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BRAIN ELECTROPHYSIOLOGICAL CONCOMITANT OF COGNITIVE CONTEXT

A REAPPRAISAL OF P300†

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Abstract

To examine a possible brain-electrophysiological concomitant of the two-way process in cognition, event-related potentials were recorded during a specifically devised two-tone semantic differentiation task. Physically identical but semantically multifaceted stimuli in this task produced differential effects on the late positive components, implying that the late positive components, particularly P300, are useful indices of psychological processes in terms of brain-electrophysiological processes.

In human cognition, physically identical stimuli may frequently be recognized differently, indicating an absence of a one-to-one correspondence between stimulus and response. This phenomenon is often explained in terms of a two-way process in cognition, that is, a data-driven (bottom-up) process and a conceptually-driven (top-down) process, which mutually interact in perceiving and recognizing stimuli (1). In other words, on the basis of the perceiver's expectancy or cognitive context, that has been established by previous experiences, selected stimulus information is consciously processed in the central channel with limited processing resources (2), a process termed focal attention (3). However, this psychological explanation is relatively undocumented with evidence from neurophysiological experimental data (4).

In this study, we conducted a verification of this psychological explanation through Event-Related Brain Potential (ERP) recordings during auditory cognitive tasks. ERPs have been utilized as electrophysiological measures that reflect cerebral processes underlying human perceptual and cognitive activities. One specific component of ERPs, P300, has been considered a cognitive potential that varies according to a perceiver's expectancy. Donchin et al. have reported that P300 reflects the maintaining or updating of the working memory, or "context-updating" (5).

In our experiment, a series of two tone-bursts (A and B) with equal a priori probabilities, ... B A B A A B B A ... , were

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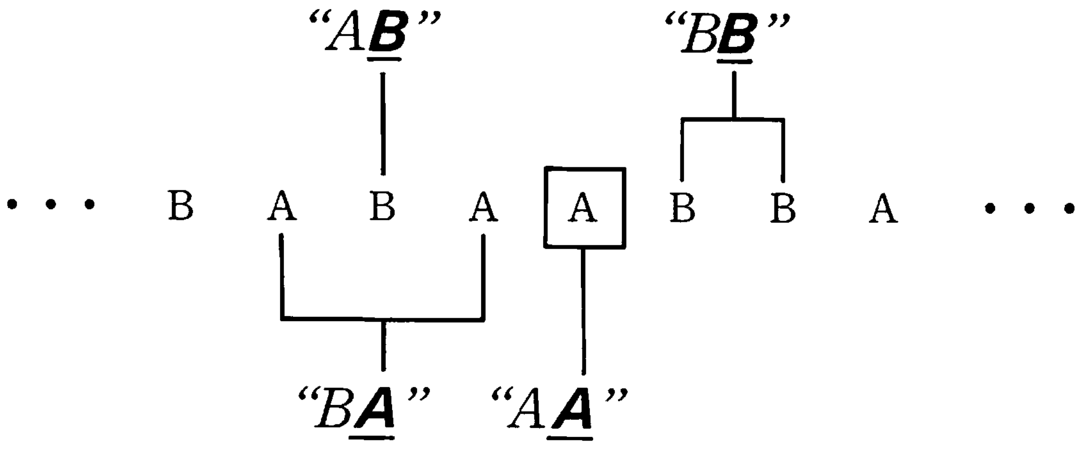

Fig. 1. A schematic representation of a tonal series employed in this experiment. Tonal stimuli can be categorized into four groups, abbreviated as follows: "AA," target A tone; "BA," non-target A tone; "AB," non-target B tone following "BA" tone; "BB," non-target B tone following B or "AA" tone.

presented as stimuli (Fig. 1). Subjects were required to respond upon detection of two consecutive A tones in a tonal series (6). Thus, physically identical A tones, that is ... A A ... and ... BA ..., might produce different interpretations according to the anticipatory context established by the preceding tones. Differences in ERPs to ...A A... and ...B A..., if any, would indicate an existence of the top-down process in neurophyiological terms.

