COGNITIVE LOAD AFFECTS EARLY BRAIN POTENTIAL INDICATORS OF PERCEPTUAL PROCESSING

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A major problem in cognitive psychology is the determination of the effects of primary tasks on concurrent processing of other information. Cerebral event-related potentials (ERPs) offer one approach to this problem by examining the influence of task-induced cognitive load on discrete brain events related to the processing of stimuli. In dual task situations, the introduction of tasks such as discrimination or problem solving has been found to attenuate various components of the ERP to stimuli in the secondary task (Defayolle, Dinand, & Gentil, 1971; Lille, Audin, & Hazemann, 1975). Systematic manipulations of processing demands were studied by Isreal, Wickens, Chesney, and Donchin (1980) who report an attenuation effect on the P300 component of the ERP with increasing display load in a tracking task, where workload was also assessed with a secondary reaction time task.

In a dual task the ERP-eliciting stimulus is generally relevant to a task and consequently has to be processed at a relatively high level which precludes the observation of the effects of cognitive load on earlier stages of stimulus processing. The present study was undertaken to observe the effects of cognitive load on task-irrelevant stimuli using pupil size as an independent measure of processing demands during problem solving (see Beatty, 1979).

ERPs were obtained to irrelevant auditory probes presented before and after the presentation of digits in a mental multiplication task. This task has been shown to produce pupillary dilations with a peak amplitude that is monotonically related to the a priori difficulty of the problems (Hess & Polt, 1964; Payne, Parry, & Harasymiw, 1968).

Method

Subjects and Material

Eleven college level students of both sexes were used in the experiment. The EEG and vertical electro-oculogram (EOG) were recorded with Ag-AgCl electrodes placed at Fz, Cz, Pz, F3, F4, P3, P4, referred to linked ear lobes and for the EOG from electrodes placed above and below the right eye. All signals were amplified by Grass series 8 amplifiers with a 0.1 to 70 Hz bandpass. Pupillary diameter was measured using a Whittaker 1050S video pupillometer.

Data collection and stimulation was controlled by a PDP-11/34 computer. All signals were sampled at 200 Hz for one second starting 50 msecs prior to stimulation and were digitized on-line at 12 bits. Digitized single-trial data were stored on magnetic tape for later analysis.

The auditory prompts and digits were presented through digitized speech and had a duration of 0.6 secs. The irrelevant stimuli consisted of 1000 Hz tones presented at an intensity of approximately 56 dB SL with a duration of 20 msecs. The tones were generated by a Hewlett-Packard audio oscillator (model 200 AB) and delivered through a loudspeaker 1.5 m in front of the subject. Subjects had access to a keyboard to start the trials and enter their answers on every trial.

Procedure

After the electrode placement, the subject was told that he would be required to solve 30 easy and 30 difficult multiplication problems in a random sequence. Problems were called easy when both numbers were between 2 and 9 and difficult when one number was between 3 and 9 and the other was between 13 and 19.

The procedure for each trial, as described to the subject was as follows. The subject heard the word "Ready" through the loudspeaker at which time he was to fixate a dot in front of him and depress a key to start the trial. He was then to attend to the auditory presentation of the two digits separated by a one-second pause and to ignore all other stimuli. After the second digit the subject was to silently multiply the two digits until he heard the word "Respond", at which time he could stop fixating and was to enter the correct answer on the keyboard.

A tone was presented at a random time between one and two seconds after the subject's initiation of the trial and also between one and two seconds after the presentation of the last digit. The interval between the end of the last digit and the response cue varied between 3.5 and 4.5 secs.

Results

For each subject, the individual EEG epochs were edited for artifacts using an RMS voltage criterion rejecting an average of 10% of the trials. The epochs were then averaged separately for each of the four conditions defined by the two recording periods and the two difficulty levels. Averaged pupillary responses were also obtained using the same trials. Three of the initial eleven subjects had to be excluded from the analysis because their EEG records contained a large amount of ocular artifacts.

Two main components could be identified in all the averaged waveforms by visual inspection: a negative one having a latency ranging from 80 to 130 msecs (N100) and a positive one with a latency range of 170 to 220 msecs (P200).

Group averages were obtained (see Figure 1) for the four conditions and difference waveforms were computed between ERPs in baseline and problem solving periods. Slow potential shifts could not be discerned in any of the difference waveforms.

The peak amplitude of the components relative to an average pre-stimulus baseline was obtained using the maximum value within the latency ranges described above. At Fz, N100 amplitude was found to be generally lower during problem solving periods than during baseline periods $(F1,7)=11.7$, p .01).

At Cz the mean baseline amplitude was slightly higher for the difficult condition compared to the easy condition but a much lower amplitude was observed in the difficult condition during the task compared to the other three conditions. Significant effects were obtained for the main effect of task presence ($F(1,7)=9.36$, p .05) and for the interaction between task presence and difficulty level ($F(1,7)=5.66$, p .05). An analysis of the simple effects in this interaction revealed that task presence produced a significant amplitude decrement on N100 only in the difficult condition ($F(1,7)=10.8$, p .025) and not in the easy condition (F 1).

