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# STIMULUS NOVELTY, TASK RELEVANCE AND THE VISUAL EVOKED POTENTIAL IN MAN[1]

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A late positive waveform of the human evoked potential, the $P_3$ or $P_{300}$ (latency 300-500 msec), has been shown by numerous researchers to accompany the delivery of task-relevant information which requires a decision or response from the subject. (Sutton et al. 1965, 1967; Ritter and Vaughn 1969; Squires et al. 1973; Picton et al. 1974). The amplitude of this waveform is enhanced when such stimuli are delivered infrequently and unpredictably to the subject (Tueting et al. 1971; Squires et al. in press). This wave can be elicited by task-relevant stimuli in any modality (or even by omitted stimuli) and is found to be widely distributed across the central and parietal regions of the scalp (Hillyard et al. in press; Ritter et al. in press). Similar waveforms (also termed $P_3$), however, have also been reported to follow unpredictable and infrequent stimuli when no explicit task assignment is given to the subject (Ritter et al. 1968; Vaughn and Ritter 1970; Roth 1973). This finding has prompted these authors to suggest that the $P_3$ is one index of the orienting response to any rare, unpredictable event, even when it is not task-relevant. These two sets of data thus pose a paradox for solution: apparently $P_3$ waves can be elicited both by task relevant stimuli which require a decision, and by stimuli that are seemingly irrelevant to any ongoing task.

In order to investigate the effect of task-relevance on $P_3$ waves, several methodological steps seem appropriate. First, rare stimuli of both types (task-relevant and task-irrelevant) should be presented unpredictably within the same session to control for changes in attention or arousal. Second, in order to establish whether the $P_3$ "generators" involved are the same for the two classes of stimuli, the scalp distributions of the respective $P_3$ waves should be compared. Finally, the irrelevant stimuli should differ in their ease of recognition; stimuli which are unrecognizable or difficult to categorize should be included to maximize stimulus novelty and so enhance any orienting response to it.

Accordingly, in the present study, the visual evoked potential (VEP) to rare, task-relevant (counted) numerical stimuli was compared with VEPs to rare, task-irrelevant stimuli, both being randomly interspersed within a sequence of tachistosopically-flashed background numbers. These task-irrelevant stimuli were of two classes: 1) easily recognizable (eg. simple geometric shapes) and 2) completely novel (i.e. complex, colorful abstract-type drawings which were unrecognizable). It was found that such novel stimuli did, in fact, evoke large $P_3$ waves, but they had different scalp distributions from those which followed the task-relevant stimulus. This indicates that at least two types of late positive $P_3$ waves exist, differing both in brain sources and psychological correlates.

## METHODS

### Subjects

In this study 18 graduate and undergraduate students each served as subjects in one 2-hour session. For four subjects, this was their first experience in an evoked potential experiment; the others had been in similar experiments. No subject knew that the rare, task-irrelevant slides would be presented or what the purpose of the experiment was.

Stimuli

The subject reclined in a chair 2.5m from a viewing screen. Slides were flashed onto this screen at regular intervals of 1.3 sec; each flash lasted 80 msec and subtended 2.3° of visual angle.

Four types of visual stimuli were on the slides used in different phases of this study: a) the number 2 ("background stimulus"), b) the number 4, c) "novel" stimuli, each consisting of a different quasi-random color pattern unrecognizable by the subject and d) "simple" stimuli, each consisting of an easily recognizable black and white pattern (eg. the word "THE", a simple line drawing of a face, a black and white grid, geometric figures, etc.). The luminance of the slides in each category was 1.3, 1.4, 0.0 and 1.0 log foot-lamberts, respectively.

Procedures

Each subject was exposed to three experimental conditions in the following order:

1) Passive. Subjects were told to relax and to look at

the numbers 2 and 4 which were to be presented while they fixated their eyes on a dot at the center of the viewing screen. Fifty slides consisting of 10% 4s and 90% 2s, randomly mixed, were then presented in a block. Each subject received three such blocks interrupted by 2-minute rest periods.

2) Count-4. Subjects were next instructed to keep a running count in their heads of how many 4s were seen in each block and to "disregard all other stimuli". At the end of each block they reported this count to the experimenter. Again a total of 50 slides randomly mixed, was presented per block. All subjects received 10% 4s and 80% 2s; for 7 of the 18 subjects the remaining 10% were novels and for 11 of them the 10% was equally distributed between novels and simples. Six such blocks were presented, again with 2-minute rest periods between blocks. After viewing the first block many subjects remarked about the odd slides (i.e. novels and simples), and occasionally asked what they were for. The experimenter always responded by telling the subject to completely ignore them and to concentrate on counting the 4s.

3) Count-odds. Subjects were instructed this time to ignore 2 and 4 stimuli and to count only the novels and simples. Otherwise the procedure was identical to that just described for the count-4 condition.

No novel or simple stimulus was ever presented more than once to a given subject. Two completely different sets of novels were used: one set for those 11 subjects who also received _simples_, and another for the 7 subjects who did not.

4) _Control for Stimulus Complexity_. Following their completion of the above three conditions, each of six subjects was asked to look at the screen where the first _novel_ stimulus presented in the count-_4_ condition was repeatedly flashed (50 times). He was then given four separate blocks of 50 slides, each block consisting of 80% _2_s, 10% _4_s and 10% of this same repeated _novel_ slide. He reported his count of _4_s at the end of each block. As in the previous conditions, these _4_s were randomly situated throughout each sequence, but in this case each _4_ was followed two slides later by the repeated _novel_ slide; the subject was informed of this positioning arrangement prior to the start of each block. For each of the six subjects, the entire control sequence just described was repeated using the second _novel_ stimulus presented in the count-4 condition.

## Recording and Data Analysis

Beckman non-polarizable electrodes were placed at Fz, Cz and Pz according to the 10-20 system; each was refered to the right mastoid process. The EOG was recorded with Beckman electrodes placed diagonally above and below one eye so as to detect eyeblinks as well as lateral and vertical eye movements.

All subjects were recorded with a Grass Model 7 polygraph with 7P5 A.C. preamplifiers (bandpass down 3dB at 0.3 and 500c/sec);

the 11 subjects who received both novels and simples were concurrently recorded with a Grass Model 5 polygraph with 5 P1 D.C. preamplifiers (TC=DC, 3dB down at 45 c/sec). For all subjects the EEG output was stored on FM magnetic tape.

VEPs to each of the four stimulus categories were averaged separately from the taped records using a Fabritek 1052 signal averager. Amplitudes of all components were measured from baseline to peak with 200 msec of the average pre-stimulus EEG tracing serving as baseline. The $N_1$ wave was designated as the highest negative peak (re baseline) between 90 and 150 msec post-stimulus, $P_2$ the highest positive peak between 160 and 240 msec, $N_2$ the highest negative peak between 230 and 320 msec, and $P_3$ the highest positive peak between 300 and 450 msec.

## RESULTS

### Passive Condition

Figure 1 shows the VEPs to the background 2s (90%) and to infrequently presented 4s (10%) during the passive condition; each of the superimposed tracings is the averaged response at Cz from a different subject.[2] The earlier waves, $N_1$, $P_2$, and $N_2$, did not differ significantly in amplitude between the 2 and 4 stimuli; however, the infrequent 4s evoked substantially larger $P_3$ waves than did the more common 2s.

INSERT FIG. 1 HERE

Count-4 Condition

The EPs to the 2, 4 and novel stimuli while the subject counted the infrequent 4s are compared in Figure 2, in which each tracing again represents the averaged response from a different subject. Although $N_1$-$P_3$ was slightly larger to the 4s in the count-4 condition than in the passive condition, the increase was not significant.

