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The relevance of the irrelevant: Attention and task-set adaptation in prematurely born adults

Ida Emilia Aasen [a,b,c,*], Asta Kristine Håberg [a,d], Alexander Olsen [e,f], Ann-Mari Brubakk [g], Kari Anne I. Evensen [g,h,i], Anne Elisabeth Sølsnes [g], Jon Skranes [g,j], Jan Ferenc Brunner [b,c,d,f]

[a] Department of Medical Imaging, St. Olavs Hospital, Trondheim University Hospital, Norway
[b] Department of Psychology, Norwegian University of Science and Technology (NTNU), Trondheim, Norway
[c] Department of Neuropsychology, Helgeland Hospital, Mosjøen, Norway
[d] Department of Neuroscience, NTNU, Trondheim, Norway
[e] MI Lab and Department of Circulation and Medical Imaging, NTNU, Trondheim, Norway
[f] Department of Physical Medicine and Rehabilitation, St. Olavs Hospital, Trondheim University Hospital, Norway
[g] Department of Laboratory Medicine, Children's and Women's Health, NTNU, Trondheim, Norway
[h] Department of Public Health and General Practice, NTNU, Trondheim, Norway
[i] Department of Physiotherapy, Trondheim Municipality, Norway
[j] Department of Pediatrics, Sørlandet Hospital, Arendal, Norway

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HIGHLIGHTS

- This study investigated ERP components in a group of adults born preterm with very low birth weight.
- The preterm group allocated excessive attention to irrelevant stimuli as reflected in P3 amplitudes.
- Unlike term-born controls, the preterm group persisted in attending to irrelevant stimuli over time.

ABSTRACT

Objective: To investigate attention and task-set adaptation in a preterm born very low birth weight (PT/VLBW) population by means of event-related potential components from an adapted cued go/no-go task.
Methods: P3 components after target and non-target cues, as well as target, no-go and non-target imperative stimuli were compared in 30 PT/VLBW young adults and 33 term-born controls. Changes in P3 amplitudes as a function of time-on-task were also investigated.
Results: The PT/VLBW group had larger P3 amplitudes to non-target cues and non-targets compared with controls. There were no significant group differences in the P3s to target or no-go stimuli. Moreover, the amplitude of the P3 to non-target cues and non-targets decreased significantly over time in the control group but not in the PT/VLBW group.
Conclusions: PT/VLBW young adults allocate more attention to behaviorally irrelevant information than term-born controls, and persist in attending to this information over time.
Significance: This is the first study to investigate ERP components in an adult population born preterm with very low birth weight.

1. Introduction

Being born preterm (PT, before week 37 of gestation) with very low birth weight (VLBW, <1500 g) is associated with increased risk of perinatal brain injuries and compromised brain development that can have negative long-term consequences for cognitive function (Løhaugen et al., 2010; Nosarti et al., 2012). Increased prevalence of problems in the domains of executive attention and learning are particularly notable in PT/VLBW populations (Mulder et al., 2009; Murray et al., 2014; van der Weijer-Bergsma et al., 2008). Processes of attention and learning are interactive, and a central aspect of learning is to prioritize to which aspects of the environment attention should be allocated. Some

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Abbreviations: ADHD, attention deficit hyperactivity disorder; VLBW, very low birth weight; ERP, event-related potential; PT, preterm; S–R, stimulus–response.

* Corresponding author at: Department of Psychology, Norwegian University of Science and Technology, 7491 Trondheim, Norway.

E-mail address: ida.aasen@ntnu.no (I.E. Aasen).

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studies indicate that attention problems in PT/VLBW infants are related specifically to excessive attention to distractors (van de Weijer-Bergsma et al., 2008). Furthermore, inflexible and persistent gazing as well as unusual and random errors involving responses to previously non-rewarded stimuli characterizes young PT/VLBW populations (Espy et al., 2002; Kittler et al., 2011; Woodward et al., 2005). Whether or not the described characteristic of excessive attention to irrelevant information still characterizes PT/VLBW populations in adulthood has not previously been investigated.

Earlier studies on PT/VLBW populations, have primarily investigated attention problems by means of behavioral measures and clinical interviews. Behavioral measures, however, represent the end-point of many sensory, perceptual and cognitive processes. In contrast, event-related potentials (ERPs) have exquisite temporal resolution and give insight into neural processes underlying behavior. The method also enables the study of cognitive processes in task conditions where no overt responses are made. Previous cognitive ERP studies on PT/VLBW populations are limited, and have only investigated oddball paradigms in children, not finding any significant differences in the target P3 component (e.g. Lindgren et al., 2000; Potgieter et al., 2003). To date, no studies of cognitive ERPs have been conducted in adult VLBW populations.

1.1. P3 Components and the cued go/no-go task

Cued go/no-go tasks can be used to study ERP components related to attention and executive processes (Aasen and Brunner, 2016; Brunner et al., 2015; Checa and Rueda, 2011; Wiersema and Roeyers, 2009). The different conditions in such tasks elicit variants of the P3 ERP component, with different timing, amplitude and topography, reflecting different cognitive processes. Importantly, the amplitudes of all P3s are modulated by the amount of attentional resources allocated to specific cognitive operations (Polich, 2007). The different P3 components therefore reflect both specific cognitive processes, as well as the degree of attention allocated to these processes.

