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Research paper

P3b correlates of inspection time

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A R T I C L E I N F O

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A B S T R A C T

Both P3b and the inspection time (IT) are related with intelligence, yet the P3b correlates of IT are not well understood. This event-related potential study addressed this question by asking participants (N = 28) to perform an IT task. There were three IT conditions with different levels of discriminative stimulus duration, i.e., 33 ms, 67 ms, and 100 ms, and a control condition with no target presentation (0 ms condition). We also measured participants' processing speed with four Elementary Cognitive Tests (ECTs), including a Simple Reaction Time task (SRT), two Choice Reaction Time tasks (CRTs), and a Pattern Discrimination task (PD). Results revealed that an increase in P3b latency with longer duration of the discriminative stimulus. Moreover, the P3b latency was negatively correlated with the accuracy of the IT task in the 33 ms condition, but not evident in the 67 and 100 ms conditions. Furthermore, the P3b latency of the 33 ms condition was positively correlated with the RT of the SRT, but not related with the RTs of CRTs or PD. A significant main effect of duration on the amplitude of P1 was also found. We conclude that the present study provides the neurophysiological correlates of the IT task, and those who are able to accurately perceive and process very briefly presented stimuli have a higher speed of information process, reflected by the P3b latency, yet this relationship is more obvious in the most difficult condition. Combined, our results suggest that P3b is related with the closure of a perceptual epoch to form the neural representation of a stimulus, in support of the "context closure" hypothesis.

Introduction

Processing speed is considered an established cognitive correlate of psychometric intelligence (Hill et al., 2011; Sheppard and Vernon, 2008), which can be assessed by the Inspection Time (IT) task (Deary, 1993, 1996; Deary et al., 1991; Deary and Stough, 1996; Vickers et al., 1972; Waiter et al., 2008). During this task, participants are briefly shown a series of simple visual stimulus, such as a pair of lines, and are asked to make a two-alternative, forced-choice discrimination (2AFC) (Deary et al., 2004). The duration of a stimulus varies, and the stimulus is backward-masked. The mask interrupts or erases iconic storage and precludes target identification from the iconic image after the target has physically offset (Alcorn and Morris, 1996). The participant's performance can be affected by the duration of the stimuli, which increases from near-to-chance at very brief durations to near-perfect responding at longer stimulus exposure durations (Deary, 1993; Waiter et al., 2008). Individual differences in the efficiency of information processing assessed by this task were correlated moderately with differences in higher cognitive abilities and intelligence (Alcorn and Morris, 1996; Crawford et al., 1998; Deary, 1993, 1995, 2001; Deary et al., 1991; Deary and Stough, 1996; Egan, 1994; Grudnik and Kranzler, 2001; Liu & Shi, 2003; McGarryroberts et al., 1992; Nettelbeck & Rabbitt, 1992), for a meta-analysis, see Grudnik and Kranzler (Grudnik & Kranzler, 2001).

Surprisingly, the neurophysiological correlates of IT were not well understood, and most of existing literature focused on the early components elicited by IT using the event-related potential (ERP) approach. For example, the topography of the earlier brain potentials between 100 and 200 ms after stimulus onset was related to IT ability and intelligence (Caryl, 1994; Hillyard and Anllo-Vento, 1998; Morris and Alcorn, 1995). Also, the high IQ group exhibited a significantly larger N1 response that elicited by IT (Hill et al., 2011), possible reflecting individual differences in directing attention to a spatial region. However, the relationships between the later P3b and IT were not thoroughly studied. The P3b is a task-evoked ERP component that occurs about 300 ms after stimulus

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onset, has a positive polarity, and is largest at parietal electrode sites (Basareroglu et al., 1992; Steiner et al., 2013; van Dinteren et al., 2014). To our knowledge, only two studies have reported that the amplitude of P3, but not its latency, was correlated with IT (Alcorn and Morris, 1996; Zhang et al., 1989). Alcorn and Morris found that the P3 amplitudes at the temporal and occipital sites were strongly correlated with IT as well as with Raven's Standard Matrices (Alcorn and Morris, 1996). Zhang et al. reported that P3b amplitude varied significantly with the difficulty of the discrimination; the easier the task, the greater the amplitude (Zhang et al., 1989). It is believed that P3b latency represents the information processing time that related with higher cognitive functions; and longer latency represents slower processing (Kutas et al., 1977; McCarthy and Donchin, 1981), and P3b latency may be changed in patients. For example, people with APOE4, the strongest genetic risk factor for Alzheimer's disease, has a longer P3 latency (Pedroso et al., 2021). Recent results indicated that ERP latencies, but not their amplitudes, explain 90.1% of the variance in general intelligence (Schubert et al., 2017), and intelligence is strongly associated with shorter latency of later ERP components, including the P3b (Schubert et al., 2017). For example, Jausovec and Jausovec reported that less intelligent individuals showed increased P3b latency and reduced amplitude (Jausovec and Jausovec, 2000, 2001). They suggested that more intelligent individuals benefit from a more efficient transmission of information from frontal attention and working memory processes to temporo-parietal processes of memory storage (Jausovec and Jausovec, 2000, 2001; Miller, 1994; Schubert et al., 2017). Indeed, it has been argued that the frontal network, along with a posterior network of sensory-related and associative regions, might subserve processing of the IT task, as reported in previous fMRI studies (Deary et al., 2001; Deary et al., 2004). As both IT and P3b are related with intelligence, a correlation between P3b latency elicited by IT and its performance should be expected, yet has not been revealed.