INSERT FIG. 2 HERE

Some striking changes between the passive and count-4 conditions were evident, however, in the later components. As Figure 2 shows, the counted 4s elicited a much larger $P_3$ wave (by 154% at Cz, $p<.01$, Wilcoxon) than did the 4s in the passive condition. Furthermore, the unexpected novels, which were task-irrelevant, evoked an even larger $P_3$ wave at Cz than the counted 4s; this $P_3$ wave to novels was typically preceded by a large $N_2$ wave.

As seen in Figure 2 and Table I the amplitudes of the $P_3$ waves evoked by the novels were more anteriorly distributed on the scalp (being 93% of maximum at Fz, 100% at Cz and 72% at Pz) than those evoked by the counted 4s (being 71% of maximum at Fz, 93% at Cz and 100% at Pz). This spatial difference between the two $P_3$ distributions was significant ($F$ for scalp locus x stimulus-type interaction $(2,78)=13.7$, $p<.001$). The $P_3$ to the novels, was significantly larger at Fz and Cz than at Pz (both $P<.02$, Wilcoxon), while the $P_3$ to the counted 4s was larger at Fz than at Cz and larger at Cz than at Fz (both P<.01). On the basis of this evidence it seems clear that the $P_3$ generators of the counted 4s and the unexpected novels are different.

INSERT TABLE I HERE

A separate analysis of variance was done on the amplitudes of the D.C. recorded $P_3$ waves evoked by novels, simples and counted 4s for those subjects who received all three types of stimuli. The novels evoked significantly more frontally distributed $P_3$ waves than either the $P_3$ waves to the simples or the counted 4s (both $p<.01$, see Table II). The simples evoked $P_3$ waves that were slightly but significantly less parietally distributed than the P3 waves to the counted 4s ($p=.05$).

INSERT TABLE II HERE

Although the subjects who received both novels and simples did show a slight tendency to produce larger and more frontal $P_3$ waves to novels than those subjects who saw only novels, these differences were not significant (comparing A.C. recordings).

The $N_2$ wave evoked by the 4s was larger (at Cz) in the count-4 condition than in the passive condition ($p<.05$). The novels, however, evoked a larger $N_2$ wave than either simples or 4s ($p<.01$; see Tables I & II). All three types of stimuli elicited $N_2$ waves with a similar centro-frontal scalp distribution.

D.C. Recordings. The scalp distributions of the $P_3$ waves to the counted 4s and the novels were equivalent for the A.C. and D.C. recordings (compare Tables I & II). The dissociation of these $P_3$ waves from the preceding slow potential shift (CNV) is illustrated in Figure 3; again each tracing is the averaged waveform from a different subject from whom D.C. records were obtained. In particular, the large parietal $P_3$ waves evoked by the

INSERT FIGURE 3 HERE

counted 4s do not simply represent the termination or "return to baseline" of a prior, phasic CNV since the CNV here is small in relation to the $P_3$ waves. Furthermore, there was no sustained positive baseline shift after the $P_3$ to the 4s that would suggest the resolution of a "resident" CNV (Wilkinson and Asby 1974). Similarly, the large centro-frontal $P_3$ evoked by novels cannot be accounted for by a D.C. baseline shift (possibly the termination of a CNV), since this shift occurs after the $P_3$ wave is over and has a more uniform scalp distribution (6.2μV at Fz, 6.8μV at Cz and 4.0μV at Pz). Thus, the differences in $P_3$ amplitude seen at the three scalp sites cannot be attributed to D.C. baseline shifts which may accompany deliveries of the stimuli.

This dissociation between the $P_3$ to novels and any concommitant D.C. baseline shift is also evident in single-trial D.C. records, as shown in Figure 4. Here the VEPs to the very first novel stimulus presented show, once more, that the centro-frontal $P_3$ waves are very large (ca. 30μV) compared to the $P_3$ waves at Pa, and that they appeared without any D.C. shift at any electrode site.

INSERT FIGURE 4 HERE

When the $P_3$ waves evoked by the first, second and third novel stimuli were averaged separately for these subjects, the mean amplitude of the second dropped by 50.0% and of the third by 60.1%, as compared to the first. There was no further significant decrement in $P_3$ wave amplitude evoked by subsequent novels. Since these novel stimuli came at least 12 sec. apart, it is unlikely that refractoriness of the $P_3$ generator can account for this large amplitude decrement.

## Stimulus Control Condition: Repeated Exposure to a Novel Stimulus

No aspect of the evoked potentials to the counted 4 stimuli differed significantly between the count-4 and stimulus control conditions within the 6 subjects studied. This similarity between these two conditions was also found for the 2 stimuli. In contrast, the novel stimuli in the count-4 condition elicited $P_3$ waves which were at least 300% higher in amplitude at Fz than those elicited in the stimulus control condition by a predictable, repreated novel stimulus ($p<.001$, Wilcoxon, see Fig. 5 and 6B).

INSERT FIGURES 5 AND 6 HERE

Figure 6 illustrates this difference for one subject: the large single-trial response (70 μV at Fz) in panel A was elicited in the count-4 condition by the same novel slide used in the stimulus control condition to produce the averaged evoked waveforms shown in panel B (dotted lines). Evidently a formerly novel stimulus that has been seen many times and that is presented predictably in time no longer elicits a large frontal $P_3$; instead, it comes to evoke a posteriorly distributed $P_3$. This rules out the possibility that the frontal $P_3$ to the novel stimuli is simply an effect of the physical complexity of an infrequent stimulus.

Atypical Responses from Two Subjects

Two subjects (in the D.C.-recorded series) had very atypical VEPs, dominated by a large negative wave in response to both novels and simples. For this reason they were not included in the figures or in the tabular data analysis. This negative wave began at a latency of about 200 msec, reached a maximum amplitude of about 25μV to novels and 15μV to simples about 100 msec later, and was sustained for about 450 msec before abruptly returning to baseline (at least 600 msec before the next stimulus). This potential was maximal at Fz, had 95% of this amplitude at Cz, and was not discernible at Pz. Its time-course and topographic characteristics did not resemble those of CNV or skin potential (Picton and Hillyard, 1972) nor were there any eye movements correlated with it. A "$P_3$" wave appeared as a relatively small deviation (at 400 msec latency) riding on top of this large negative potential. The P3 waves evoked by the counted 4s in these subjects appeared to be similar to those of the other subjects: the mean $P_3$ amplitude was 5.00μV at Fz, 15.00μV at Cz, and 16.40μV at Pz; $P_3$ latency was 400 msec for both subjects.

Count-Odds Condition

The amplitudes of $N_1$ and $P_2$ to the 2s, 4s and simples in this condition did not differ significantly from those seen in the count-4 condition (compare Tables II and III).

INSERT TABLE III HERE

There was, however, a substantial increase in the $N_1$ amplitude evoked by the novels in the count-odds condition (by 106% at Fz).

The amplitude of the $P_3$ waves evoked by both the novels and the simples were substantially increased at Cz and Pz when these stimuli became task-relevant, but no significant change occurred at Fz. Analysis of variance showed that the $P_3$ scalp distribution for the <u>novels</u> in this condition differed significantly from that in the count-<u>4</u> condition ($p<.05$). The $P_3$ waves evoked by the <u>4</u>s, on the other hand, were significantly decremented relative to the count-<u>4</u> condition, primarily at Cz and Pz sites. Thus, making a stimulus task-relevant (by counting) resulted in a significant enhancement of its $P_3$ amplitude over the posterior scalp.

The $N_2$ wave at $C_z$ was larger to counted <u>4</u>s than to the task-irrelevant <u>4</u>s. However, the $N_2$ waves to the <u>novels</u> and the <u>simples</u> did not show any significant increase when these stimuli became task-relevant in the count-odds condition. As in the previous conditions the <u>novels</u> evoked the largest $N_2$ waves.