The most studied P3 component is the parietal P3b, which increases in amplitude as the behavioral significance of the preceding stimulus is learned (Rose et al., 2001). Although a matter of long-standing debate, there is accumulating evidence that the P3b reflects a bridge between stimulus evaluation and response selection, referred to as a stimulus–response (S–R) link (Verleger et al., 2005; Verleger et al., 2014a,b). Most often, the P3b is studied in the target condition where an active response is given immediately. In addition to targets, however, cue stimuli that provide essential information for response selection following the imperative stimulus, will also elicit a P3b-like component. This component has been interpreted as a pre-activation of the P3b (Verleger et al., 2015), thereby primarily reflecting the same process as the target P3b. Alternatively, the cue-P3 has been interpreted as a process is somewhat different from the target P3, reflecting the resolution of response uncertainty regarding what S–R mappings that should be prepared (Barceló et al., 2007). In some types of tasks, two cue-P3 components with differing latencies can be identified (Barceló et al., 2007; Nicholson et al., 2006). In those tasks, it has been hypothesized that the later latency component reflects more detailed, or in depth preparatory processes, whereas the earlier latency component reflects more automatized activation of well-learned, and readily available task rules.

1.2. Task-setting, S–R links, and the P3b

One possible explanation for the elevated rates of random and unusual errors in PT/VLBW populations is problems related to task-setting. Task-setting, or the forming and selection of task relevant rules, is fundamental to all learning (Stuss and Alexander, 2007). The task-set can be regarded as the sum of all the S–R links in a task that are regarded as relevant for task performance.

The relative weighting of the different S–R links is adapted during task performance, as the participant understands the relevance of the different links. This process selectively drives attention to relevant task characteristics while reducing attention to irrelevant information. These adaptations lead to corresponding changes in P3 amplitudes (Rose et al., 2001). The amplitude of the P3 elicited by stimuli that do not require any type of active (mental or behavioral) response is significantly reduced over the course of the first few stimulus presentations (Verbaten et al., 1986), whereas a large number of trials is needed before a reduction in P3 amplitude is detected for stimuli that have a significant *signal value* (Polich and McIsaac, 1994; Romero and Polich, 1996). In accordance with the S–R link hypothesis of the P3b, the initial P3 activation following non-targets could be interpreted as non-targets (S) being linked with a non-response (R). After some practice, however, attention is selectively allocated to the S–R links that are regarded as relevant for task performance. Investigating changes in P3 amplitude as an effect of time-on-task may therefore elucidate how being born preterm can affect how the task-set is adapted during task performance.

In this study, ERP components from a cued go/no-go task was used to investigate attentional allocation and task-set adaptation in a population of PT/VLBW adults. The results will be interpreted in the framework of the S–R link hypothesis of the P3b. P3b amplitudes elicited by stimuli with significant behavioral relevance (target cues and targets) as well as P3b amplitudes elicited by behaviorally irrelevant stimuli (non-target cues and non-targets) were investigated. The more anteriorly distributed no-go P3 was also included in the analysis, as this component has been found to be of reduced amplitude in other populations with attention problems (Johnstone et al., 2013; Woltering et al., 2013). To investigate dynamics of task-set adaptation, changes in these P3s as an effect of time-on-task were analyzed. It was hypothesized that the PT/VLBW group would demonstrate significantly larger P3b amplitudes to behaviorally irrelevant stimuli, compared with controls. The PT/VLBW group was also expected to exhibit smaller reduction of these P3 amplitudes over time compared with controls. Correlation analyses were performed in order to explore whether group ERP differences were related to birth weight or gestational age.

2. Materials and methods

2.1. Participants

The PT/VLBW group consisted of 30 young adults (18 female) born preterm (before 37th week of gestation) with very low birth weight ($\leqslant 1500$ g). At 14 years of age, 63 adolescents met for examination. At 23 years, seven of these young adults were untraceable and two were not testable due to severe quadriplegic cerebral palsy. The remaining 54 PT/VLBW young adults were contacted for participation in the study. Of these young adults, 21 (39%) did not consent, leaving 33 (61%) young adults for examination. The recording of one participant was excluded due to excessive artifacts in the EEG, and two were excluded because of technical difficulties that terminated the recordings prematurely.

At the time of testing, 16 (53%) of the PT/VLBW participants had completed high school and/or started higher education, whereas the remaining 14 (47%) participants had chosen vocational training rather than ordinary high school or had not completed high school. Three of the PT/VLBW participants had cerebral palsy as assessed through a neurological examination at age 23. Removing these three participants from the analyses did not significantly alter any of the results from the present study. Based on the IQ assessment, two of the participants had an IQ below 70, qualifying for a diagnosis of mental retardation. Also, based on diagnostic interviews at age 19, three of the participants fulfilled criteria for a diagnosis of attention deficit hyperactivity disorder (ADHD; information missing for four participants), and one participant fulfilled criteria for an autism spectrum disorder. In the PT/VLBW group, the mean age at ERP registration was 22.0 years (SD = 0.8 years, range = 21–23 years).

The control group consisted of 33 young adults (18 female) born at term with a birth weight greater than the 10th percentile adjusted for gestational age based on data from the Norwegian Medical Birth Registry (Skjaerven et al., 2000). From a list of 76 eligible controls, we contacted 48 controls matched for age and sex to the VLBW participants. Five of these controls had moved too far away and seven did not consent. One participant was excluded due to excessive artifacts in the EEG. At the time of testing, 24 (73%) of the control participants had completed high school and/or started higher education, whereas the remaining 9 (27%) participants had chosen vocational training rather than ordinary high school or had not completed high school. None of the control participants qualified for a diagnosis of any neurological or developmental disorder. The mean age at ERP registration was 22.1 years (SD = 0.8 years, range = 21–23 years) in the control group.

The clinical characteristics of the PT/VLBW and control participants and non-participants can be found in Table 1. Socio-economic status was calculated according to the Hollingshead Two Factor Index of Social Position, based on the education and occupation of one parent or the mean index from both parents (Hollingshead, 1958). Information about education and occupation of the parents was obtained through an interview. IQ was assessed with a standardized IQ test (Wechsler's Adult Intelligence Scale; WAIS-III) at age 19 by a trained neuropsychologist. One of the control participants in the present study did not participate in the IQ assessment. Neither the PT/VLBW or control participants in the present study differed significantly from the non-participants on birth weight, gestational age, socio-economic status or IQ.