Ten young male volunteers (mean age 24.9 years) were tested. Two tones (1 kHz and 2 kHz bursts) with durations of 200 msec were presented binaurally through headphones at 60 dBSL, with inter-stimulus intervals varying randomly between 1500 and 1700 msec. The assignment of these two tones as the A or B tone was alternated among sessions. A series of tones, containing 100 occurences of each tone, were presented pseudo-randomly. A tones after A ("AA;" see the legend of Fig. 1 for detailed explanations of abbreviations) required mental counting (MC) in one task; and, in another task, "AA" required button-pressing (BP) with the middle finger of the right hand, while tones other than "AA" required pressing another button with the right index finger. Prior to these tasks, subjects performed two other tasks: first, they listened to the tones with no task requirements (NT); second, they were asked to discriminate between the two different tones (TD) by pressing two designated buttons (7).

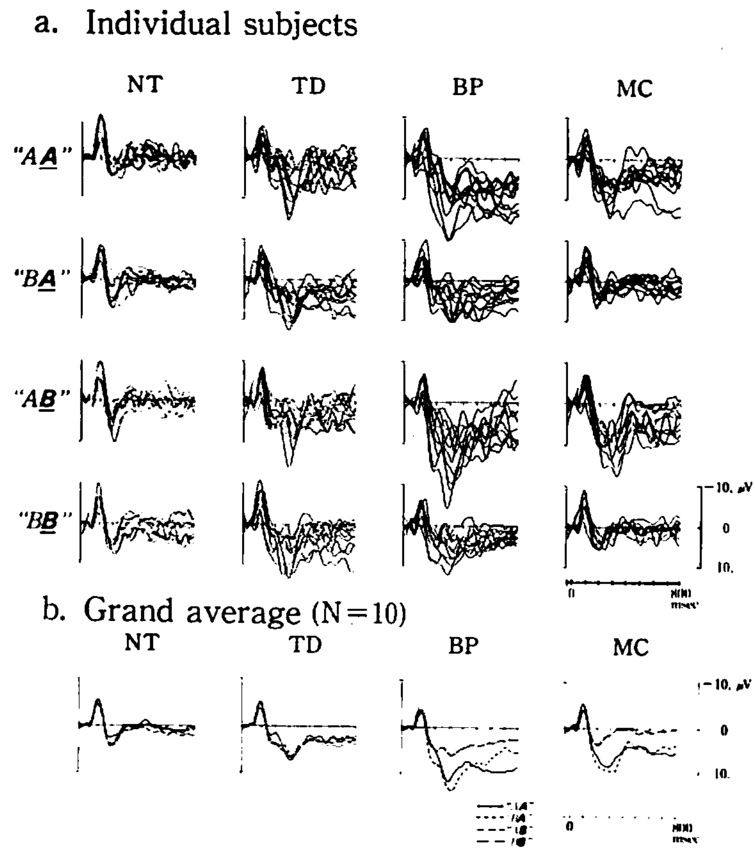

Fig. 2. ERP waveforms derived from the Cz region. a: ERP waveforms of 10 subjects are superimposed separately for the 4 conditions (NT, no task condition; TD, tone discrimination condition; BP, button pressing condition, and MC, mental counting condition) and 4 stimulus categories ("AA," "BA," "AB," and "BB"). b: Grand average ERP waveforms across 10 subjects for the 4 stimulus categories ("AA," solid line; "BA," dotted line; "AB," small dashed line and "BB," large dashed line) are superimposed separately for each condition.

