2018) and is thought to reflect implicit learning. It has been suggested that increased learning of the sequence structure results in bias towards positions that are part of that structure and a parallel increase of errors on random trials that cannot be predicted from the sequence structure (Howard Jr et al., 2006). Sequence-specific learning occurred in both groups and no differences were found in the extent of implicit sequence learning between groups, suggesting that implicit learning processes in very preterm born adolescents are intact. However, when looking at specific phases of practice, the extent of learning in the last epoch was larger in very preterm born adolescents than in controls, while no differences were found in previous epochs. Similar results were found when the slower baseline speed of very preterm born adolescents – which could indicate a larger room for improvement – was taken into account. This means that very preterm born adolescents showed prolonged learning compared to full-term born peers.

The present findings indicated intact implicit learning abilities in very preterm born adolescents and converge with earlier findings of Jongbloed-Pereboom et al. (2017). These findings may be explained by the relative independence of implicit learning processes from executive control processes, which are thought to be one of the fundamental impairments after very preterm birth (Burnett, Scratch, & Anderson, 2013). Indeed, no meaningful association was found between implicit learning and visuospatial working memory and intelligence in the present study. The functional interaction between the prefrontal cortex and other brain regions is critical for working memory (D'Esposito, 2007). Functional MRI studies showed overlapping activation patterns during explicit and implicit learning, but increased prefrontal activation during explicit relative to implicit sequence learning (Aizenstein et al., 2004). Moreover, results from Destrebecqz et al. (2005) suggest that the medial prefrontal cortex and anterior cingulate cortex exert control over the striatum during explicit learning, while frontal and striatal regions did not interact during implicit sequence learning. Very preterm birth is associated with abnormal white matter microstructure that is thought to contribute to an important extent to neurodevelopmental impairments after very preterm birth (Keunen et al., 2017; Woodward, Clark, Bora, & Inder, 2012). These white matter abnormalities may have less impact on implicit learning, because of the limited involvement of executive control processes in implicit learning (Janacsek & Nemeth, 2013; Kaufman et al., 2010; Unsworth & Engle, 2005) which was supported by the uncoupled frontal and striatal activity during implicit sequence learning (Destrebecqz et al., 2005).

Our findings show that very preterm born adolescents were not only able to implicitly learn a sequence, but they were able to do so to a similar extent as their full-term born counterparts. Moreover, implicit learning was apparent in the first epoch and to a similar extent in both groups. This demonstrates that very preterm born adolescents did not need more practice to acquire the hidden sequence structure, i.e. they were equally responsive to probabilistic learning as full-term born peers. These findings may have important implications for interventions in this population, suggesting that very preterm born adolescents may benefit from implicit learning approaches that place minimal demands on executive control processes. Maxwell, Masters, Kerr, and Weedon (2001) stated that implicit as opposed to explicit learning is less likely to involve the formulation of rules and hypothesis modification in response to errors. They proposed that implicit learning could, therefore, be encouraged by reducing errors during the learning process (Maxwell et al., 2001). The so-called errorless learning approach has been shown to result in improved motor skill learning in children with low motor ability (Maxwell, Capio, & Masters, 2017) and children with intellectual disability (Capio, Poolton, Sit, Eguia, & Masters, 2013) compared to explicit errorful learning. For very preterm born children, an implicit learning approach may also be effective to improve motor skills, which have been found to be considerably impaired in this population (De Kieviet et al., 2009). Whether similar implicit learning approaches can be used to improve academic performance in very preterm born children is questionable. Both implicit and explicit processes are involved in learning and performance in a certain domain cannot be fully ascribed to either implicit or explicit learning (Sun, Slusarz, & Terry, 2005). Academic performance reflects the aggregation of a large range of cognitive skills of which we do not know whether these can be enhanced using implicit learning strategies. Moreover, academic performance measures are mostly focused on explicit, declarative knowledge.

In our sample of very preterm born adolescents, there was evidence for selective loss to follow up. Moreover, parental education levels were high. These limitations may affect the generalization of the present findings to the population. Furthermore, there may be subgroups of very preterm born children that do exhibit impaired implicit learning. Given the interaction between implicit and explicit processes in skill learning, another drawback of the present study is that explicit learning was not assessed. Future studies with larger samples are necessary to further study different aspects of learning in very preterm born children with consideration of individual variation, and to examine whether these children indeed benefit from implicit as opposed to explicit learning strategies. Despite the aforementioned limitations, the current study makes an important contribution to the limited research on learning in very preterm born children. Besides studying difficulties in very preterm born children, identification of possible strengths is important as well, as these can be built on in developing interventions. The intact implicit learning ability as shown in the present study is such a strength that may provide a different approach for interventions in this population, which is necessary given the lack of improvements of outcomes after very preterm birth and the limited evidence of effective intervention strategies.

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