The participants were assigned project ID-numbers concealing group membership, blinding the researcher performing the EEG-recordings (JFB) to group membership until data collection was finalized. Written informed consent was obtained from all participants prior to participation in the study. The Regional Committees for Medical and Health Research Ethics in Norway approved this study.

2.2. Cued go/no-go task

While performing the cued go/no-go task, the participants sat ~1.5 m from a 17-inch computer screen. The task consisted of 400 pairs of images presented against a white background. To minimize quick habituation due to frequently and repeatedly presented stimuli, the task contained 60 different images, divided into three categories of stimuli with 20 different images of each type—animals (A), plants (P) and humans (H). These images were presented in pairs. The first stimulus in a pair was either a target cue (A1) or a non-target cue (P1). The cue was followed by another image in one of four possible combinations: A-*A* (target), A-*P* (no-go), P-*P* (non-target) or P-*H* (novel). To maintain alertness, the human (H) stimuli were paired with sounds of different frequencies (500, 1000, 1500, 200 and 2500 Hz) presented at an intensity of 70 dB. The four possible combinations were equally probable, and the first and second stimulus in A-A and P-P pairs were always identical. The stimuli were presented for 100 ms with a 1000 ms inter-stimulus interval between the cue and the imperative stimulus, and 1800 ms between the offset of the imperative stimulus and the onset of the cue for the next trial, giving an inter-trial interval of 3000 ms. The images were of approximately equal size and luminance. The trials were grouped into four 100 trial blocks, each of which consisted of a set of five new images of each category. Each block contained an equal number of trials of each type, but were otherwise presented in a random order.

Participants were instructed to press a button as quickly as possible when seeing the last A in every A-A trial, and not to press the button A-P trials, and that no response would be required for P-P or P-H trials. The first image in a pair therefore represented either a cue signaling to keep attending and preparing for the imperative stimulus (target cue; A1), or a signal that the second image will not be relevant for action (non-target cue; P1). The participants were not informed about the probability of the different task conditions, and were not explicitly told that A-cues are relevant whereas P-cues are irrelevant. Responses were given by pressing a mouse button with the right index finger.

Mean reaction time, standard deviation of the reaction time, and the number of errors of omission and commission were calculated for each participant. Responses were regarded as correct when occurring 200–1000 ms after the imperative stimulus in target (A-*A*) trials. Responses in the same time interval in no-go (A-*P*) trials were defined as commission errors.

2.3. EEG recording

A 21-channel Mitsar (http://www.mitsarmedical.com) EEG system with a 19-channel tin electrode cap was used for recording EEG. The cap contained electrodes Fz, Cz, Pz, Fp1/2, F3/4, F7/8, T3/4, T5/6, C3/4, P3/4, and O1/2, which were fitted according to the international 10–20 system. The electrodes on the cap were referenced to earlobe electrodes. The ground electrode was localized between the Fp1/2 and Fz electrodes. Impedance was below

Table 1
Group characteristics.

	VLBW			Control			VLBW vs. Control
	Participants *n* = 30 Mean (SD)	Non-participants *n* = 21 Mean (SD)	*p*	Participants *n* = 33 Mean (SD)	Non-participants *n* = 42 Mean (SD)	*p*	Participants *p*
Age at ERP recording (years)	22.03 (0.77)			22.12 (0.78)			.643
Birth weight (g)	1221 (240)	1169 (251)	.463	3598 (359)	3702 (482)	.307	<.001
Gestational age (weeks)	29.1 (2.8)	29.2 (2.7)	.942	39.5 (1.1)	39.7 (1.3)	.401	<.001
Parental SES at 14 years[a]	3.6 (1.1)	2.9 (1.3)	.056	3.6 (1.0)	3.8 (1.2)	.326	.787
Full scale IQ at 19 years (WAIS-III)[b]	87.7 (11.7)	92.8 (16.0)	.248	100.5 (11.2)	101.3 (12.4)	.934	<.001

Note: Independent samples *t*-tests for parametric variables, and Mann–Whitney *U* tests for non-parametric variables. VLBW = very low birth weight; SES = socio-economic status; WAIS-III = Wechsler's Adult Intelligence Scale, 3rd edition.

[a] Missing data for two control participants.

[b] Missing data for two control participants, eight VLBW non-participants and 11 control non-participants.

5 kΩ for all recordings. The recording had a sampling rate of 250 Hz, and a band pass of 0.3–50 Hz.

2.4. Correction of artifacts

Artifacts caused by eye-blinks were corrected by applying independent components analysis to the raw EEG, and then canceling out the activation curves of independent components corresponding to eye blinks (Jung et al., 2000; Vigario, 1997). Epochs of EEG with absolute amplitude above >100 μV in the unfiltered EEG were automatically excluded from further analysis. Error trials (omissions and commissions) were also excluded from analysis.

In the PT/VLBW group, the average number of artifact and error free trials used to compute ERPs was 185.0 (SD = 13.3; range = 149–200) for the target cue condition, 183.7 (SD = 16.1; range = 139–200) for the non-target cue condition, 92.8 (SD = 7.5; range = 65–100) for the target condition, 95.6 (SD = 4.2; range = 87–100) for the no-go condition, and 92.2 (SD = 7.9, range = 72–100) for the non-target condition.