Moreover, what psychological process is associated with the P3b is still controversial (Donchin and Coles, 1988; Verleger et al., 2016), and there are two main hypotheses among others (Verleger, 2020). The context updating hypothesis, raised by Donchin & Coles, takes the view of P300 as a manifestation of the updating of working memory, and the theory also associates the P3b with strategic processing that serves planning for future responses, i.e., metacognition (Donchin and Coles, 1988; Klein et al., 1984; Polich, 2007); in Donchin & Coles 's own words, the context updating model "asserts nothing more than that the P300 is elicited by processes associated with the maintenance of our model of the context of the environment" (Donchin and Coles, 1988). However, Verleger et al. thought the P3b is evoked by expected target events that are awaited when subjects deal with repetitive, highly structured tasks; marking the closure of a perceptual epoch, i.e., the "context closure" hypothesis (Verleger, 1988, 1991; Verleger et al., 2018), which we think is closer to Donchin et al.'s initial thoughts, that the P300 is a measure of stimulus evaluation time (Kutas et al., 1977). To address this question, we also measured participants' processing speed with four Elementary Cognitive Tests (ECT), including a Simple Reaction Time (SRT), two Choice Reaction Time tasks (CRT), and a Pattern Discrimination (PD) task. ECTs are believed measuring the speed of basic cognitive functions, but not strategic processing (Schubert et al., 2017). Should P3b be related with "context closure" hypothesis, significant correlations between the P3b latency of IT and performances of these ECTs were expected. The SRT task was used to measure basic information processing speed with minimal higher cognitive loads, while the CRT and PD was at least memory-dependent. A tapping task was also used to measure the basic motor function.

The aims of the present study were to investigate 1) the neurophysiological correlates of an IT task, especially the P3b; and their relationships with the behavioral results of IT; 2) the possible relationships between the neurophysiological components of IT and RTs of the four ECTs. We hypothesized that 1) the P3b can be elicited by the IT, and its amplitude/latency can be modulated by the discriminative stimulus duration; 2) those who are able to accurately perceive and process very briefly presented stimuli have a shorter P3b latency, as well as shorter P1 and N1 latencies; and 3) the P3b latency, as well as the latencies of N1/P1, are related with the RTs of ECTs, as both of them are related with the speed of information transmission.

Methods

Participants

Twenty-eight healthy undergraduate students participated in the study. Data from three participants was excluded because of poor behavior performance (N = 1) or high noise in EEG data (N = 2, see later). The mean age of the remaining 25 participants (sex assigned at birth: 18 females and 7 males) was 21.3 (SD = 2.4), ranged from 18 to 25 years. All were right-handed, had normal or correct-to-normal vision and normal color vision. No history of neurological or psychiatric symptom was reported. Participants received monetary payment. Written informed consent was obtained from all participants. The protocol was approved by the University Committee on Human Research Protection of the East China Normal University.

Apparatus

The electrophysiological recordings were made with a 64 Channel EGI (EGI, Oregon, USA) system that located in a shielded Faraday chamber. Participants wore the HydroCel GSN 130 Geodesic Sensor Nets (https://www.egi.com/clinical-division/geodesic-sensor-nets), and they completed all tasks with the EEG cap on. The sampling rate is 250 Hz. The signals were amplified with GES 400, and all electrodes were referenced to a common electrode placed on the Cz. Vertical eye blinks were recorded with electrodes (E62, E63) below bilateral canthi. Impedances were kept below 10 kOhm. During recording, participants were seated in a comfortable chair at approximately 80-cm distance from an LCD monitor.

Procedure

Participants attended two sessions of ECTs and one IT task, with the order of the tasks as follows: the first session of ECTs; IT task; then the second session of ECTs. For all the tasks, visual stimuli were black with gray background that presented on an 80-cm (24-inch) LCD monitor with a 60 Hz refresh rate. The inter-trial-interval (ITI) was 2–3 s randomly. E-prime 1 software system (Psychology Software Tools, Inc.) was used for stimuli presentation and data collection.