## Latency Changes

There were only a few significant changes in the latencies of the various evoked potential components as a function of experimental condition or stimulus category (Table IV). In the count-<u>4</u> condition, the

INSERT TABLE IV HERE

<u>simples</u> evoked $P_3$ waves with latencies significantly longer than those evoked by <u>2</u>, <u>4</u>, and <u>novel</u> stimuli ($p<.01$). This difference

did not appear in the count-odds condition, however. The latency to the $N_2$ peak was significantly shorter to the novels than to the 4s in both count-4 and count-odds conditions (both $p<.05$, Wilcoxon). Finally, $N_1$ and $P_2$ were shorter in latency to the 4s than to the 2s in the passive condition ($p<.05$, Wilcoxon).

## DISCUSSION

### Scalp Distribution of $P_3$ Waves

These findings indicate that the late positive wave, the $P_3$, is not a unitary brain phenomenon, but can be subdivided into distinct varieties which differ both in scalp distribution (and hence in brain generators) and in psychological correlates. On the one hand, task-relevant, counted stimuli (eg. 4s) elicited $P_3$ waves that were largest over the parietal scalp while, on the other hand, task-irrelevant and unrecognizable, novel stimuli elicited $P_3$ waves that were largest over the centro-frontal scalp. Control experiments demonstrated that this frontal variety of $P_3$ wave was not a response to the physical complexity of the stimulus, but, instead, was dependent upon the stimulus being unrecognizable and unpredictable in its time of delivery. Thus, when a novel stimulus became familiar in content and predictable in time of delivery, it evoked only small and posterior $P_3$ waves similar to those elicited by the irrelevant but structurally simple and recognizable stimuli (the simples).

Posteriorly located $P_3$ waves similar to those found in the present study to task-relevant stimuli have also been reported by other investigators (Ritter *et al*. 1972; Picton and Hillyard 1974; Hillyard *et al*. in press; Squires *et al*. in press) using task-relevant stimuli in the auditory modality. Other investigators (Cohen and Walter 1966; Lifshitz 1966) who have studied vertex responses to complex visual patterns have recorded small long-latency positive waves, but no information about the scalp distribution of these waves was presented.

On the basis of the D.C. recordings, it seems unlikely that slow potential shifts (CNVs) arising before the stimuli were delivered or returning to baseline thereafter can account for either the frontal or parietal variety of $P_3$ or the scalp distribution differences between them. Large frontal $P_3$ waves to novels were found to occur in the absence of appreciable slow potential shifts, and such shifts as did occur, were on the average equally large at frontal and parietal sites and occured after the peaking of the $P_3$ (Fig. 3). There were also no appreciable positive baseline shifts to the counted 4s which could have biased the scalp topography of the $P_3$. The scalp distribution of the various $P_3$ waves in this paradigm, therefore, did not appear to be affected by slow potential shifts.

## Psychological Correlates of the $P_3$

The $P_3$ wave has been correlated with information delivery (Sutton et al. 1967), decision making (Hillyard 1969; Smith et al. 1970; Rohrbaugh et al. 1974), template matching (Squires et al. 1973), target recognition (Hillyard et al. in press), and stimulus salience (Paul and Sutton 1972); however, each of these hypotheses interprets the $P_3$ wave as being dependent upon the recognition of known, task-relevant stimuli which are anticipated.

This interpretation does not seem applicable to the centro-frontal $P_3$ wave elicited by the novel stimuli. Not only were the novel stimuli irrelevant to the counting task, but their contents could not be anticipated beforehand nor recognized and categorized upon presentation. This centro-frontal $P_3$ may, therefore, be a sign of the cognitive component of Pavlov's "what is it" reaction to novel or unrecognizable stimulation. However, it is not possible to determine from the present design whether this wave is more closely associated with the orienting or the investigating aspects of this response; furthermore, the relationship between the centro-frontal $P_3$ and the autonomic and behavioral activities associated with the "what is it" reaction has yet to be determined. The data also tend to support a second hypothesis which suggests that the difference between frontally and posteriorly located $P_3$ waves to irrelevant stimuli lies along the single dimension of ease of recognition. Thus, the unrecognizable novels evoked frontal $P_3$ waves while the easily recognized simples and 4s evoked posterior $P_3$ waves. Other hypotheses for the psychological correlates of the frontal and posterior $P_3$ waves may be entertained (eg. the perceived quantity of information contained in stimuli or perhaps the non-linquistic pictorial and linquistic qualities of stimuli could play a role in $P_3$ generation), but at present the two mentioned above appear most parsimonious.

Ritter and his colleagues (Ritter et al. 1968; Ritter and Vaughn 1969) were the first to suggest that the $P_3$ wave was correlated with the orienting response. In their earlier study, subjects were presented with a train of 1000 c/sec tones interspersed at rare and unpredictable points in time with 2000 c/sec tones. This 2000 c/sec tone was the only "change in pitch" throughout this experimental session. Such pitch changes elicited posterior-dominant $P_3$ waves while "relatively little activity at 300 msec was obtained from the frontal ($F_z$) responses." Since they observed similar $P_3$ waves whether the subject was attending and responding to rare stimulus changes or was told to ignore them, Ritter and Vaughn (1969) suggested that this wave was a correlate of the "cognitive evaluation of stimulus significance" which occurs in conjunction with both the orienting response and the judgment of task-relevance. It is evident, however, that any orienting responses or cognitive evaluations of such repeated and easily recognized pitch changes are in principle very different from those called forth by the highly novel, unrecognizable stimuli used in the present study.

Recently, Squires _et al_. (in press) have distinguished a frontally distributed late positive wave, which they termed "$P_{3a}$", from the typical, posteriorly distributed "$P_{3b}$" elicited by task-relevant stimuli. This $P_{3a}$ wave was elicited by pitch or intensity shifts occurring unpredictably in a train of tone pips. For several reasons, however, there appears to be little connection between this $P_{3a}$ wave and the frontal $P_3$ wave ("_novels_ $P_3$") reported in the present study. First, the _novels_ $P_3$ was elicited when subjects actively attended to visual stimuli, whereas the $P_{3a}$ appeared only when auditory stimuli were ignored. Second, the _novels_ $P_3$ decrements rapidly with repeated exposure to initially effective stimuli and such repeated stimuli then elicit posterior $P_3$ waves; Squires _et al_ did not report any habituation or changes in scalp distribution over a long session. Third, the _novels_ $P_3$ was elicited only by complex unrecognizable stimuli, whereas $P_{3a}$ was elicited by simple, easily recognizable stimuli. Finally, the _novels_ $P_3$ averages 360-450 msec in latency and 12.5-15.8μV in amplitude, whereas $P_{3a}$ averages 220-250msec in latency and only 6μV in amplitude. Given these substantial differences, it seems unlikely that the auditory $P_{3a}$ and visual _novels_ $P_3$ reflect the same brain systems, although both occur in response to unpredictable shifts in a stimulus train.

## Changes in Other VEP Components

A negative wave with latencies between 250-350 msec has previously been linked to an orienting response to temporally aberrant clicks (Haider et al. 1968); similarly, in this study the $N_2$ wave (240-300 mec), was largest to those stimuli most likely to produce an orienting response, i.e. the novels. In addition, however, we found that task-relevance (counting) also enhances $N_2$ waves evoked by 4s. Apparently, those factors which tend to increase the frontal and the posterior types of $P_3$ waves also increase the preceding $N_2$ wave.

An atypical, high amplitude negative process (onset latency 200 msec and duration 450 msec) was observed in two subjects. It is not yet clear whether this process is related to $N_2$ generators, although both processes have similar scalp distributions. This large negativity proved to be similar for both types of unexpected stimuli novels and simples, so it does not seem to be highly sensitive to gradations in stimulus complexity or novelty. Other researchers have also reported the occurrence of large negative deviations of the VEP at vertex to complex visual patterns (Cohen and Walter 1966; Lifshitz 1966; Symmes 1972). At present we can only guess at what this process may reflect, eg. orientation, arousal, stress, etc.