In the control group, the average number of artifact and error free trials used to compute ERPs was 189.3 (SD = 10.7; range = 155–200) for the target cue (A1) condition, 188.7 (SD = 11.7; range = 154–200) for the non-target cue (P1) condition, 93.1 (SD = 6.6; range = 76–100) for the target (A-*A*) condition, 94.5 (SD = 5.2; range = 79–100) for the no-go (A-*P*) condition, and 94.6 (SD = 5.3, range = 78–100) for the non-target (P-*P*) condition.

2.5. Measurement of ERP component amplitudes

ERP component amplitudes were measured as the mean voltage in a time interval based on a collapsed localizers method (Luck, 2014), where the data are collapsed across the two groups to create grand mean ERP waveforms from which the time intervals are chosen. This method was chosen to avoid biasing selection of time-interval to where group differences are largest. To ensure that the chosen time-intervals contained what could be considered the component peak and not capturing larger parts of activity from preceding or following components, the chosen time intervals were also inspected individually for each participant. This inspection resulted in an adjustment of the time interval of the target and non-target P3 components to avoid picking up activity from the P2 component, an overlap, which was obscured in the collapsed ERPs. The choice of mean rather than peak amplitude measurement, was made because peak amplitude measurements are more vulnerable to distortion by noise than are mean amplitude measurements (Luck, 2014), which is a particular concern when measuring low voltage components such as the non-target P3.

Baseline was adjusted to the averaged voltage 100 ms before presentation of the stimulus of interest (stimulus 1 for the cues, stimulus 2 for the target, non-target and no-go stimuli).

The cue-P3 following target cues (A1) had two peaks with an early peak with maximum amplitude ~330 ms and a later peak with maximal amplitude ~440 ms after stimulus presentation. As can be observed in Fig. 1, both peaks had maximal voltage at the Pz electrode. For the cue-P3 following non-target cues (P1), a singular smaller peak with maximal amplitude at Pz was observed, corresponding in timing to the early cue-P3. The amplitude of the early cue-P3 in the target and non-target cue conditions were measured as the mean amplitude 300–380 ms after the presentation of the cue stimulus at the Pz electrode. The late cue-P3 was measured as the mean amplitude 400–480 after the presentation of the target cue at the Pz electrode.

The amplitude of the centro-parietally distributed target P3 component (from the A-*A* condition) was measured as the mean amplitude 280–370 ms after the presentation of the imperative stimulus at the Pz electrode. The parietally maximal non-target P3 (from the P-*P* condition) component was measured as the mean amplitude 300–380 ms after the presentation of the imperative stimulus at the Pz electrode. The amplitude of the fronto-centrally distributed no-go P3 component was measured as the mean amplitude 300–400 ms after the presentation of the no-go stimulus (A-*P*) at the Cz electrode.

2.6. Statistics

The data were analyzed using IBM SPSS Statistics 21.0. Tests of significant differences between the groups on the behavioral parameters from the cued go/no-go task were performed using independent samples *t*-tests for parametric variables and Mann–Whitney *U* tests for non-parametric variables.

Tests of significant differences in the ERP amplitudes and effects of time-on-task between the VLBW and the control group were calculated using a 2 × 2 ANOVA with group (PT/VLBW or control) as a between subjects factor and time-on-task (1st or 2nd half of the task) as a within subjects-factor. Alpha was set at $p < .05$. Partial eta squared was calculated as a measure of effect size. Post hoc comparisons were conducted using the Bonferroni correction. All data are reported as means and standard deviations. Correlations between ERP and background variables were performed for the ERP variables significantly differentiating the PT/VLBW and control groups.

3. Results

3.1. Performance data

Summary of the behavioral parameters from the cued go/no-go task in the two groups can be found in Table 2. There were no statistically significant differences in task performance between the two groups. When excluding the three participants who fulfilled diagnostic criteria for ADHD, the trend level group difference in omission errors ($p = .071$) disappeared ($p = .292$).

3.2. P3 amplitudes elicited by behaviorally relevant stimuli

The means and standard deviations of the ERP component amplitudes in the PT/VLBW and control group are presented in Table 3. After target cues (A1), the amplitude of the early cue-P3 was a mean of 1.23 μV (±0.90) larger in the PT/VLBW compared with the control group ($F(1, 61) = 7.52$, $p = .008$, $\eta_p^2 = .11$), and larger in the first compared with the second half of the task ($F(1, 61) = 24.45$, $p < .001$, $\eta_p^2 = .29$). The time-on-task by group interaction was not statistically significant ($F(1, 61) = 1.41$, $p = .239$, $\eta_p^2 = .02$).

There were no significant group differences in the amplitude of the late cue-P3 ($F(1, 61) = 0.52$, $p = .474$, $\eta_p^2 = .01$), but there was a significant effect of time-on-task, with larger amplitudes in the first compared with the second half of the task ($F(1, 61) = 5.06$, $p = .028$, $\eta_p^2 = .08$). The time-on-task by group interaction was not statistically significant ($F(1, 61) = 0.02$, $p = .899$, $\eta_p^2 = .00$).

The amplitude of the target P3 (from the A-*A* condition) was not significantly different across the PT/VLBW and control groups ($F(1, 61) = 0.10$, $p = .756$, $\eta_p^2 = .00$), but was significantly larger in the first compared with the second half of the task ($F(1, 61) = 17.80$, $p < .001$, $\eta_p^2 = .23$). The time-on-task by group interaction was not significant ($F(1, 61) = 0.01$, $p = .913$, $\eta_p^2 = .00$).