IT task

We adept the IT task that has been used in Waiter's study (Waiter et al., 2008). The stimuli were displayed in Fig. 1A&B&C. The stimulus

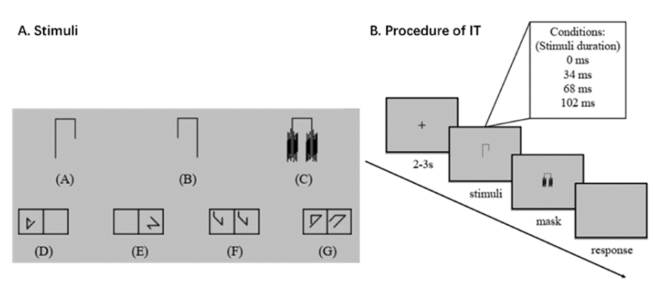

Fig. 1. A: Stimuli. (A) and (B) were used in the Inspection Time (IT) Task and the first Choice Reaction Task (CRT1), and (C) was used as the mask in the IT task; (D) and (E) were used in the CRT2; (F) and (G) were used in the Pattern Discrimination (PD) task. All stimuli were presented with a gray background. B: A sample trial of the IT task. The total duration of a stimulus and its mask in one trial was 1000 ms. IT: inspection time.

lines were 5 cm for the longer line and 2.5 cm for the shorter line. They were joined at the top with a 2.5 cm crossbar. The lines were about 1.6 mm wide, Fig. 1A and Fig. 1B. The backward mask was constructed of a jumble of vertical lines 1.6 mm wide that overwrote the vertical lines in the stimulus, Fig. 1C. A target stimulus was presented on the center of the screen with varied durations (i.e., 33, 67 or 100 ms, the three conditions with different levels of difficulty; and a control 0 ms condition in which only the mask was presented), then a mask was followed. The total duration of the stimulus and mask was 1000 ms. After that, a blank screen was presented, and participants were instructed to press “f” if the long line was at the left side, and to press “j” if the long line was at the right side, i.e., a 2AFC. All trials were presented pseudorandomly. Each condition consisted of 96 trials.

ECTs

There were four ECTs, including one SRT, Two CRTs, and one PD task. A tapping task was also used, which was a measure of movement speed that has been used in a previous study (Lutz, 2005). The SRT and CRTs paradigms were based on Penke et al., Alloza, et al., and Chopra, et al.’s studies (Penke, 2010; Alloza, 2016; Chopra, 2017). Each session of the ECTs lasted about 15 minutes (about 2.5 minutes for SRT, 6 minutes for two CRTs, 4 minutes for PD, 1.5 minutes for Tapping, and four inter-task breaks, about 1 minute), and the IT task lasted about 30 minutes. The following were the details of the four ECTs.

SRT: There were two parts, one for left hand and one for right hand. In the first part, participants were firstly instructed to press “j” on the keyboard with left index finger when a letter “j” appeared on the screen. In the next part, participants were asked to press k with the right index finger when a letter “k” appeared. As only one stimulus would appear in each part, participants were not required to judge the context. Each part consisted of 18 trials.

CRT1 and CRT2: The paradigm of the CRT1 was used in Waiter’s study (Waiter et al., 2008) and the stimuli were the same as the IT task, but without the mask stimuli. Participants were instructed to press “f” if the long line was at the left side and press “j” if the long line was at the right side. In CRT2, the stimuli were displayed in Fig. 1D&E (Salthouse, 1993). Participants were instructed to press “j” with their left index finger when the pattern appeared in the left box while press “k” with their right index finger when the pattern appeared in the right box, i.e., a 2AFC. There were 36 trials in each task, half left and half right, and they were presented pseudorandomly.

PD: Participants were asked to decide whether the two patterns on the screen were the same or not, i.e., a yes/no 2AFC. There were 36 trials, presented pseudorandomly, and half of the trials were the same. The patterns were used in Salthouse’s study (Salthouse, 1993), Fig. 1F&G.

Tapping: We adopted the tapping task used by Lutz et al. (Lutz, 2005). There were two parts, one for left hand and one for right hand. In the first part, a “j” was presented on the center of screen, participants were instructed to continuously with left index finger as quickly as possible until “j” disappeared. In the next part, a “k” appeared on the screen and participants were instructed to continuously with right index finger as quickly as possible until “j” disappeared. The stimuli would disappear after 160 times pressings.

Data Analysis

Statistical analyses were carried out using JASP (https://jasp-stats.org/, JASP team, 2019) (Marsman & Wagenmakers, 2017; Wagenmakers et al., 2018) and SPSS version 23 (IBM), including repeated measures ANOVAs, t-test, and correlation analyses. The threshold was set at $p < 0.05$, two tailed.

IT and ECTs

Accuracies in the three IT conditions (i.e., discriminative stimulus durations of 33, 67 or 100 ms) were analyzed using a repeated measures ANOVA (Waiter et al., 2008). For the ECTs, the mean RTs were calculated. Only RTs from the correct trials were included, and trials with RTs exceeded two SD were excluded. For the Tapping task, the interval between one press and the next press was measured (Time from Press to Press, TPP).