In conclusion, the results of this study indicate that "the $P_3$" does not represent a unitary phenomenon, rather, it appears that a variety of $P_3$ waveforms with differing generator origins exist which are differentially affected by stimulus novelty, recognition and task-relevance. The general approach of presenting psychologically provocative stimuli while monitoring scalp distributions of EP components, may well prove valuable in furthering our understanding of the psychological underpinnings of late components of the VEP in man.

## SUMMARY

Visual evoked potentials (VEPs) were recorded from normal adult subjects performing in a visual discrimination task. Subjects counted the number of presentations of the numeral 4 which was interposed rarely and randomly within a sequence of tachistoscopically flashed background stimuli (numeral 2s). Intrusive, task-irrelevant (not counted) stimuli were also interspersed rarely and randomly in the sequence of 2s; these stimuli were of two types: simples, which were easily recognizable (e.g. geometric figures), and novels, which were completely unrecognizable (i.e. complex, colorful patterns). It was found that the simples and the counted 4s evoked posteriorly distributed $P_3$ waves (latency 380-430 msec) while the irrelevant novels evoked large, frontally distributed $P_3$ waves (latency 360-380 msec). These large, frontal $P_3$ waves to novels were also found to be preceded by large $N_2$ waves (latency 278 msec). These

findings indicate that "the $P_3$" wave is not a unitary phenomenon but should be considered in terms of a family of waves, differing in their brain generators and in their psychological correlates. These late positive components are discussed in terms of task-relevance, recognition and Pavlov's "what is it" response.

## FOOTNOTE

1. We are grateful to Rachel Courchesne for her helpful comments on the manuscript. This work was supported by NASA Grant NGR 05-009-198 awarded to Robert Galambos, NIH Grant 1 R01 MH 25594 awarded to Steven A. Hillyard and by NIH training grant USPHS NS 05628.

2. VEPs from only 15 of the 18 subjects are presented in Figures 1 and 2. The data from two subjects with atypical waveforms are described in a separate section below and are excluded from the present analysis. Another subject, K.M., produced unusually high amplitude evoked responses. For this reason it was not possible to display her waveforms on the same scale as that of the other subjects in Figures 1 and 2. Her responses are shown individually in Figure 6, and her data were included in all pertinent graphs, tables, and analyses.

## REFERENCES


Cohen, J. and Walter, W.G. The interaction of responses in the brain to semantic stimuli. Psychophysiology, 1966, 2:187-196.

Haider, M., Groll, E. and Studynka, G. Orientierung-und Bereitschaftspotentiale bei unerwarten Reizen. Experimental Brain Research, 1968, 5:45-54.

Hillyard, S.A. The CNV and the vertex evoked potential during signal detection: a preliminary report. In: E. Donchin and D.B. Lindsley (Eds.), Averaged evoked potentials: methods, results and evaluations. NASA, SP-191, Washington, D.C., 1969: 349-353.

Hillyard, S.A., Courchesne, E., Krausz, H.I. and Picton, T.W. Scalp topography of the "$P_3$" wave in different auditory decision tasks. In: W.C. McCallum and J.R. Knott (Eds.), Event-related slow Potentials of the Brain. John Wright and Sons, Bristol, in press.

Lifshitz, K. The averaged evoked cortical response to complex visual stimuli. Psychophysiology, 1966, 3:55-68.

Paul, D. and Sutton, S. Evoked potential correlates of response criterion in auditory signal detection. Science, 1972, 177:362-364.

Picton, T.W. and Hillyard, S.A, Human auditory evoked potentials. II: Effects of attention. Electroenceph. clin. Neurophysiol., 1974, 36:191-199.

Picton, T.W., Hillyard, S.A. and Galambos, R. Cortical evoked responses to omitted stimuli. In: M.N. Livanov (ed.), Major Problems of Brain Electrophysiology. USSR Academy of Sciences, 1974:302-311.

Ritter, W., Simson, R. and Vaughn Jr., H.G. Association cortex potentials and reaction time in auditory discrimination. Electroenceph. clin. Neurophysiol., 1972, 33: 547-555.

Ritter, W., Simson, R. and Vaughn Jr., H.G. Topographic analysis of task-related cerebral potentials. International Symposium on Cerebral Evoked Potentials in Man, Brussels, in press.

Ritter, W. and Vaughn, H.G. Averaged evoked responses in vigilance and discrimination: a reassessment. Science, 1969, 164:326-328.

Ritter, W., Vaughn, H.G. Jr., and Costa, L.D. Orienting and habituation to auditory stimuli: A study of short term changes in averaged evoked responses. Electroenceph. clin. Neurophysiol. 1968, 25:550-556.

Rohrbaugh, J.W., Donchin, E. and Eriksen, C.W. Decision making and the P300 component of the cortical evoked response. Perception and Psychophysics, 1974, 15: 368-374.

Roth, W.T. Auditory evoked responses to unpredictable stimuli. Psychophysiology 1973, 10:125-138.

Smith, D.B.A., Donchin, E., Cohen, L., and Starr, A. Auditory averaged evoked potentials in man during selective binaural listening. Electroenceph. clin. Neurophysiol. 1970, 28:146-152.

Squires, K.C., Hillyard, S.A. and Lindsay, P.L. Cortical potentials evoked by confirming and disconfirming feedback following an auditory discrimination. Perception and Psychophysics, 1973, 13:25-31.

Squires, N.K., Squires, K.C. and Hillyard, S.A. Two varieties of long-latency positive waves evoked by unpredictable auditory stimuli in man. Electroenceph. clin. Neurophysiol., in press.

Sutton, S., Braren, M. and Zubin, J. Evoked potential correlates of stimulus uncertainty, Science, 1965, 150:1187-1188.

Sutton, S., Braren, M., Zubin, J. and John, E.R. Information delivery and the sensory evoked potential. Science, 1967, 155:1436-1439.

Symmes, D., and Eisengart, M.A. Evoked response correlates of meaningful visual stimuli in children. Psychophysiology, 1971, 8:769-778.

Tueting, P., Sutton, S., and Zubin, J. Quantitative evoked potential correlates of the probability of events. Psychophysiology, 1971, 7:385-394.

Vaughn, H.G. and Ritter, W. The sources of auditory evoked responses recorded from the human head. Electroenceph. clin. Neurophysiol., 1970, 28:360-367.

Wilkinson, R.T. and Ashby, S.M. Selective attention, contingent negative variation and the evoked potential. Biol. Psych., 1974, 1:167-179.

TABLE I

The mean baseline-to-peak amplitude (μV) and standard error (SE) of various EP components in the Count-4 condition. N=16. Based on A.C. recordings.

| | | Component | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $N_1$ | | $P_2$ | | $N_2$ | | $P_3$ | |
| Stimulus | Electrode Site | Mean | SE | Mean | SE | Mean | SE | Mean | SE |
| 2s | $F_z$ | 2.64 | 0.37 | 7.04 | 0.83 | 2.21 | 0.66 | 3.17 | 0.48 |
| | $C_z$ | 2.07 | 0.41 | 8.02 | 0.89 | 1.63 | 0.97 | 3.24 | 0.76 |
| | $P_z$ | 1.18 | 0.33 | 7.07 | 0.68 | 1.33 | 0.91 | 2.97 | 0.66 |
| 4s | $F_z$ | 3.42 | 0.65 | 7.98 | 0.68 | 4.82 | 1.43 | 7.11 | 1.13 |
| | $C_z$ | 2.87 | 0.62 | 9.15 | 0.66 | 5.46 | 1.39 | 10.78 | 1.36 |
| | $P_z$ | 1.78 | 0.49 | 8.37 | 0.84 | 2.78 | 0.90 | 11.60 | 1.53 |
| Novels | $F_z$ | 2.40 | 0.56 | 4.90 | 0.69 | 7.58 | 1.30 | 12.56 | 1.25 |
| | $C_z$ | 2.38 | 0.49 | 6.54 | 0.76 | 7.90 | 1.30 | 13.57 | 1.34 |
| | $P_z$ | 2.08 | 0.45 | 6.16 | 0.88 | 4.91 | 1.25 | 9.70 | 0.95 |