The no-go P3 (from the A-*P* condition), was not significantly different in the PT/VLBW compared with the control group ($F(1, 61) = 0.10$, $p = .749$, $\eta_p^2 = .00$), but was significantly larger at in the first

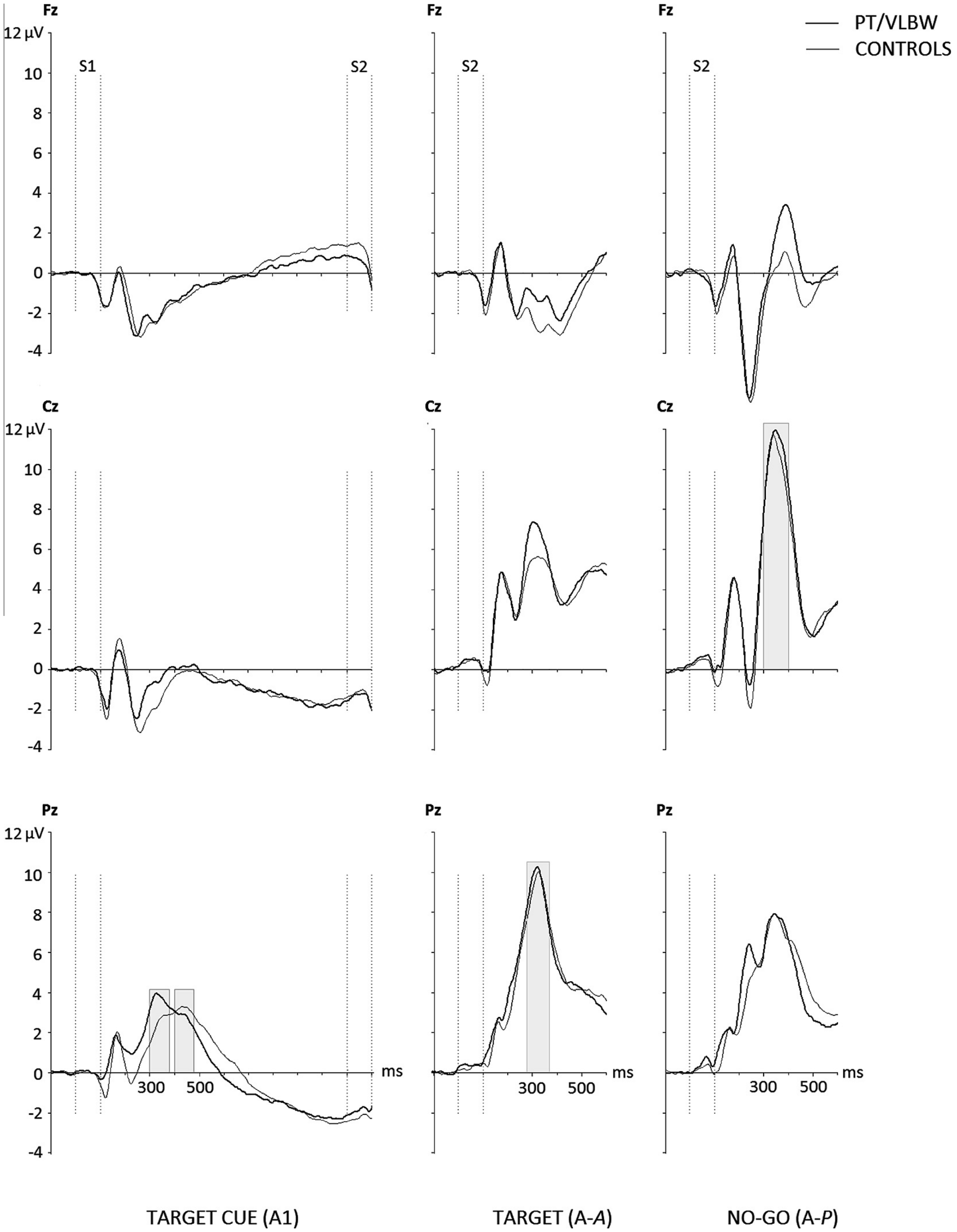

Fig. 1. ERPs following presentation of target cues, targets and no-go stimuli in the PT/VLBW (thick lines) and control (thin lines) groups at the midline electrodes. The time window for measurement of the P3 is marked.

Table 2
Performance data from the cued go/no-go task.

	VLBW Mean (SD)	Control Mean (SD)	*p*
Reaction time	355.8 (44.2)	348.0 (40.9)	.471
SD of reaction time	81.44 (24.4)	75.58 (21.4)	.314
Commission[a]	0.87 (1.5)	0.64 (1.0)	.864
Omission[a]	3.40 (4.3)	1.42 (1.6)	.071

Note: Means and standard deviations (SD) of the performance data from the cued go/no-go task in the VLBW ($n = 30$) and control ($n = 33$) groups, and tests of significant differences (t-tests or Mann–Whitney *U* tests) between the groups.

[a] Non-parametric variables.

compared with the second half of the task ($F(1, 61) = 24.45$, $p < .001$, $\eta_p^2 = .29$). The time-on-task by group interaction was not statistically significant ($F(1, 61) = 1.40$, $p = .242$, $\eta_p^2 = .02$). The ERPs from the target cue, target, and no-go conditions in the two groups can be seen in Fig. 1. Fig. 2 shows the ERPs from the first and second half of the task in the two groups.

3.3. P3 amplitudes following behaviorally irrelevant stimuli

After non-target cues (P1), the amplitude of the cue-P3 was a mean of 1.17 µV (±0.71) larger in the PT/VLBW compared with

Table 3
Descriptive statistics for the P3 component amplitudes.

