



Psychometric intelligence and P3 of the event-related potentials studied with a 3-stimulus auditory oddball task

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HIGHLIGHTS

- High intelligence can be linked with enhanced amplitude of P3a and P3b components.
- This relation was observed for targets and non-targets in three-stimulus oddball.
- High IQ is linked with enhanced activity of the neural sources of P3a and P3b.

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ABSTRACT

Relationship between psychometric intelligence measured with Raven's Advanced Progressive Matrices (RAPM) and event-related potentials (ERP) was examined using 3-stimulus oddball task. Subjects who had scored higher on RAPM exhibited larger amplitude of P3a component. Additional analysis using the Standardized Low Resolution Electromagnetic Tomography (sLORETA) revealed that this effect corresponds with stronger activity within the frontal cortex and the cingulate gyrus. High intelligence can also be linked with greater P3b response and stronger activity within the parietal cortex and the posterior cingulate gyrus. It may be concluded that the processes related to the initial stage of attention engagement as indexed by P3a, as well as the later stimulus evaluation and classification reflected in P3b, are more intense in subjects scoring higher on RAPM. The quality of mental abilities can therefore be related to differences of the activity in frontal and parietal brain regions.

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1. Introduction

Event-related potentials (ERPs) with their high temporal resolution provide with the important information about the neural activity related to mental activity. Important aspects of information processing, which are closely linked to attentional resource allocation, can be studied using the measurement of P3 (or P300). It is a positive potential, easily recorded in the 'oddball task', peaking between 250 and 600 ms with a maximum at centro-parietal areas [23,24]. P3 reflects cognitive processing, such as stimulus identification and elaboration, and its amplitude is thought to reflect resource allocation of attention [6,19,30]. The amplitude and latency of this component can be used as the markers of the cognitive processes.

The latency of P3 seems to be negatively correlated with the level of intelligence [2,3,5,8,9,11,20,25,28,29,31,32,37]. These findings might be interpreted as an indication that intelligence is inversely

related to the speed of information processing. At the same time, however, the relationship between P3 amplitude and intelligence is far from clear. Amplitude of P3 has been found to be negatively correlated with intelligence [20,36]. On the other hand, in several other studies a positive correlation between the amplitude of P3 and intelligence has been observed [1–3,5,9,11,27,28,31]. In some other cases a near-zero correlation between P3 amplitude and intelligence is reported [16].

This contradiction may be partially explained by major differences in the research procedures. For example, a negative correlation can result from studies in which subjects' memory is tested, while positive relations can be obtained when primary perceptual tasks, implementing detection of stimuli, are used. Thus, in each case two different sets of cognitive processes are initiated, and simultaneously two different sets of ERP components are measured. The P3 measured in memory tasks can overlap with the 'slow wave', which is a negative deflection appearing in a similar time window as the P3, related to memory rehearsal [19]. This can lead to an attenuation of the P3 amplitude [18]. A negative correlation between intelligence and P3 amplitude measured in memory tasks can indicate the differences in memory recall in a way that the more intense the memory search, the greater the reduction of the

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P3 amplitude. On the other hand, when P3 is measured in perceptual tasks, no such overlap is expected, and a positive correlation between intelligence and P3 amplitude can be obtained.

It is important to notice that P3 is not a unitary potential, but it rather represents the summation of activities from widely distributed brain areas, reflecting distinct information processing stages. A distinction can be made between two subcomponents, which temporally overlap, named P3a and P3b [23,24,33]. P3a has a fronto-central distribution, with relatively short peak latency, and reflects involuntary engagement of attention during processing of novel and salient stimuli [35]. This component is typically recorded in a three-stimulus oddball paradigm [4,17,33]. P3b (or classical P3) has a more posterior-parietal distribution, longer latency, and reflects target stimulus classification when a response to stimuli is required [6,19]. Its amplitude indexes voluntary allocation of attentional resources [19].

Due to this distinction, it can be suggested that the relationship between mental ability and P3a can be different to that observed for P3b. While the relationship between P3b amplitude and cognitive ability is consistently positive with identical experimental procedure, the link between intelligence and P3a amplitude is more unclear. Fjell et al. [11] have reported positive correlation between P3a amplitude measured in three-stimulus visual oddball and fluid reasoning. They have also found positive correlation between P3a amplitude and cortical thickness in posterior frontal and parietal areas. However, this relationship was only evident in elderly participants. In other study, Fjell and Walhovd [10] have found negative relationship between variability of P3a amplitude and Wechsler subtests' scores. Simultaneously, variability of P3a amplitude was negatively correlated with P3a amplitude. This suggests that cognitive ability might be positively related to the amplitude of P3a. On the other hand, however, DePascalis et al. [5] have reported that the P3a amplitude did not differ between groups with high and low intelligence. Thus, the initial attention allocation seems to be comparable, despite the differences at the psychometric level. However, this conclusion is weakened by the fact that the amplitude of the P3a in this study showed a progressive increase from frontal to parietal locations. This relationship suggests that the maximum for this component was observed over parietal cortex, and that this response should rather be labeled as P3b instead of P3a.