TABLE II

The mean baseline-to-peak amplitude (μV) and standard error (SE) of various EP components in the Count-<u>4</u> condition for those subjects who received both simples and novels. N=9. Based on D.C. recordings.

| | | Component | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $N_1$ | | $P_2$ | | $N_2$ | | $P_3$ | |
| Stimulus | Electrode Site | Mean | SE | Mean | SE | Mean | SE | Mean | SE |
| 4s | $F_z$ | 3.97 | 1.12 | 8.21 | 0.96 | 5.00 | 2.70 | 9.81 | 2.09 |
| | $C_z$ | 2.86 | 1.19 | 9.23 | 0.94 | 4.26 | 2.50 | 14.58 | 2.05 |
| | $P_z$ | 1.57 | 0.77 | 8.54 | 1.15 | 0.94 | 1.18 | 15.77 | 2.59 |
| Simples | $F_z$ | 2.73 | 0.98 | [illegible].57 | 1.40 | 4.50 | 1.75 | 8.67 | 1.56 |
| | $C_z$ | 2.52 | 1.03 | 9.25 | 1.01 | 3.57 | 1.41 | 10.51 | 1.68 |
| | $P_z$ | 0.89 | 1.70 | 8.54 | 1.35 | 0.89 | 1.48 | 10.10 | 1.83 |
| Novels | $F_z$ | 3.57 | 1.08 | 4.77 | 1.18 | 8.69 | 2.09 | 15.25 | 2.15 |
| | $C_z$ | 3.39 | 0.61 | 6.25 | 1.35 | 7.23 | 2.00 | 15.78 | 2.50 |
| | $P_z$ | 3.08 | 0.42 | 5.77 | 1.31 | 3.33 | 1.91 | 11.17 | 1.91 |

TABLE III

The mean baseline-to-peak amplitude (μV) and standard error (SE) of various EP components in the count-odds condition for those subjects who received both simples and novels. N=9 Based on D.C. recordings.

| | | Component | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $N_1$ | | $P_2$ | | $N_2$ | | $P_3$ | |
| Stimulus | Electrode Site | Mean | SE | Mean | SE | Mean | SE | Mean | SE |
| 4s | $F_z$ | 4.43 | 1.39 | 8.00 | 0.72 | 5.35 | 3.70 | 5.25 | 1.23 |
| | $C_z$ | 3.16 | 0.95 | 9.75 | 2.11 | 1.04 | 1.31 | 7.68 | 0.92 |
| | $P_z$ | 2.33 | 0.27 | 8.40 | 2.10 | 0.66 | 1.49 | 6.17 | 1.17 |
| Simples | $F_z$ | 2.80 | 1.78 | 7.80 | 1.27 | 3.14 | 2.14 | 10.66 | 3.20 |
| | $C_z$ | 3.54 | 1.73 | 9.41 | 1.68 | 2.66 | 2.47 | 17.08 | 2.72 |
| | $P_z$ | 1.02 | 1.66 | 7.63 | 1.85 | 0.25 | 2.06 | 15.90 | 1.93 |
| Novels | $F_z$ | 7.34 | 1.71 | 3.10 | 2.80 | 6.33 | 2.94 | 12.31 | 3.48 |
| | $C_z$ | 5.39 | 1.07 | 1.46 | 1.50 | 6.99 | 3.85 | 17.28 | 4.14 |
| | $P_z$ | 1.93 | 1.48 | 3.82 | 1.41 | 3.30 | 2.67 | 16.26 | 3.55 |

TABLE IV

The mean latency in msec and standard error (SE) of various EP components at $C_z$ in all conditions for all subjects receiving both simples and novels. N=9. Based on D.C. recordings.

| | | Conditions | | | | | |
|---|---|---|---|---|---|---|---|
| | | Passive | | Count-4 | | Count-Odds | |
| Component | Stimulus | Mean | SE | Mean | SE | Mean | SE |
| | 4s | 126 | 5.8 | 119 | 6.5 | 125 | 5.6 |
| $N_1$ | Novels | | | 114 | 6.2 | 117 | 8.0 |
| | Simples | | | 120 | 4.0 | 116 | 1.4 |
| | 2s | 121 | 5.7 | 122 | 5.4 | 127 | 6.9 |
| | 4s | 194 | 7.0 | 189 | 4.9 | 184 | 6.6 |
| $P_2$ | Novels | | | 189 | 5.4 | 196 | 8.1 |
| | Simples | | | 189 | 11.0 | 207 | 6.0 |
| | 2s | 178 | 5.5 | 184 | 6.6 | 176 | 7.0 |
| | 4s | 305 | 13.8 | 290 | 6.0 | 305 | 14.3 |
| $N_2$ | Novels | | | 278 | 6.5 | 271 | 9.3 |
| | Simples | | | 288 | 10.6 | 296 | 8.3 |
| | 2s | 280 | 14.3 | 266 | 11.7 | 271 | 12.5 |
| | 4s | 379 | 13.8 | 386 | 11.9 | 384 | 19.5 |
| $P_3$ | Novels | | | 379 | 10.6 | 365 | 13.0 |
| | Simples | | | 427 | 8.3 | 393 | 8.3 |
| | 2s | 376 | 15.1 | 385 | 8.5 | 376 | 14.2 |

## FIGURE LEGENDS

Fig. 1: Evoked responses to 2s and 4s at $C_z$ in the passive condition. Each trace is an average of 15 responses to the 4s from one subject. VEPs to the 2s are averages of 120 responses. 15 subjects. A.C. recordings.

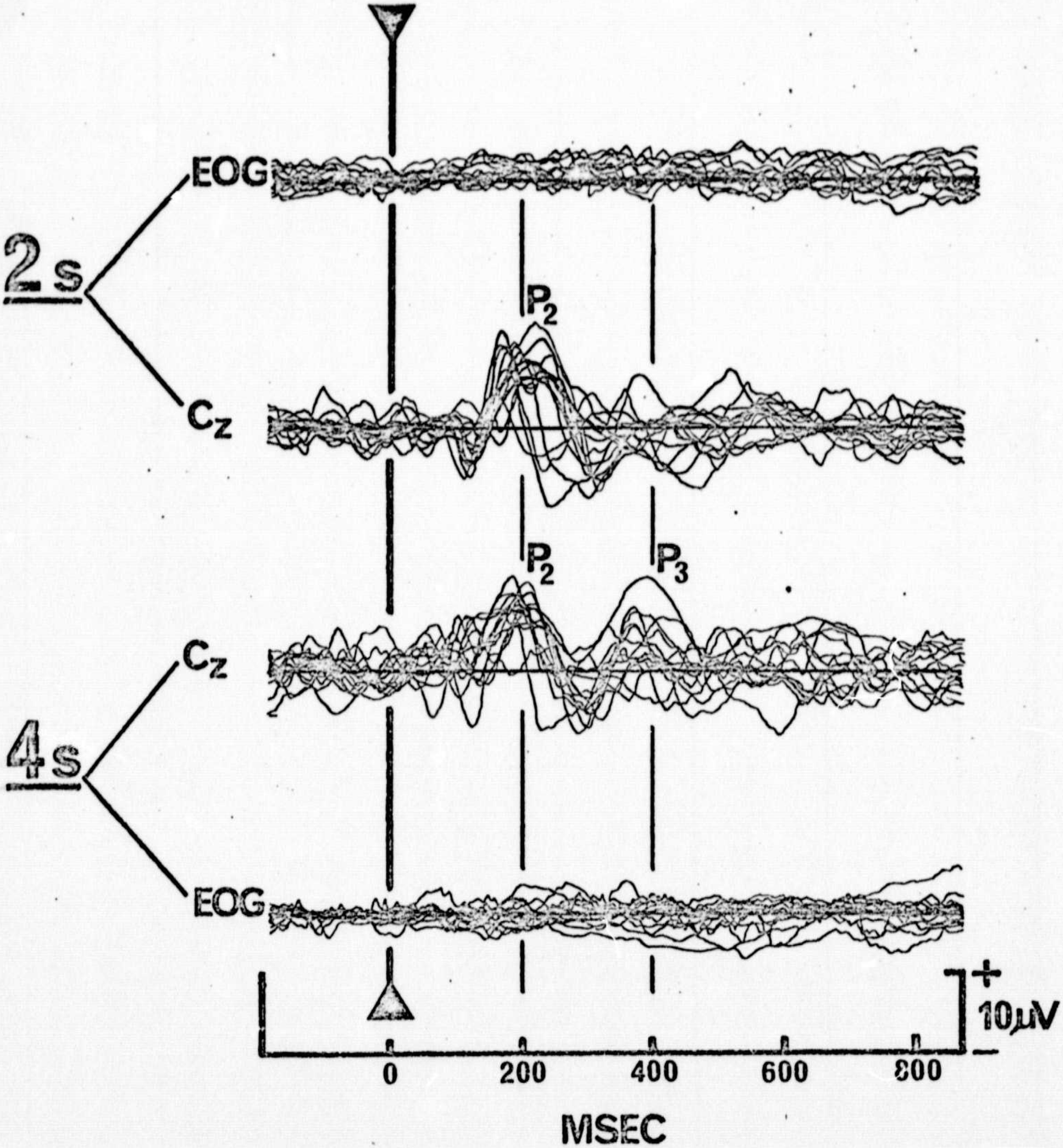
Fig. 2: Evoked responses to 2, 4, and novel slides in the count-4 condition. Each trace to the 4 and novel slides represent an average of 15 responses for one subject; those to the 2s are averages of 120 responses. 15 subjects. A.C. recordings.