	Electrode	VLBW			Control		
		Total Mean (SD)	T1 Mean (SD)	T2 Mean (SD)	Total Mean (SD)	T1 Mean (SD)	T2 Mean (SD)
Relevant stimuli							
Early cue-P3	Pz	3.58 (1.7)	3.89 (1.7)	3.40 (1.9)	2.46 (1.9)	2.81 (1.9)	2.01 (1.8)
Late cue-P3	Pz	2.81 (1.7)	3.00 (1.7)	2.65 (1.9)	3.19 (2.0)	3.32 (2.1)	3.02 (2.1)
Target P3	Pz	9.22 (3.0)	9.62 (3.2)	8.83 (2.9)	9.02 (2.3)	9.39 (2.2)	8.64 (2.7)
No-go P3	Cz	10.76 (5.0)	11.18 (5.4)	10.30 (4.9)	10.36 (4.8)	11.06 (5.0)	9.62 (4.7)
Irrelevant stimuli							
Early cue-P3	Pz	2.37 (1.7)	2.44 (1.7)	2.36 (1.8)	1.23 (1.1)	1.63 (1.3)	0.83 (1.2)
Non-target P3	Pz	1.70 (1.3)	1.89 (1.3)	1.57 (1.5)	0.79 (1.2)	1.30 (1.4)	0.25 (1.3)

Note: Mean amplitudes and standard deviation (SD) of the P3 components from the cued go/no-go task in the VLBW ($n = 30$) and control group ($n = 33$) in the total recording, as well as in the first (T1) and second (T2) half of the task.

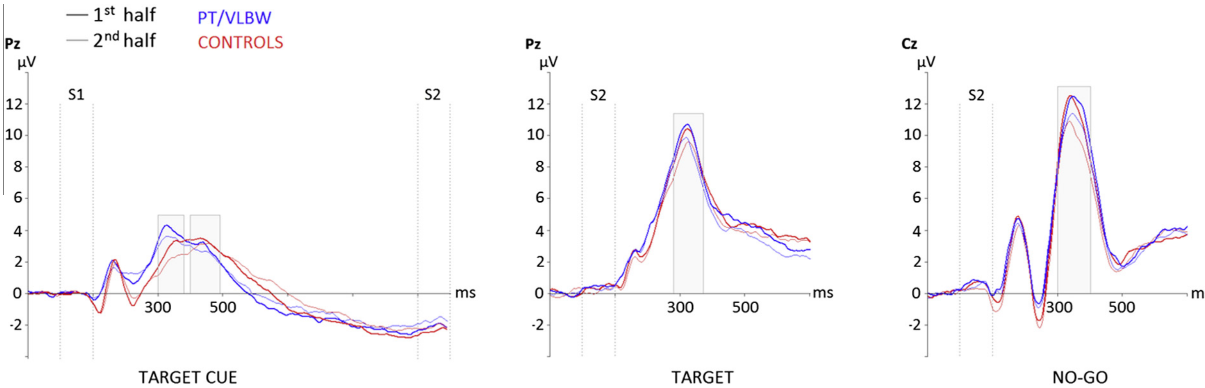

Fig. 2. Effects of time-on-task on the ERPs following the presentation of target cues (left panel), targets (middle panel), and no-go stimuli (right panel) in the PT/VLBW (blue lines) and control (red lines) groups. The thick lines show the ERPs from the first half of the task and the thin lines show the ERPs form the second half of the task.

the control group ($F(1, 61) = 10.86$, $p = .002$, $\eta_p^2 = .16$), and larger in the first compared with the second half of the task ($F(1, 61) = 13.25$, $p = .001$, $\eta_p^2 = .18$). The time-on-task by group interaction was also significant ($F(1, 61) = 8.89$, $p = .004$, $\eta_p^2 = .13$), with the amplitude of the cue-P3 decreasing significantly more in the control group compared with the PT/VLBW group. Pairwise comparisons revealed that the P3 to non-target cues decreased significantly in amplitude in the control group over time (−0.80 µV, ±0.36), while there was no significant reduction in the PT/VLBW group (−0.08 µV, ±0.44).

The non-targets (P-*P*), elicited a non-target P3 that was a mean of 0.95 µV (±0.63) larger in the PT/VLBW group compared with the controls ($F(1, 61) = 9.13$, $p = .004$, $\eta_p^2 = .13$), and larger at in the first compared with the second half of the task ($F(1, 61) = 18.51$, $p < .001$, $\eta_p^2 = .23$). The time-on-task by group interaction also significant ($F(1, 61) = 4.18$, $p = .026$, $\eta_p^2 = .08$) in the same direction as for the non-target cue-P3. Pairwise comparisons of the non-target P3 at the two time points in the two groups revealed that whereas there was no statistically significant change in the PT/VLBW group (−0.32 µV, ±0.51), this was the case in the control group (−0.99 µV, ±0.54). The ERPs from the non-target cue and non-target conditions in the two groups can be seen in Fig. 3, and the time-on-task effects for these conditions can be seen in Fig. 4.

3.4. Relations to gestational age and birth weight

There were no statistically significant correlations between gestational age and the non-target cue-P3 ($r = .17$, $p = .370$) or non-target P3 ($r = -.12$, $p = .531$) amplitude, or between birth weight and the non-target cue-P3 ($r = -.03$, $p = .877$) or non-target P3 ($r = -.35$, $p = .060$) amplitude in the PT/VLBW group. Neither were there any significant relationships between the change in amplitude of the non-target cue-P3 or non-target P3 and gestational age ($r_{\text{cue-P3}} = -.14$, $p = .456$; $r_{\text{non-target P3}} = .25$, $p = .175$) or birth weight ($r_{\text{cue-P3}} = .20$, $p = .287$; $r_{\text{non-target P3}} = .02$, $p = .939$).

4. Discussion

In this study, we investigated neuronal correlates of attention and task-set adaptation in a cohort of PT/VLBW young adults and term born controls using ERPs from a cued go/no-go task. As predicted, the PT/VLBW group demonstrated significantly elevated P3 amplitudes to behaviorally irrelevant stimuli compared with controls. This reflects that the PT/VLBW group directed more attentional resources to processing such stimuli. These results support the hypothesis from behavioral studies on children (Espy et al., 2002; Kittler et al., 2011; Woodward et al., 2005) that allocation of attention to aspects of a task that are not relevant for task performance characterizes PT/VLBW populations. The results also demonstrated that whereas the amplitude of the P3 to non-target cues and non-targets were reduced over time for the controls, the PT/VLBW group continued directing attention to these behaviorally irrelevant stimuli throughout the task.