The purpose of the present study was to examine the relationship between the amplitude of both P3 subcomponents and the psychometrically determined level of cognitive abilities. A three-stimulus oddball task was used to separate P3a from P3b [4,17,33,34]. Experimental instruction required a mental counting instead of motor response, in order to minimize a temporal overlap between P3a and P3b. It was expected that higher amplitude of P3b should be obtained for subjects with higher cognitive abilities. Moreover, it was anticipated that P3a should be more evident in higher ability groups, which might reflect a more intense attention involvement in early stages of stimulus processing. To determine which brain areas can be linked with the differences observed in scalp recorded ERP, we used the Standardized Low Resolution Electromagnetic Tomography (sLORETA). We expected that intelligence-related differences in P3a amplitude could be linked with distinct activity within the frontal areas, while the effect on P3b amplitude would be connected with the differences in parietal activity. These brain regions have previously been suggested to be neural sources of P3 [7,10,23,24,34].

2. Materials and methods

Twenty six right-handed students (22 females & 4 males, mean age = 21.2 yrs, S.D. = 1.45 yrs) participated in the experiment. All of them had normal, or corrected to normal, vision, as well as normal

hearing. All of them reported to be free from neurological or psychiatric disorders, with an absence of drug abuse and medication. Students signed an informed consent and received course points for their participation. Subjects performed their tasks during two 20-min sessions (RAPM & EEG), scheduled at the same day, with an hour break in between.

The individual form of the Raven's Advanced Progressive Matrices (RAPM) was used [26]. The RAPM scores were roughly normally distributed (skewness = -0.57; kurtosis = -0.42), with a range of 16–29. The RAPM scores ($M = 24.2$, $SD = 3.3$) were used to create two groups with higher and lower psychometric intelligence. High ability (HA) group ($n = 13$) scored higher than the median ($Md = 24$), and low ability (LA) group ($n = 13$) scored lower than or equally to the median ($M = 27.1$, $SD = 1.0$, and $M = 21.4$, $SD = 2.2$, respectively for raw scores of HA and LA group). Both groups had a similar mean age ($M = 21.0$, $SD = 1.4$, and $M = 21.5$, $SD = 1.5$, respectively).

During EEG sessions participants were presented with random series of tones, consisting of standard 1 kHz, target 1.1 kHz, and non-target 1.2 kHz tones, with probabilities of .80, .10 and .10, respectively. The task was to silently count the target tones, and to report the number at the end of the session. Stimuli were presented with random ISI (1.25–2 s) through a loudspeaker located in front of the subject at 65 dB SPL, with 100 ms duration, and with 10-ms rise/fall time.

EEG was recorded using a BioSemi Active-One system from electrodes placed on the scalp using an Electro-Cap. Two additional electrodes, a common mode sense (CMS) active electrode and a driven right leg (DRL) passive electrode, were used as reference and ground electrodes, respectively (cf. www.biosemi.com/faq/cms&drl.htm). The EOG was monitored by 4 electrodes, placed above and below the right eye and in the external canthi of both eyes. EEG and EOG recordings were sampled at 512 Hz. The EEG was separated into epochs of 1000 ms duration, containing 100 ms pre-stimulus activity. Each epoch was baseline corrected, filtered (band pass 0.01–35 Hz, 24 dB/oct), and re-referenced to average reference. Trials containing blinks and eye movements were corrected [12].

The P3 amplitudes were measured on different waveforms, calculated by subtracting the average ERP elicited by the standard stimuli from that elicited by the target or non-target stimuli [33]. Components were defined as the mean voltage within a specific latency window: 200–350 ms and 300–600 ms for the P3a and P3b, respectively. These windows were selected on the basis of visual inspection of grand averaged ERP obtained for each condition. Peak amplitude was calculated relative to the pre-stimulus baseline. Repeated-measures analyses of variance (ANOVA) were performed examining the effect of within-subjects factor of STIMULUS type (target vs. non-target) on P3 amplitude, as well as the between-subjects factor of RAPM scores (HA vs. LA).

The sources of bioelectrical activity were estimated using the 2008 version of sLORETA (free academic software available at <http://www.uzh.ch/keyinst/loreta.htm>). The sLORETA images reflect the three-dimensional distribution of current density [22]. The sLORETA images corresponding to P3a and P3b components were defined as the mean current density values for intervals between 200 and 350 ms post-stimulus and between 300 and 600 ms post-stimulus, respectively.

3. Results

The P3a amplitude obtained in response to target stimuli ($1.79 \mu V$ $SD = 2.73$) was significantly smaller when compared to the P3a evoked by non-target stimuli ($3.58 \mu V$ $SD = 3.15$), $F(1,24) = 22.32$, $p < .001$, $\eta^2 = .482$. In both cases, maximal amplitudes were recorded at vertex (Fig. 1). The P3a amplitude measured

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