EEG data

Electrophysiological Processing

EEG data was analyzed using MNE 0.15.2 (Gramfort et al., 2014). Only data from corrected trials was used. The continuous EEG data was first filtered by 0.5–20 bandpass filter. The continuous data set was segmented into 900-ms response locked epochs starting 200 ms prior to stimulus and lasting until 700 ms after stimulus onset; Signal Subspace Projectors (SSP) was used to corrected the ECG and EOG (> 150 μV) artifacts; Reject Bad channel if the amplitude was higher than 300 μV; entire epochs were linearly detrended and baseline corrected relative to a 200 ms time window prior to stimulus onset; Data of 2 participants that had less than 20 segments per condition left after the artifact rejection were excluded from further analysis. Finally, EEG data from 25 participants was used in the formal analysis. In the next step, the segments of each condition were averaged for each participant. The averaged segments were summarized across participants in a grand average (GA) for each condition.

Detection of P3b, P1, and N1

A topographic mapping analysis was used to evaluate the overall electrical potentials over the scalp. The results indicated the presence of a typical P3b component, about 300 ms after target presentation (Tononi et al., 2016) and located around the Pz electrode site (Verleger et al., 2005), Fig. 2, bottom. We focused on the P1, N1 and P3b at the parietal electrode Pz, where the P3b component was typically found (Verleger et al., 2018). Latencies and amplitudes of P1, N1, and P3b were determined using peak detection approach.

Peak detection

The detection of peak employed a semi-automatic procedure. The time interval for the automatic peak detection (i.e., by first difference method) was set from 100 ms to 500 ms after stimulus onset. Then, the peaks were visually inspected by a researcher who was not aware of the experimental purpose, and if required, manually adjusted. GA and the activity of other channels were used as guidance for the potential manual adjustment of the peaks (Hoorman et al., 1998). To be specific, in some cases, two distinct peaks were observed within the 200–500 ms time window and marked by the researcher as P3b candidates. The identification of the final P3b wave was determined by the position of the N1 component, it was the first peak after N1. The latencies and amplitudes of the peaks of different components (N1, P1, and P3b) were recorded (Hoorman et al., 1998).

Correlation analysis

The relationships between accuracy of the IT task, amplitudes and latencies of ERP components, and RTs of ECTs were analyzed by Pearson’s correlation analyses.

Results

Behavioral results

The descriptive results were listed in Table 1 and Table 2. For the accuracy of the IT task, a significant main effect of IT duration was found ($F(2,48) = 253.5$, $p < 0.001$, $\eta^2 = 0.95$), with a greater proportion of errors in the shorter duration compared to the longer duration. The accuracies were 0.60 (33 ms), 0.82 (67 ms) and 0.93 (100 ms)