The PT/VLBW group did not, however, show the common pattern of reduced P3 amplitudes to target cues, targets, or no-go stimuli that is often observed in clinical populations with attention deficits (Johnstone et al., 2013). In agreement with previous studies (Lindgren et al., 2000; Potgieter et al., 2003) no significant group differences in the target P3 amplitude was found.

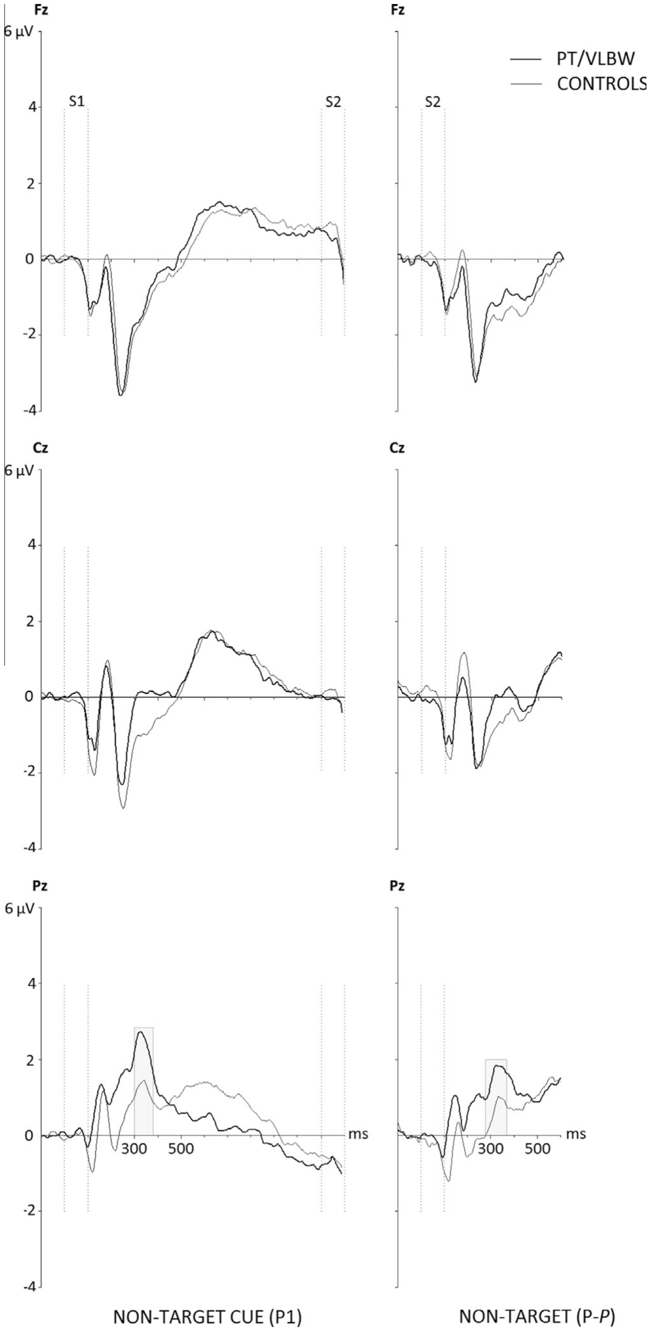

Fig. 3. ERPs following presentation of non-target cues and non-targets in the PT/VLBW (thick lines) and control (thin lines) groups at the midline electrodes. The time window for measurement of the P3 is marked.

4.1. Interpretation according to the S–R link hypothesis

According to the S–R link hypothesis of the P3b, the target cue-P3 is a reflection of the relevant S–R link being brought into a pre-activated state (Verleger et al., 2015). In the target condition, this S–R link is fully activated, and a large P3b is elicited. There was no evidence of the PT/VLBW group having any problems establishing or reactivating the S–R links to target cues or targets, as the P3 amplitudes to neither of these stimuli were reduced compared with the control group. In the relatively long-lasting task used in the present study, these P3 components demonstrated a general habituation effect that was of similar magnitude in both groups.

Although of smaller amplitude, the non-target cues and non-targets also activated P3 components. In these conditions, however, the responses linked to the stimuli are *non-responses.* As none of these stimuli were linked to any active responses, and were thereby irrelevant for optimal task performance, attention to these S–R links should have become reduced over time. Consequently, one would expect the P3s following these stimuli to show a significant amplitude reduction as a function of time-on-task. Such amplitude reduction occurred only in the control group. In the PT/VLBW group, the amplitudes of the P3 components elicited by these behaviorally irrelevant stimuli remained practically unchanged over time.

As targets never followed the non-target cues, these cues provided conclusive information that no response would be required after the imperative stimulus. The persistent P3 reactivation following non-target stimuli (which were also perceptually identical to the preceding non-target cues) in PT/VLBW individuals is therefore a particularly clear example of redundant processing of irrelevant information in this group.

4.2. A task-set involving switching?

Taken together, the present results could be conceptualized as the controls forming a task-set selectively focusing on the target S–R link, largely ignoring the non-targets and their corresponding non-responses. The task-set formed by the PT/VLBW participants, however, also assigned some relevance to the non-target S–R link. Such a task-set bears a resemblance to performing a task-switching paradigm, where the changing cues indicate which S–R links will be relevant for responding to the imperative stimulus. In task switching paradigms, it has been consistently shown that cues signaling a switch in the task to be performed, lead to increased cue-P3 amplitudes compared with repeat trials (e.g. Nicholson et al., 2006). If the PT/VLBW group activated the S–R links to both target- and non-target cues, this would lead to an increase the amplitude of the cue-P3 on every trial where the cue was not of the same category as that in preceding trial. Indeed, the PT/VLBW group also had increased early cue-P3 amplitudes in the target cue condition compared with the controls, which would be in accordance with such an interpretation.