In Fig. 2, the averaged ERP waveforms at Cz for each individual and the grand average waveforms are displayed (8). In the MC tasks, P300s were elicited by the targets "AA" and non-targets "AB"; although "BA" and "BB" had physically identical characteristics to "AA" and "AB," respectively, they did not elicit P300s at all similar to the NT conditions. Also, in the BP tasks, "AA" and "AB" produced larger P300s, while "BA" and "BB" produced smaller P300s [$F(3,33)=9.12$, $p<.001$](9) similar to small P300s for both A and B tones in the TD tasks. These small P300s seem to have been elicited by the required motor responses. To be more precise, in the BP tasks, the P300 amplitudes for "AA" were significantly larger than for "BA" [$t(16)=2.99$, $p<.01$](10), while those for "AB" were significantly larger than for "BB" [$t(17)=4.01$, $p<.001$](11). Thus, physically identical A (B) tones produced different neural responses in terms of P300.

What are the implications of these large P300s, which were elicited by both the targets "AA" and non-targets "AB," and were not dependent either on the physical characteristics of the stimuli (tone A or B) or on teh simple sequential effects of the stimuli (match or mismatch with the immediately preceding stimulus)? "AA" and "AB" are similar in that both are preceded by "BA." The task requirement of responding to "AA" encouraged subjects to develop a frame of reference in which an anticipation of the forthcoming stimulus tended to elicit preparation for a second A tone. This preparation for a possible second A tone (target-location effect) seems to be related to the production of the large P300s. If stimuli were processed solely through the bottom-up process with no subjective expectation or cognitive context, then whenever B tones were initially recognized as B and judged as non-targets we would expect to find no differences between ERPs for "BB" and "AB". On the contrary, these results suggest a difference between the cerebral processes for the perception of "BB" and "AB". In other words, the specific elicitation of P300s by "AA" and "AB" was an electrophysiological reflection of a working subjective strategy that led to a selective processing, with the initial A serving as an effective indicator in preparation for the detection of designated targets. This result distinctly indicates that, along with the bottom-up process, the top-down process was at work while the subjects were performing the BP and MC tasks. These results are in accordance with the psychological hypothesis that perception is a two-way process including bottom-up and top-down processes. Thus, sensory input is processed most economically through (top-down) focal attention contingent upon the perceiver's present cognitive context.

While the two tones following A were similar in that they were potential targets, "AA" and "AB" should be represented differentially in cerebral processes due to their semantic differences. When comparing ERPs at the Fz, Cz, and Pz regions elicited by the target "AA" and non-target "AB", it was found that P300s were maximum at the Pz region for "AA", while a predominance was found at the Fz and Cz regions for "AB" in both the MC and BP conditions (Fig. 3)(12). Similar results have been cited