No significant effects were observed on the N100 component at any other derivation and no effects were found on the amplitude of P200 at any electrode site.

Average pupil size at stimulus onset was also analyzed using ANOVA and significant effects were obtained for the level of difficulty ($F(1,7)=6.17$, p .05) and for the interaction between task presence and difficulty level ($F(1,7)=38.27$, p .01). Analyses of simple effects determined that, as with N100 amplitide, the effect of the task on pupil diameter was only significant in the difficult condition ($F(1,7)=8.4$, p .025). Figure 2 contrasts the effects obtained on pupil size and on N100 amplitude at Cz.

In order to examine the relation between the effects observed on the pupil and N100 measures across subjects rank correlations were obtained between the changes in pupil size and in N100 amplitude from baseline to task periods across subjects for both the easy and difficult conditions. A significant negative correlation was obtained in the easy condition (p=-0.77, p .05) but not in the difficult condition (p=0.22, N.S.).

Discussion

The present data suggest that the amplitude of the N100 component evoked by irrelevant stimuli can be affected by cognitive load as indexed by pupillary measures.

The fact that no N100 attenuation could be observed in the easy trials argues against an interpretation of the results in terms of a general activation effect due to the performance of a task. The same argument can be used to refute significant effects due to the long recovery period of N100 with multiple stimulation, and significant contamination due to response preparation or CNV-like potentials. Multiplication problems involving single digit pairs have been shown to produce identifiable pupillary dilations in other studies (e.g., Hess & Polt, 1964) but in the present experiment the second probe was presented rather late after the last digit and, on most trials, probably occurred after the resolution of the pupillary response.

The absence of slow potential shifts in the global difference waveforms is not sufficient to conclude that the N100 attenuation is not due to variations in overlapping potential shifts. It is clear however, that the influence of the task on the ERP takes place at an early stage. Indeed, the N100 component has been shown to be closely associated with processes related to the early perceptual strength of stimuli indexed by sensitivty measures in signal detection situations (e.g., Squires, Hillyard, & Lindsay, 1973) and intensity parameters in multichannel selective listening situations (Schwent, Hillyard, & Galambos, 1976). The finding that the cognitive load induced by problem solving can affect CNS activity at latencies similar to those of processes related to the strength of physiological signals can have an important impact on conceptualizations of information processing. These suggestive results will have to be complemented by more direct observations to establish the nature of this possible influence of problem solving on early stages of perceptual processing.

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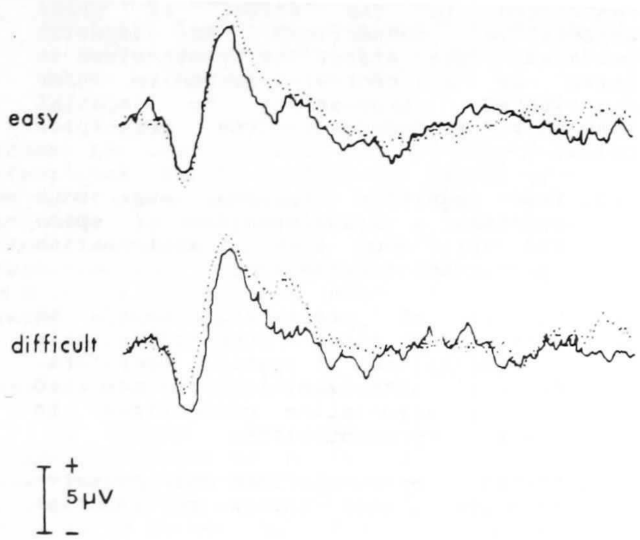

Figure 1. Group average waveforms for the two experimental conditions obtained to stimuli during baseline (solid) and problem solving (dotted) periods.

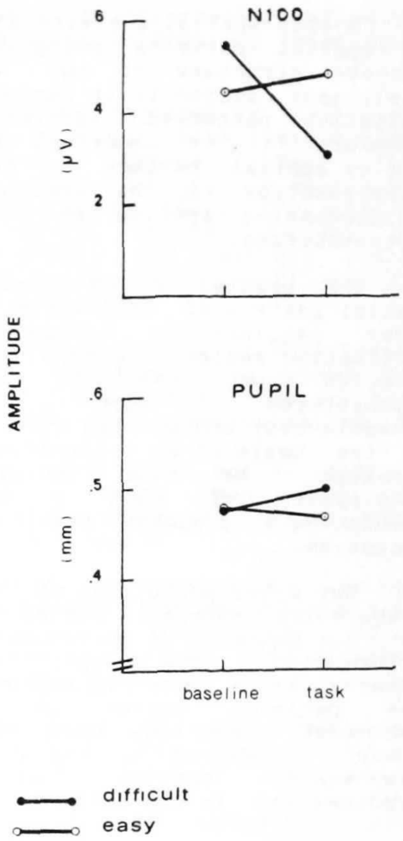

Figure 2. Mean amplitudes of N100 and mean pupil diameters in the four conditions.