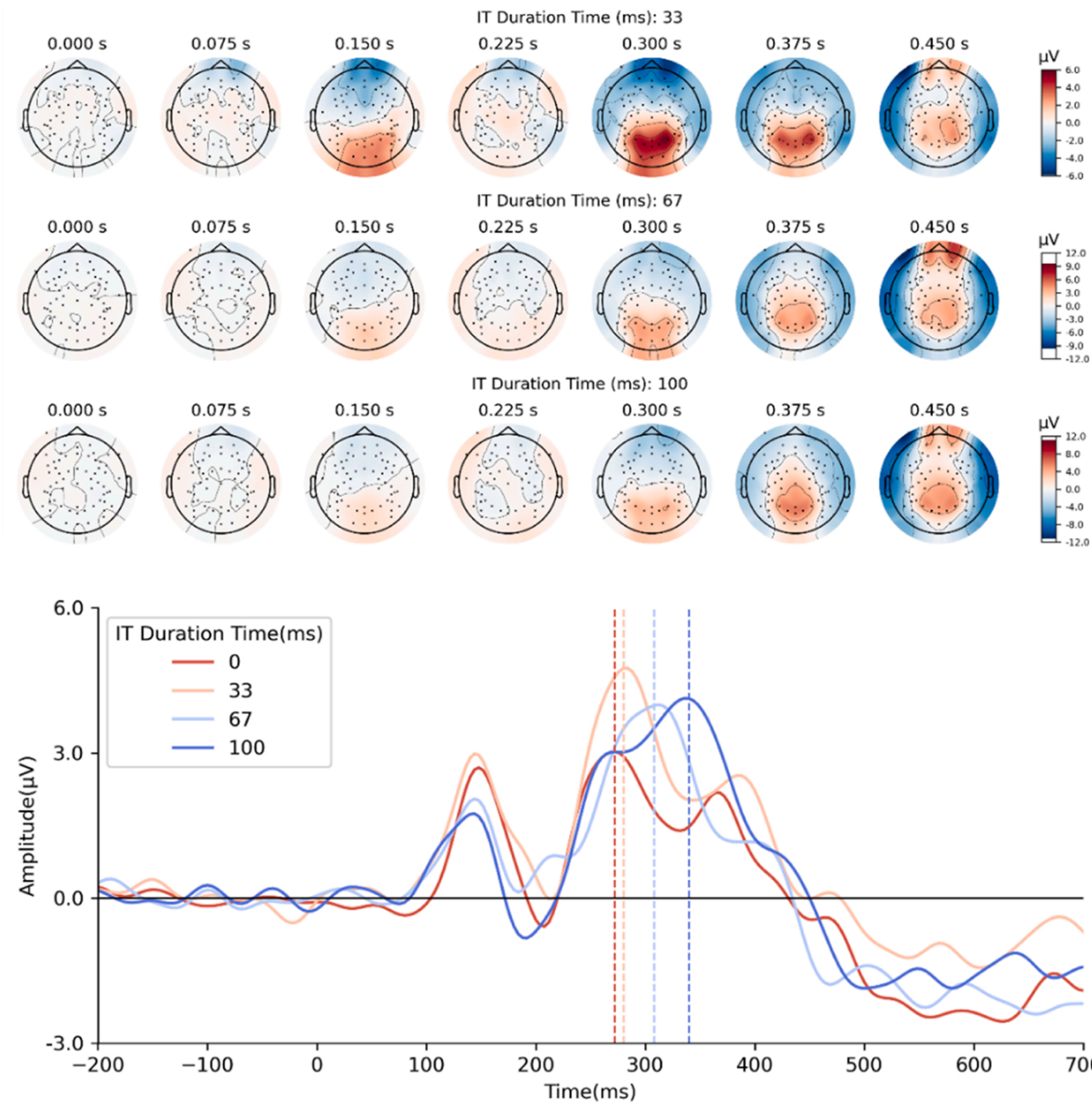

Fig. 2. Top panel: The temporal topology maps are displayed with positive values (red) and negative values (blue) and with display of the maxima and minima of scalp field potentials under the three IT durations and 0 ms control condition. The time window is from 0 ms to 450 ms. Bottom panel: Averaged time course at electrode sites Pz, including the 0 ms control condition. IT: inspection time.

Table 1
Mean accuracies of the IT task.

Duration (ms)	Accuracy (%)	SD	Min (%)	Max (%)
33	60	8	45	81
67	82	11	65	99
100	93	8	76	100

respectively. The *post hoc* pairwise comparison between all the three conditions were significant, $p < 0.001$, *Bonferroni* corrected. The mean results of ECTs were listed in Table 2 and the reliability was assessed by computing Pearson's r between the two sessions, Table S1 and S2.

ERP results

The descriptive results of ERP components were listed in Table S3, S4, and S5, and illustrated in Fig. 3.

Table 2
Performance of ECTs and tapping task.

ECT	Mean (ms)	SD	Min	Max	Accuracy (%)
SRT	307	56	180	443	100
CRT1	416	51	333	608	98.2
CRT2	415	50	344	561	99.1
PD	866	200	618	1458	95.8
TPP	184	19	152	235	/

Note: ECT, elementary cognitive test; SRT, Simple Reaction Time; CRT1 & CRT2, Choice Reaction time, task 1 and task 2; PD, pattern discrimination; TPP, Time from press to press.

P3b

For the latency, a repeated measurement ANOVA with duration as within-subject factor (33, 67, and 100 ms) revealed a significant main effect of duration, $F(2,48) = 24.9$, $p < 0.001$, $\eta^2 = 0.51$. The *post hoc* analysis t-test revealed the P3b latencies increased with IT durations;

