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THE EFFECT OF MODIFYING RESPONSE AND PERFORMANCE FEEDBACK PARAMETERS ON THE CNV IN HUMANS

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THE EFFECT OF MODIFYING RESPONSE AND PERFORMANCE FEEDBACK PARAMETERS ON THE CNV IN HUMANS[1]

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Running Title: Response, feedback, and the CNV

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Efforts to determine the topographical distribution of CNV on the human scalp and in the cortex of monkeys have yielded discordant results. Walter et al (1964) originally indicated that the electrical field was restricted to "anterior regions" which Walter (1967) enlarged to include "frontal association, motor, and somatosensory zones". Maximal CNV on the human scalp has been reported at the frontal pole (Low et al, 1966) and vertex (Cohen, 1969). CNV-like CNV waveforms in monkeys have been found to commence earlier (Low, 1969), reach greater magnitude (Borda, 1970) and occur more reliably (McSherry, 1971; Rebert, 1972) in premotor than precentral cortex. Donchin et al (1971), on the other hand, found maximal negative variations over postcentral cortex during an interstimulus waiting interval. The postcentral pattern described in the latter study may not be strictly analagous to the CNV since it was observed during sustained motor response.

Donchin et al (1971) found a dissociation of frontal and postcentral transcortical negative variation (TNV) dependent on imposed response contingencies. When a sustained motor response was required prior to appetitive reinforcement, a prominent postcentral TNV, but little frontal TNV, was observed in monkeys. When response was delayed until the end of the waiting interval, this pattern reversed. The present study was undertaken to examine the topographical distribution of CNV on the human scalp during analagous sustained and delayed response tasks.

Two additional factors were assessed: (1) the effect on CNV of visual feedback signifying correct or incorrect performance and (2) lateralization of CNV over left and right motor hand regions during performance with the dominant and non-dominant thumbs.

METHODS

Fifteen males, aged 18-25, participated in the study. Ss were seated comfortably in a sound-dampened, electrically-shielded chamber illuminated at low level. Visual stimuli were presented via an IEE (series 160H) one-plane display device mounted at eye level 5 feet in front of Ss. Stimuli consisted of a white cross displayed continuously for fixation, a concentric white ring (S1), a white-line square (S2), and solid green and red squares indicating correct and incorrect performance. S1 and S2 subtended .6 deg visual arc. Presentation was controlled by an Iconix 6255 preset counter.

Two basic tasks were used, each employing a fixed 10-sec intertrial interval and a 1.5 sec interstimulus interval (ISI). In the double response (DR) task, Ss were

required to depress a thumb button within 350 msec following the onset of S1, hold the button down throughout the ISI, and then release the button within 350 msec after S2 onset. S1 remained illuminated during the ISI, terminating upon presentation of S2. Correct performance of the entire sequence produced a brief green light. Incorrect performance at any point in the trial resulted in a brief red light and recycled the counter. In the single response (SR) task, corresponding to the typical CNV paradigm, the stimuli were presented in the same temporal sequence, but Ss were instructed to respond only after the second stimulus. All Ss performed tasks SR and DR with feedback (F) and without feedback (NF) in balanced alternation.

EEG recordings were obtained with chlorided silver disc electrodes placed at Fz, Cz, Pz, and bilaterally over the motor thumb area (5 cm lateral of the midline and 2.5 cm anterior to the interaural line). Eye movements were recorded with a diagonal bipolar placement of Beckman miniature NaCl pellet electrodes above the inner canthus and below the outer canthus of the right eye. Monopolar derivations referred to linked ears were recorded on magnetic tape using an Ampex DAS-100 system. FM amplifiers set at a bandpass of .1 to 50 Hz were used in all recordings.

Analog data were digitized on a LINC-8 computer in 4-sec epochs. Averages were triggered from an S2 marker pulse to eliminate trials aborted during the ISI. To quantify the results, the mean voltage level of a 1-sec pretrial baseline was determined and the negative area between the waveform and baseline computed across a 2-sec epoch commencing at S1 onset. Negative areas are expressed in arbitrary voltage-time units (uVsec) relative to the digitizing rate (16 msec/point). Nonparametric procedures for related samples described by Siegel (1956) were used in the statistical evaluation of results.

RESULTS

Response and feedback conditions. Mean negative areas were larger during the single than double response task as shown in Figure 1. SR and DR averages were superimposed for F and NF conditions during performance with the dominant and non-dominant hand. When the data were pooled across electrode position, feedback and laterality conditions, SR negativity (413.1 uVsecs) was greater than DR negativity (256.7 uVsec), two-tailed Wilcoxon test: $T=14$, $N=15$, $p<.01$. This difference appeared consistently at all scalp recording sites.