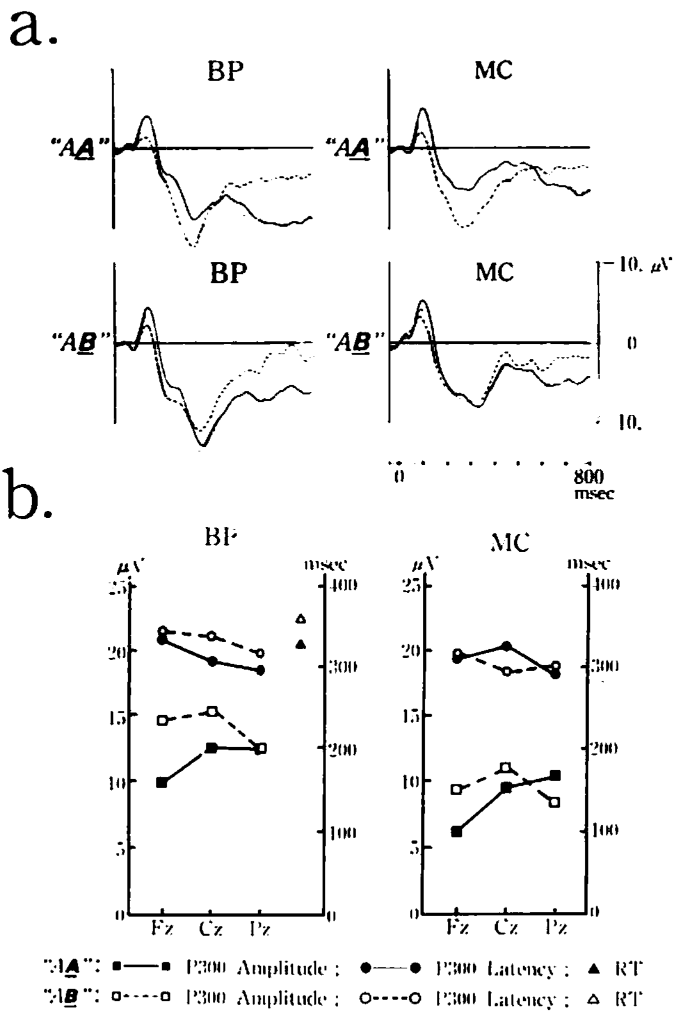

Fig. 3. P300s for "AA" and "AB" derived from the Fz, Cz and Pz regions in the MC and BP conditions. a: Grand average P300s for "AA" and "AB" at Fz (solid line), Cz (dotted line) and Pz (dashed line). b: Mean P300 amplitudes and latencies across 10 subjects corresponding to the waveforms shown in the above figure (a). Mean reaction times for the BP condition are also plotted.

concerning the differential distribution patterns of P300s for "Go" and "No-Go" stimuli, "Go" stimuli producing posterior P300s and "No-Go" anterior P300s (13). However, the results obtained in the present study are clearly different from those previously reported, in that "AA" and "AB" are both "Go" stimuli in the BP condition and both require motor responses. The only semantic difference between "AA" and "AB" in this study was their designation as targets or as non-targets, the required motor responses remaining the same. Therefore, the variance in P300s for "AA" and "AB" must be related to differences in central task-relevant processing (14). Specifically, this variance is probably related to the match or mismatch between the actual input and the schema for expected stimuli in the subject's working memory and is probably differentially represented in the neural processes. The posterior P300s elicited by the targets "AA" represent "yes" responses of the brain, with the anterior P300s for non-targets "AB" representing "no" responses, while indicates that different neural circuits are involved in "yes" and "no" responses.

Furthermore, as can be seen in Fig. 3, in the BP condition reaction times for "AA" and "AB" were shorter than, or nearly equal to, the P300 latencies (15). This result lends support to the notion that P300s reflect specific unconscious cerebral processes in memory and learning that are differentiated from, yet parallel to, the conscious processes of stimulus evaluation and response execution (16).

The possibility that P300s may be manifestations of an orienting reflex (OR) is yet to be resolved (17). ORs have been defined as originating from mismatches between input stimuli and neural models generated by preceding stimuli(18). Recently, the concept of ORs has become more generalized in definition as "calls for processing resources"; that is, an initiation of a transition from the preattentive process (automatic process) to the process of focal attention (controlled process) (19). In this study, P300s were not elicited by "BA," although "BA", as the preceding tone of any potential target tone, must certainly have "called" up central processing. On the other hand, P300s were clearly elicited by both "AA" and "AB," which were the objects of the central processing initiated by "BA" due to its contextual configuration. P300 distribution patterns differed for target and non-target stimuli. These results indicate that P300s are related to the "answer" to the "call", rather than to the "call" itself. This strongly suggests that P300s are not a manifestation of the OR.

In summary, this study has provided a successful demonstration of the psychological two-way model of cognition by means of cerebral electrical processes, adding further evidence that P300s reflect a subjects' cognitive context.