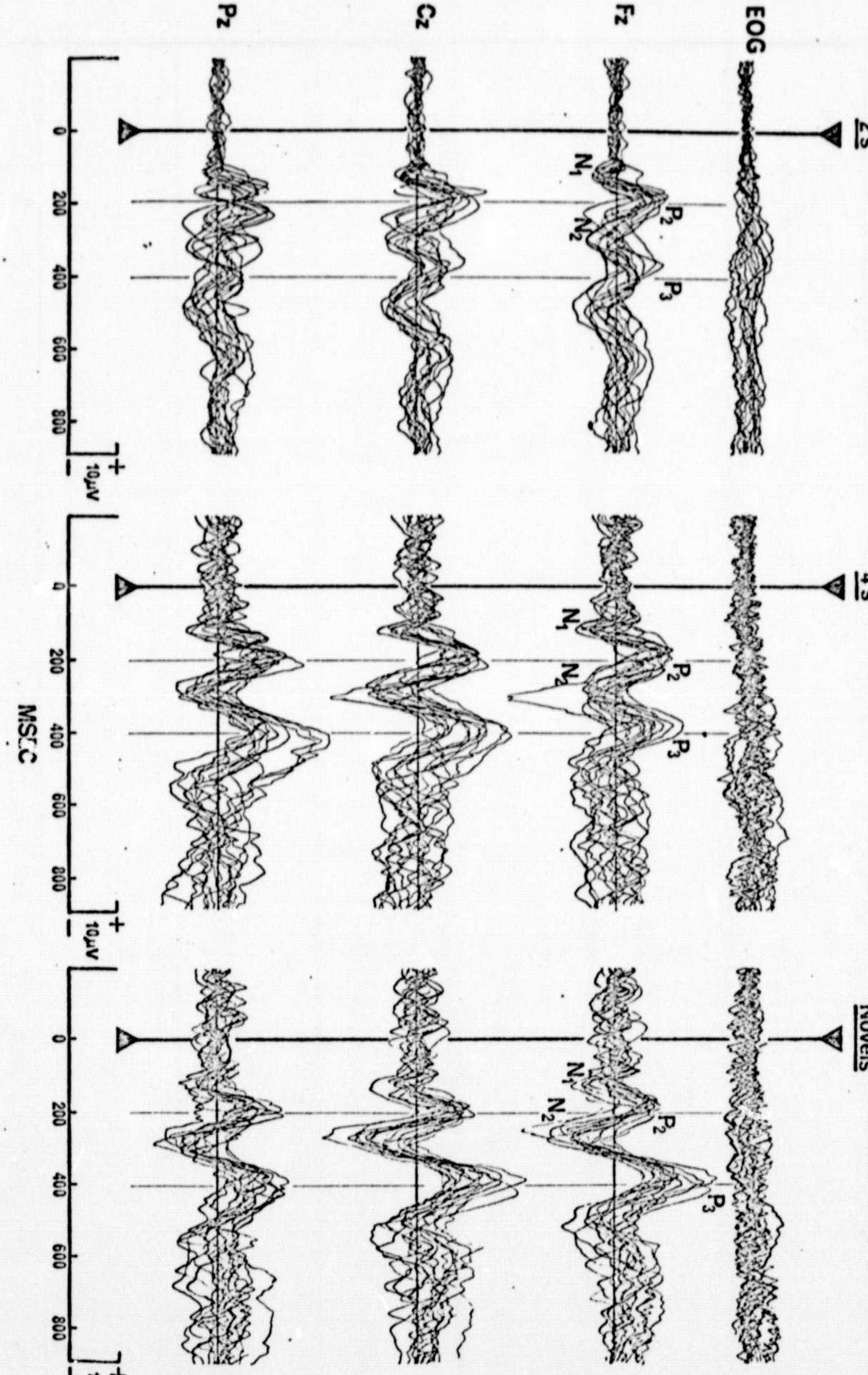
Fig. 3: Evoked responses to 2, 4 and novel slides in the count-4 condition in 5 typical subjects. The sequences 2-4-2 and 2-novel-2 are shown. Each trace represents an average of 15 responses from one subject. Traces are aligned so that the baselines at 0-200 msec pre-stimulus are superimposed. D.C. recordings.

Fig. 4: Evoked responses to the sequence 2-novel-2 slides, in the count-4 condition in 5 typical subjects. Each trace represents a single trial response to the very first novel slide for one subject. Traces are aligned so that the baseline at 0-200 msec pre-stimulus are superimposed. D.C. recordings.