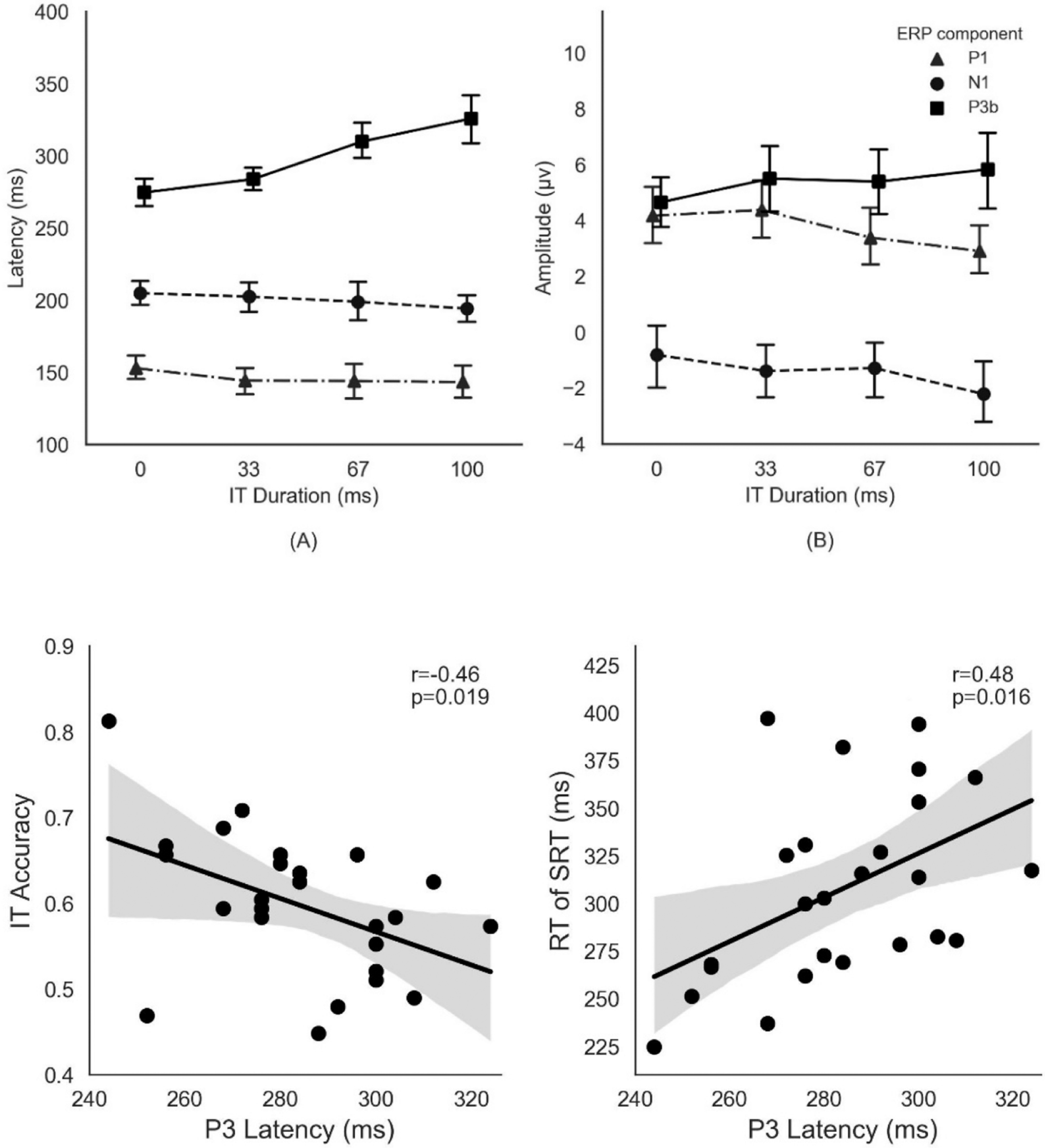

Fig. 3. Top: Averaged latencies (A) and amplitudes (B) of P1, N1 and P3b at Pz in the three levels of discriminative stimulus duration. Data of the 0 ms control condition (i.e., only masks were presented) was also displayed. Error bar indicates 95% confidence interval. Bottom: Significant correlations were found between the accuracy of IT and the P3b latency (left panel); and between the RT of the SRT and the P3b latency (right panel) in the 33 ms condition. IT: inspection time; SRT: simple reaction time; RT: reaction time.

33 ms *vs* 67 ms, $p < 0.001$; 67 ms *vs* 100 ms, $p = 0.015$, *Bonferroni* corrected, Fig. 3, top and Table S3. For the amplitude, the main effect was nonsignificant, $F(2,48) = 0.529$, $p = 0.593$, $\eta^2 = 0.022$.

P1 and N1

For the amplitude of P1, a significant main effect was found, $F(2,48) = 10.7$, $p < 0.001$, $\eta^2 = 0.31$. The *post hoc* analysis revealed that the pairwise comparisons between the 33 ms and 67/100 ms were significant. The latencies of the three conditions were nearly identical, 144,144, and 143 ms respectively, and no significant main effect was found, $F(2,48) = 0.048$, $p = 0.95$, $\eta^2 = 0.002$. For N1, the main effect of neither its amplitude nor its latency was significant, $F(2,48) < 2.25$, $p > 0.12$, $\eta^2 < 0.086$, Fig. 3, top panel.

Relationships between P3b, N1, P1, accuracy of IT, and RTs of ECTs

The correlation between the P3b latency and the accuracy of IT was significant only in the 33 ms condition, $r = -0.46$, $p = 0.019$, Fig. 3, Bottom. Moreover, the correlation between the P3b latency of the 33 ms condition and the RT of the SRT was significant, $r = 0.48$, $p = 0.016$. Other correlations were not significant. The correlation matrix between P3b latency, IT accuracy, and RTs of ECTs was shown in Table S6 and S7.

Discussion

This ERP study investigated the neurophysiological correlates of an IT task with three levels of discriminative stimulus duration. We found that the P3b can be elicited by the IT task, and its latency was negatively modulated with IT durations. Moreover, the accuracy of IT was negatively correlated with the P3b latency, but only in the 33 ms condition. Furthermore, we found that the P3b latency of the 33 ms condition was positively correlated with the RT of the SRT, but no significant correlations were found between the P3b latency and RTs of other ECTs with more cognitive load. The amplitude of the P1 was also modulated by the level of discriminative stimulus duration. These findings provide the neurophysiological correlates of the IT task, especially the P3b component.