References and Notes

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information processing (2nd ed.) (Wiley, New York, 1976).
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6) In a tonal series, more than three consecutive A tones, such as ... B A A A ..., were not included.
7) One experimental session consisted of the NT, TD, BP and MC conditions in this order. Each subject performed two sessions in which 1 kHz and 2 kHz tones were alternately designated as A tones. The order of these two sessions was counterbalanced among subjects. Reaction times for button-pressing were measured in the TD and BP conditions. In an additional study, a change in response finger from the middle to the index finger of the right hand was acertained not to have any effect on ERP waveforms. Nine out of 10 subjects were right-handed, with one being ambidextrous, according to the questionnaire devised by Kameyama et al. [T. Kameyama, S.-I. Niwa, K.-I. Hiramatsu, O. Saitoh, in Laterality and Psychopathology, P. Flor-Henry, J. Gruzelier Eds. (Elsevier, Amsterdam, 1983), pp. 163-180].
8) According to the International 10-20 Electrode System, EEGs were derived from the Fz, Cz and Pz regions monopolarly referenced to linked ear-lobe electrodes. Vertical and horizontal eye-movements were also recorded from the right eye. EEGs were amplified using DC preamplifiers (bandpass down 6 dB at 0.15 and 300 Hz) and processed on-line through micro PDP 11/23 with a sampling frequency of 250 Hz/Ch. EEG data contaminated by peak to peak potentials of more than 100 μV or accompanied by EOGs of more than 150 μV during the period 40 msec pre-stimulus to 800 msec post-stimulus were eliminated from averaging. Fig. 2 shows the averaged ERP waveforms for the individual subjects obtained after a smoothing process using a digital filter with a window-width of 33.3 msec. P300 was defined as the most positive peak between 240 and 480 msec after stimulus onset, and P300 amplitudes were measured with respect to a zero level which was defined as the mean amplitude during a 40 msec pre- and post-stimulus period. However, those P300 data of which the latencies were just assessed as either 240 or 480 msec were particularly eliminated from further statistical analyses in this study so as to avoid contamination from "falsely detected" peaks of P300s according to the above definition.
9) Results for P300s at Fz [$F(3,33)=7.54$, $p<.001$] and Pz [$F(3,32)=10.95$, $p<.001$] were quite similar to those at Cz.
10) Results for P300s at Fz [$t(16)=2.53$, $p<.05$] and Pz [$t(17)=3.82$, $p<.001$] were quite similar to those at Cz.
11) Results for P300s at Fz [$t(11.06)=3.52$, $p<.01$] and Pz [$t(15)=4.17$, $p<.001$] were quite similar to those at Cz.

12) In the MC condition, the analysis of variance for the P300 amplitudes revealed the effect of an interaction between stimulus ("AA", "AB") and location (Fz, Cz, Pz) [$F(2,52)=3.87$, $p<.05$], indicating a significant difference in the distribution patterns of P300s for "AA" and "AB". On the other hand, no significant difference in P300 latencies was found either between "AA" and "AB" [BP, $F(1,51)=3.71$, n.s.; MC, $F(1,52)=.27$, n.s.], or among locations [BP, $F(2,51)=2.74$, n.s.; MC, $F(2,52)=.49$, n.s.].
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14) In order to minimize the effect of the physical difference in the stimuli "AA" and "AB", the a priori probabilities of these stimuli were set at approximately equal("AA":"AB"= 8:9), and the designation of 1 kHz and 2 kHz tones as A and B was counterbalanced in this investigation. In addition, another experiment was conducted with 4 subjects, in which "AB" was designated as the target, with "AA" as the non-target. In this additional experiment, the target "AB" produced the posterior P300s, with the non-target "AA" displaying the anterior P300s.
15) In the BP condition, the mean reaction times for "AA" and "AB" were 328 and 360 msec, respectively: The mean P300 latencies for "AA" and "AB" were 333 and 346 msec at Fz, 308 and 339 msec at Cz, and 295 and 318 msec at Pz, respectively. This relationship observed between reaction times and P300 latencies lends support to the notion of Donchin et al. that stimulus evaluation and the judgment necessary for responses are completed before the appearance of P300s [E. Donchin, W. Ritter, W.C. McCallum, in Event-Related Brain Potentials in Man, E. Callaway, P. Tueting, S.H. Koslow, Eds. (Academic Press, New York, 1978), p. 349].
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