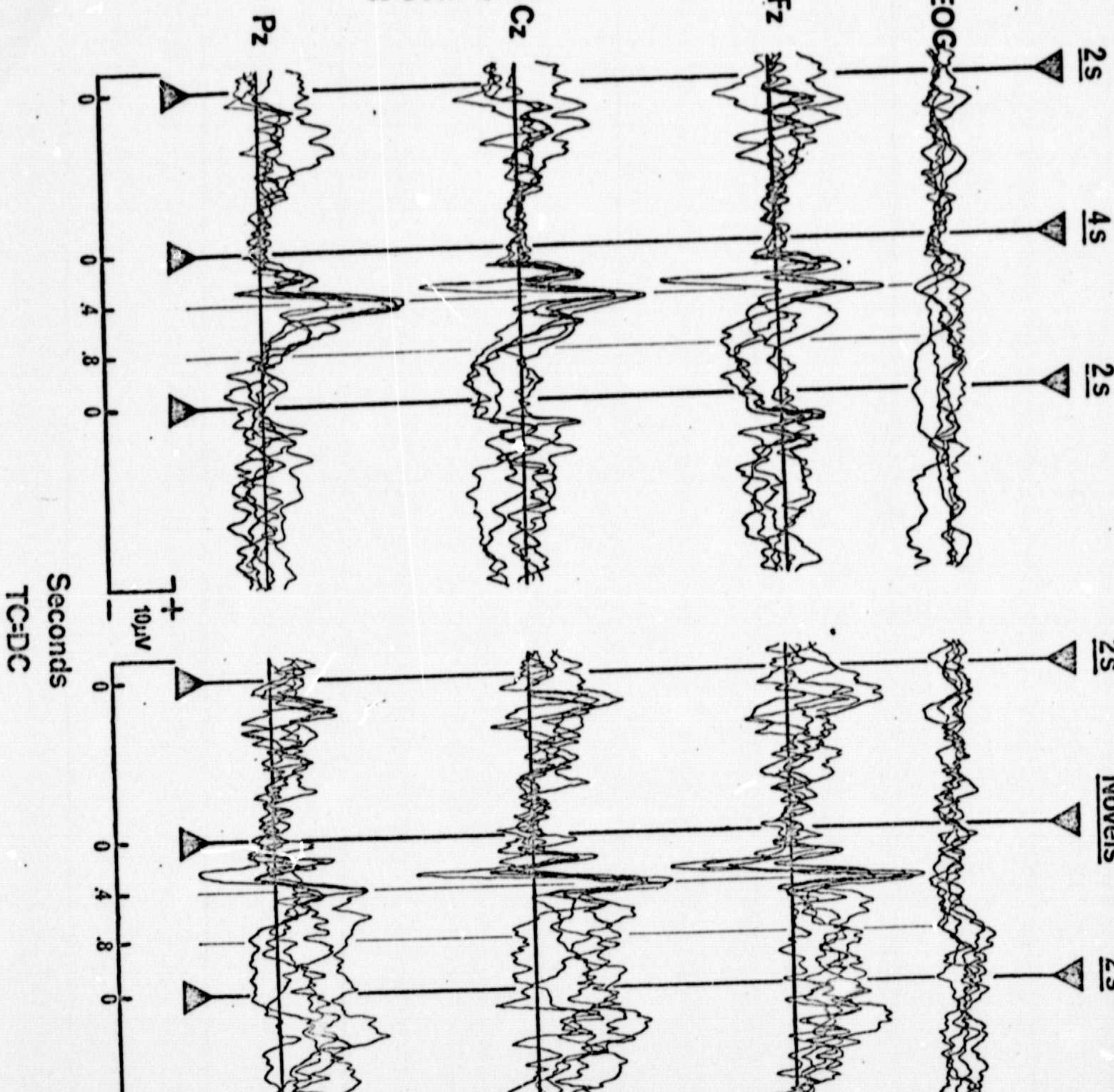
Fig. 5: Mean $P_3$ amplitudes to the novel and 4 stimuli in the count-4 and stimulus control conditions, from the 6 subjects who participated in both conditions. Based on D.C. recordings.

Fig. 6: Evoked potentials from subject K.M. The single trial traces in Panel A represent the sequence 2-novel-2 for the very first novel slide seen by K.M. The traces in panel B show the averaged evoked potentials (sum of 15) to novels in the count-4 condition (solid lines) and in the stimulus control condition (dotted lines). The same novel slide was used to elicit the single trial traces in panel A. and the stimulus control traces with dotted lines in panel B. The traces in panel C show the averaged evoked potentials (sum of 15) to the 4s in the count-4 condition (solid lines) and in the stimulus control condition (dotted lines). D.C. recordings.


EOG
2s
P2
Cz
P2
P3
Cz
4s
EOG
+
10μV
0
200
400
600
800
MSEC




ORIGINAL PAGE IS
OF POOR QUALITY


EOG
Fz
Cz
Pz
2s
4s
2s
2s
Novels
2s
0
.4
.8
0
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0
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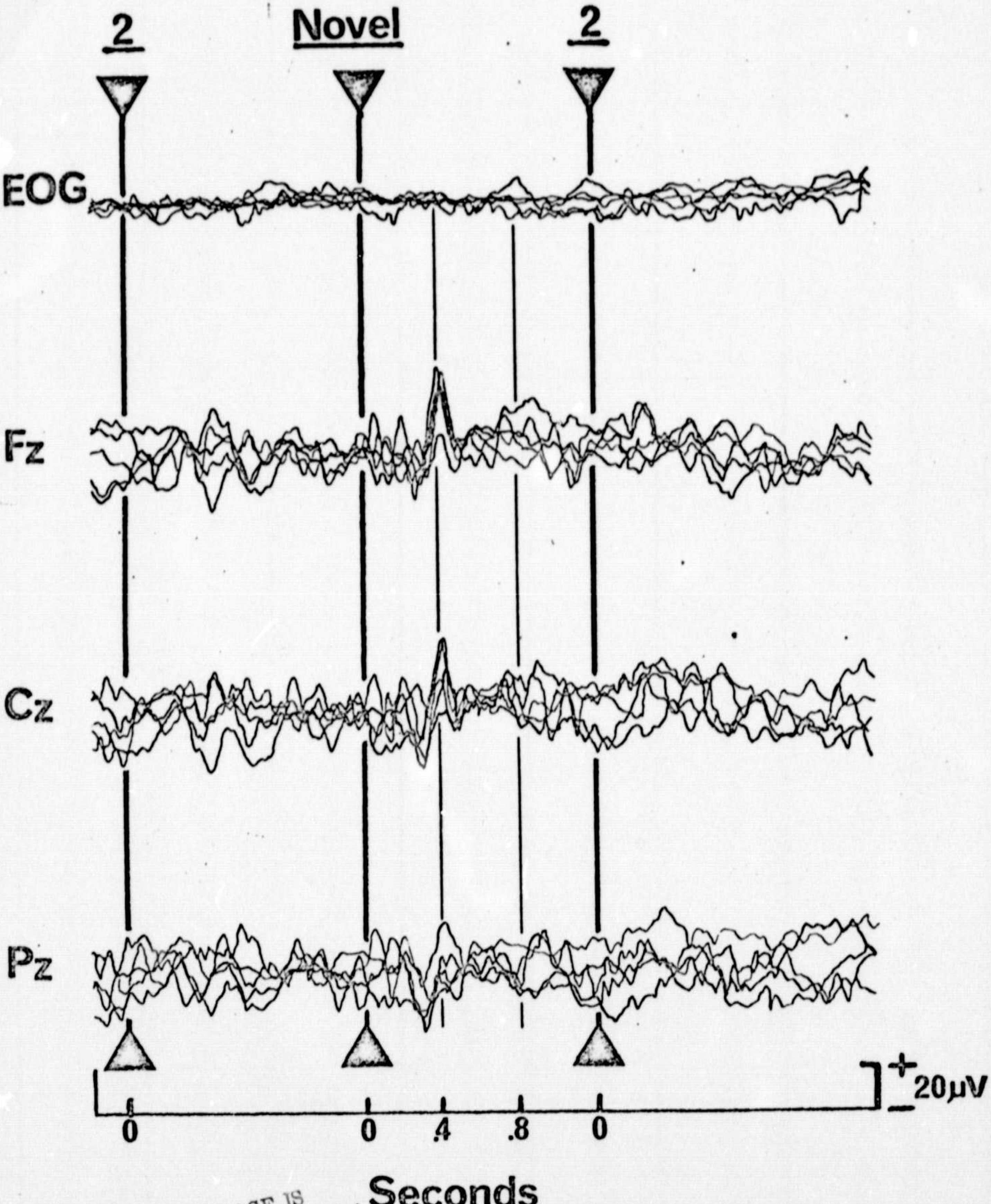
0
+
10µV
−
Seconds
TC=DC