Relationships between P3b latency and IT duration

The P3b could be elicited by the IT task, in line with previous studies (Hill et al., 2011; Zhang et al., 1989). Interestingly, we found the P3b latency was modulated by the discriminative stimulus duration, which was not reported in previous studies. These results may be in contrast with experiments in which P3b latency increased with difficulty of the discrimination, such as shorter Stimulus Onset Asynchronies (SOAs) would represent longer P3b latency (e.g., Duncan Johnson and Kopell, 1981; McCarthy and Donchin, 1981). Zhang et al. suggest an explanation: in their experiments (and ours), stimulus information was removed (masked) after a brief exposure, while in other studies stimulus information remained available, allowing further sampling, where the discrimination was difficult, and therefore a later P3b peak (Zhang et al., 1989). We agree with this explanation and the removal of a stimulus is related with the closure of a perceptual epoch (Verleger, 1988). These results are in line with the accumulator model of perception (Purcell & Palmeri, 2017). These models assume a particular response is integrated over time by one or more accumulators / sampling. A response is selected when evidence reaches a response threshold, and a longer stimulus duration allows a further sampling, and a clearer response. Variability in the time it takes for accumulated evidence to reach threshold accounts for variability in choice probabilities and response times observed in a broad range of decision-making tasks, reflected by the latency of the P3b (Purcell & Palmeri, 2017).

Intriguingly, we found that the P3b latency was negatively correlated with the accuracy of the IT task, but only in the 33 ms condition. On a neurophysiological level, information-processing speed can be measured as the latency of ERPs, and the stimulus evaluation view holds that P3 latency mainly reflects stimulus-processing time (Kutas et al., 1977). A higher speed of information processing should be reflected in shorter ERP latencies (i.e., a shorter time interval between the onset of a stimulus and the maximum peak of the components) (Schubert et al., 2017). Hence, our results indicate that those with are able to accurately perceive and process briefly presented stimuli have a higher speed of information processing to obtain a meaningful information from the visual inputs (Ruchkin & Sutton, 1978; Johnson & Donchin, 1978).

One possible explanation regarding the differences between this study and previous studies is the involvement of the later cognitive functions. In Morris and Alcorn's study, on each trial participants were required to identify one stimulus from four possible letters ('b', 'p', 'd, or 'q') (Morris & Alcorn, 1995), and P3 in the occipital cortex was measured. This task was a more cognitively demanding exercise than the 2-line discrimination task. In Zhang et al.' study, the IT stimulus consisted of two vertical lines, the participants were instructed to indicate the location of the target, and the criterion for accuracy was set at 90%. We argue that when stimulus information was removed (masked) after a very brief exposure (such as 33 ms), as the iconic storage was erased and precludes target identification from the iconic image after the target has physically offset, the top-down modulation from higher brain regions to the visual cortices is limited. However, when stimulus information remained available for a longer duration with higher accuracy, further sampling as well as some more fine-grained process or elaboration, later stage higher-order information processing is involved (Schubert et al., 2017; Verleger et al., 2005; Zhang et al., 1989). Hence the elicitation of P3b depends on the level of a more extensive extraction of information about the event and on the processing of that information (Donchin & Coles, 1988), and variability in these processing accounts for variability in response times observed in a broad range of decision-making tasks. Previous studies revealed that the P3b latency that was often positively correlated with RT could be altered or eliminated by introducing or emphasizing particular factors (McCarthy & Donchin, 1981), speed vs accuracy instructions (Pfefferbaum et al., 1983), difficulties (Leuthold & Sommer, 1998), or even background noise (Salisbury et al., 2002). As only the accuracy, but not the reaction time, is the key for this IT task, the response-time related bias to P3b is minimal, we hence argue that the involvement of more cognitive functions may lead to larger variabilities in the P3b latency of the 67 and 100 ms conditions (Schubert et al., 2015), and renders the relationship between P3b and IT less clear. It is one possible reason that conventional latency measures did not correlate with performance of IT in general (Reed, 1988). These findings are also in line with previous studies that P3b is a sensitive index when response times are brief, while its sensitivity decreasing when response times get longer (Pfefferbaum et al., 1983; Verleger, 1997), in our case, the duration of the masked stimulus.

The P3b latency and performance of ECTs

We further tested our argument with correlation analyses between the P3b latency and the RTs of ECTs. Interestingly, we found that only the P3b latency of the 33 ms condition, but not the 67 ms and 100 ms conditions, was significantly positively correlated with the RT of the SRT. Moreover, we did not find any significant correlation between the P3b latency and the performance of other ECTs. Schubert et al. argued that ECT conditions might differ in the demands as they put on several cognitive processes simultaneously (Schubert et al., 2015), and each ECT may include variance of other cognitive processes that differ between conditions, such as representation in working memory, decision making, and response preparation, etc. For example, Conway et al. (2002) found that the speed of information-processing was specifically associated with shared variance between performance in simple and complex memory span tasks, but not with a latent factor reflecting only performance in span tasks (Conway et al., 2002). Schubert et al. argued that measures of neurophysiological processing speed contain a great amount of task- and component-specific variance, and that once this unique variance has been accounted for, neurophysiological processing speed explains a great amount of variance in general intelligence (Schubert et al., 2023; Schubert et al., 2017). It seems that more cognitive functions are needed for the CRTs and PD tasks, leading to larger variabilities, while the involvement of higher cognitive functions is minimal in the SRT task, in support of our previous argument.