4.3. Relations to behavioral performance

No significant group differences in task performance between the two groups were revealed in the present study. The tendency ($p = .07$) of a group difference in omission errors disappeared ($p = .29$) when the three participants who had a diagnosis of ADHD were excluded. The group differences in ERP data were not affected by the exclusion of these participants. These findings indicate that omission errors are sensitive to other aspects of attention than are the P3 component amplitudes from the non-target cue and non-target conditions.

4.4. Relations to gestational age and birth weight

Neither birth weight nor gestational age was associated with the cue-P3 or non-target P3 amplitudes in the PT/VLBW group, although there was a tendency ($p = .06$) of PT/VLBW participants with lower birth weight having larger non-target P3 amplitudes. These findings are in line with previous studies in this PT/VLBW cohort, which have found closer relations between structural brain abnormalities and birth weight than with gestational age (e.g. Eikenes et al., 2011; Rimol et al., 2016).

The requirement of both prematurity and very low birth weight for inclusion in the PT/VLBW may have affected the relationships between gestational age, birth weight and observed abnormalities

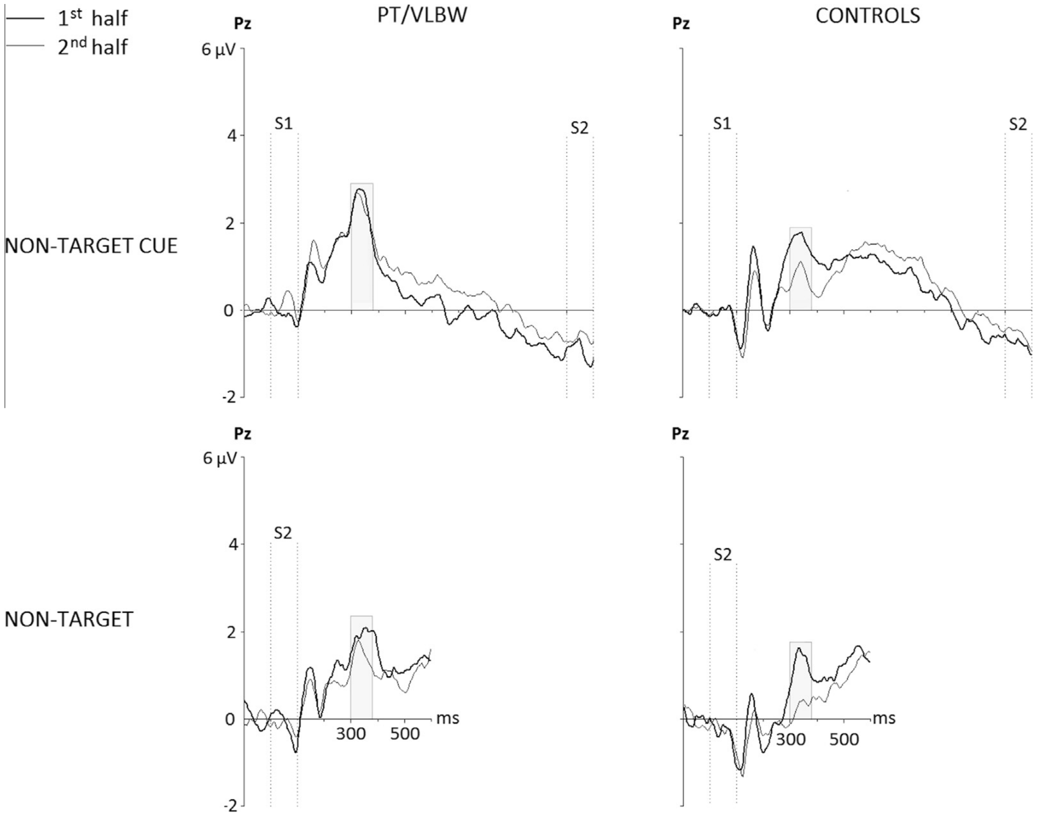

Fig. 4. Effects of time-on-task on the amplitudes of the non-target cue-P3 (upper panel) and non-target P3 (lower panel) in the PT/VLBW (left panel) and control (right panel) groups.

in neural activity and brain structure. As all the PT/VLBW participants had birth weight at or below 1500 g, being particularly small for gestational age was especially common among participants born closer to term. The protective factor of higher maturity could therefore have been canceled out by the risk factor of fetal growth retardation in these participants. Also, at the time the participants were born, the survival of potential participants born particularly early was quite low, leading to an underrepresentation of participants born very early.

Former studies of attention in preterm infants have tried to investigate the contribution of biological risk factors such as gestational age and birth weight, but the results have been mixed and complicated by possible interactions with environmental factors (van de Weijer-Bergsma et al., 2008). Indeed, rather than being directly caused by the degree of prematurity or low birth weight, the long-term consequences of preterm birth are known to be the result of complex interactions between *multiple* destructive and developmental factors (Volpe, 2009).

4.5. Implications

The results from the present study demonstrate that the use of ERPs can elucidate underlying neurocognitive processes affected by being born preterm with VLBW. Future studies aiming at understanding deviations in cognitive processes in patient groups could profit from using ERP measures and looking beyond the much-studied target P3. The present results also demonstrate that the study of how ERP components change over the course of task performance provides a new and interesting window into the study of task-setting, a perspective that could prove fruitful in the study of information processing in specific patient populations.

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