2
Novel
2
EOG
Fz
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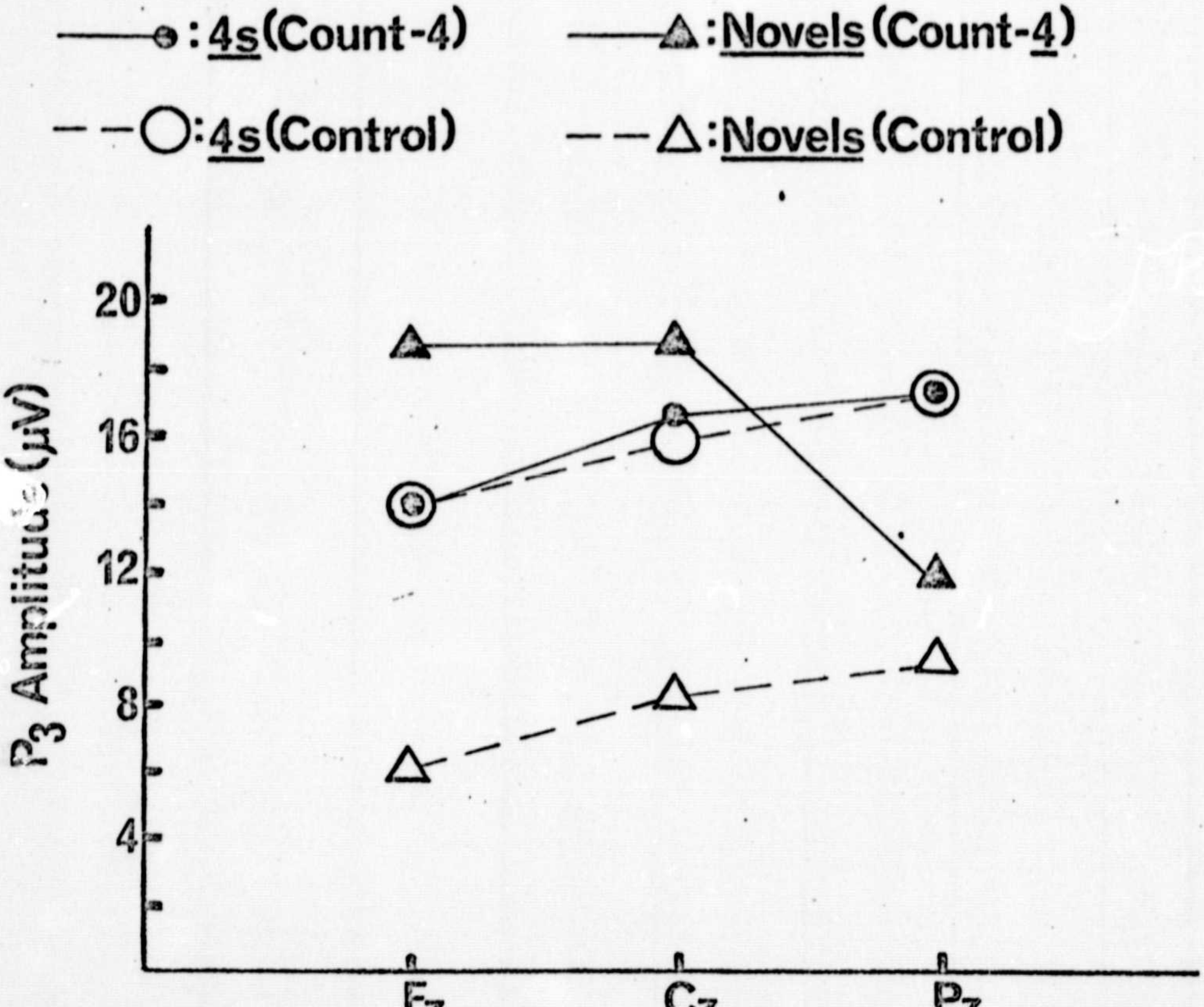
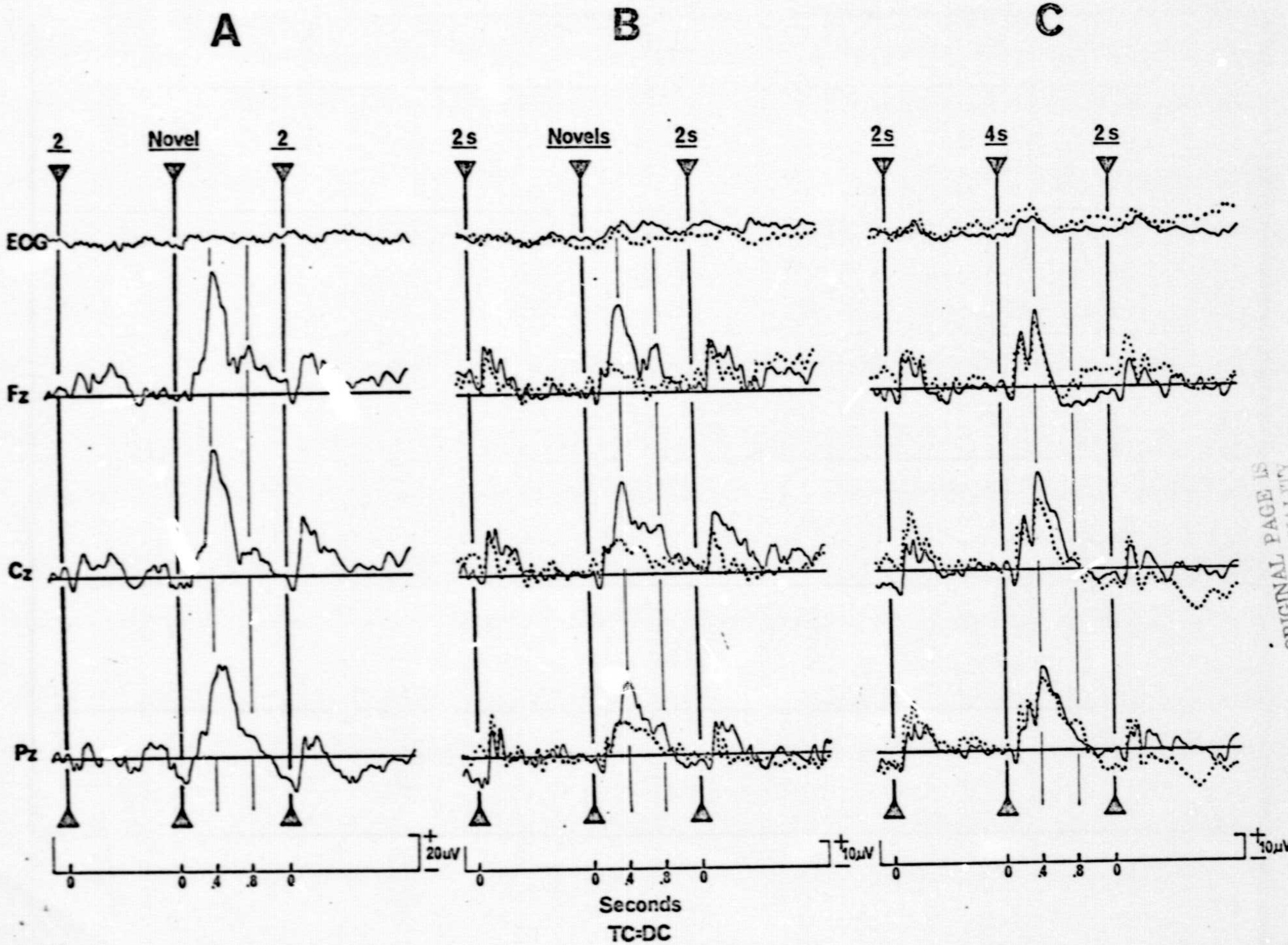


: 4s (Count-4)
: Novels (Count-4)
: 4s (Control)
: Novels (Control)
20
16
12
8
4
P3 Amplitude (µV)
Fz
Cz
Pz



A
B
C
2
Novel
2
2s
Novels
2s
2s
4s
2s
EOG
Fz
Cz
Pz
+
20µV
−
+
10µV
−
+
10µV
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Seconds
TC=DC