Roles of P1 and N1

The amplitude of the P1 was significant decreased from 33 ms to 67/100 ms. Regarding N1, although visual speculation of Fig. 3 suggests there was a trend of decreasing, we did not find a significant main effect. As reviewed by Hill et al. (Hill et al., 2011), attention directed to a region of space results in an increase in the amplitude of the P1 and N1. Yet it seems that their roles are different. The N1 component appears to reflect an enhancement of features at an attended location, and is most sensitive to unexpected or unpredictable stimuli (Sur & Sinha, 2009); while the P1 amplitude is thought to reflect the suppression of information outside of attended space (Hillyard et al., 1998), which results in greater signal from attended regions due to less competing information. This discrimination effect has been found for targets that differ in color or structural form but is not present in tasks that require only the detection of a stimulus (Vogel & Luck, 2000). Pojoga et al. (2020) found that there were specific neurons in the macaque primary visual cortex that responded to the 34 ms exposure stimulus, which enhances stimulus sensitivity and information encoding (Pojoga et al., 2020). It may further result in an automatically, immediately mobilization of attentional resource. We hence speculated that as the 33 ms condition was more difficult than 67 and 100 ms conditions, hence more efforts were needed to distinguish the stimuli, resulting in higher amplitude of P1. Yet as stimulus in this study were all foreknown, the N1 component is relatively less sensitive. The argument is in line with a previous suggestion that the earlier brain potentials between 100 and 200 ms after stimulus onset is a time window in which visual selective attention, feature encoding, and pattern analysis took place (Caryl, 1994; Hillyard & Anllo-Vento, 1998; Morris & Alcorn, 1995), and higher amplitudes of P1 is related to higher attentional involvement (Johannes et al., 1995).

However, no significant main effects were found on the latencies of P1/N1. The first possibility is that early ERP components are not good predictors of intelligence (Schubert et al., 2017), which may be hard to alter (Peisch et al., 2021). The second possibility is that P1/N1 was modulated by later stage attention or high-level cognitive functions. As performance in previous studies was very high, consistent with our previous argument, we speculate that as more high-level cognitive functions or more top-down modulation is involved, in support of our previous argument, hence between-subject differences were more evident in these studies. However, in the present study, stimuli were presented very briefly and masked, top-down modulation to the visual cortices is limited, hence its latency is less affected.

P3b: "context updating" or "context closure"?

Our results showed that the P3b latency was significantly correlated with IT accuracy in the 33 ms condition. We explain this association as a reflection of a higher speed of information processing to form a perceptual memory or neural representation of a stimulus, because the mask interrupts or erases its iconic storage. Hence, the P3b likely plays a tactical role (Walsh et al., 2017). We think that this explanation supports Verleger's idea that the P3b elicited by IT may be linked with the closure of a perceptual epoch, to form a mental representation (Verleger, 1988), even without a full analysis of the stimulus (Picton, 1995; Verleger et al., 2005). In line with this explanation, the P3b latency in the 33 ms condition was significantly correlated only with the RT of the SRT, in which only the perception of a target, but not its context, is needed. We also think that this explanation is in line with the Kutas, McCarthy, and Donchin's initial argument, that P3b is a measure of stimulus evaluation time (Kutas et al., 1977). Mostly based on experiments from Donchin's laboratory, Donald also supported the idea that P3b marks the completion of the process of stimulus evaluation as a more satisfactory tag (Donald, 1988).

We acknowledge that there should be no inter-trial strategic change in this simple IT task. Thus, whether the P3b is related with strategic process *per se* of the "context updating" hypothesis cannot be answered directly by this study. Yet, we note that the P3b latency was not correlated with the accuracy of IT in both 67 ms and 100 ms conditions, and was also not related with the RTs of both the CRTs and PD, in these tasks higher cognitive functions were needed. It appears that the P3b latency is affected nonlinearly by higher cognitive functions when further top-down modulation is allowed. We cannot exclude the possibility that P3b is related with changes in strategic processing that related with higher cognitive functions, supposedly during the perceptual representation of a stimulus, which deserves further studies.

Conclusions

The present study investigated the neurophysiological correlates of IT. Our results indicate that the P3b latency and the P1 amplitude was modulated by the duration of the discriminative stimulus duration. Moreover, those who are able to accurately perceive and process briefly presented stimuli have a higher speed of information processing, reflected by the latency of P3b. Yet this relationship is more obvious in the most difficult condition. Combined, our results suggest that P3b is related with the closure of a perceptual epoch to form the neural representation of a stimulus, in support of the "context closure" hypothesis.

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CRediT authorship contribution statement

Yilai Pei: Conceptualization, Methodology, Software, Investigation, Data curation, Formal analysis, Visualization, Writing – original draft, Writing – review & editing.

Zhaoxin Wang: Conceptualization, Methodology, Validation, Project administration, Supervision, Formal analysis, Writing – original draft, Writing – review & editing.

Tatia M.C. Lee: Conceptualization, Methodology, Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare there is no interest of conflict.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ibneur.2024.03.002.

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