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Insert Figure 1 about here

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Mean negative areas were also larger in the feedback than no-feedback condition ($T=11$, $N=15$, $p<.01$). Feedback data were pooled across electrode position, response and laterality conditions. Further analysis revealed an important interaction between feedback and response variables. Feedback enhanced negativity in the single ($T=8$, $N=15$, $p<.01$), but not the double response task ($T=45$, $N=15$, NS).

Topographical distribution. Negativity was maximal at the vertex and diminished in anterior, posterior, and lateral placements. Table I shows mean negative areas at each scalp location during dominant-handed performance. When data were averaged across response, feedback and laterality conditions at midline scalp positions, the effect of electrode location was significant (Friedman 2-way ANOVA, $X_r^2=8.1$, $df=2$, $p<.02$). Vertex negativity (410.6 uVsec) was greater than frontal (297.0 uVsec) and parietal (256.2 uVsec) negativity.

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Insert Table I about here

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Lateralization. Hemispheric asymmetry was found when performance with the dominant and non-dominant hand was compared. Data from motor electrodes were pooled across response and feedback conditions. Negativity was greater in the hemisphere contralateral (347.5 uVsec) than ipsilateral (280.8 uVsec) to the responding limb ($T=23$, $N=15$, p .05). Right-handed subjects ($N=11$) showed maximal negativity over the contralateral hemisphere regardless of responding limb, whereas left-handers ($N=4$) showed maximal negativity over the right motor region during both laterality conditions.

Extended epoch and pretrial measurements. Since the intertrial interval was fixed, subjects could anticipate the first stimulus by estimating the length of the interval, a strategy which could facilitate performance in task DR. Subjects were instructed not to use this strategy, though compliance could not be monitored effectively. Inspection of the data indicated that pretrial negative shifts occurred in half of the subjects, predominantly in task DR.

To assess pretrial anticipatory shifts, 8-sec averages commencing 3 seconds prior to S1 were computed. Two negative area measurements were then calculated: a 4-sec extended epoch integration beginning 1.5 sec before S1 and a pretrial integration containing the initial 1.5 sec of the latter measure. Baseline in both cases was computed from the initial 2 sec of the average. An example of extended epoch and pretrial measurements is shown in figure 2.

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Insert figure 2 about here

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Results indicated that (1) larger pretrial shifts occurred in the double (62.1 uVsec) than single (47.7 uVsec) response task (one-tailed Walsh test: $\min[\frac{1}{2}(d_2+d_{10})=15.9]$, N=14, p=.047) and (2) no significant difference between response conditions was evident when pretrial and interstimulus negativity were combined in the extended epoch measurement (Wilcoxon, T=56, N=15, NS).

Serial order effects. Response and feedback conditions were counterbalanced to minimize serial order artifact. When the data were regrouped to examine serial order effects, results indicated that the magnitude of frontal negativity in the single response task did not change significantly across the testing session, but decreased sharply in the double response condition.

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Insert figure 3 about here

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Figure 3 illustrates serial order effects in tasks SR and DR at midline recording sites. Feedback and laterality conditions were pooled across serial positions 1+2, 3+4, and 5+6. Serial order effects are plotted for interstimulus, extended epoch, and pretrial analyses. In the first analysis, frontal negativity during the second pair of tasks was greater than the third pair in task DR (one-tailed Walsh test, $\min[\frac{1}{2}(d_1+d_{11})=56]$, N=14, p=.047). Comparison of the first and third pairs in the extended epoch frontal data yielded a similar difference (Wilcoxon, T=11, N=13, p<.02). A gentle decline in vertex negativity across the session was found in both response conditions. No consistent parietal trend was observed. A similar analysis indicated that the magnitude of CNV declined rapidly across the testing session in the feedback condition, but remained unchanged in the absence of feedback.

DISCUSSION

CNV, orienting and habituation. The dissociation of frontal and postcentral negativity during sustained and delayed response tasks observed in monkeys (Donchin et al, 1971) was not evident in humans. A re-assessment of the monkey data (Otto, 1972) has shown, however, that frontal negativity was present during early stages of learning and briefly after major stimulus changes in the sustained response task. Frontal negativity was absent only in highly trained monkeys. These observations suggest that negative variations in frontal granular cortex during sustained motor response signify an orienting reaction to novelty or uncertainty which habituates as uncertainty is resolved. Consistent evidence of frontal habituation in humans emerged when the present data were analyzed in terms of the serial order of performance.

On the other hand, frontal habituation was not observed in monkeys or man during a delayed single response task (S1---S2-R) corresponding to the typical CNV paradigm. This finding suggests that frontal CNV represents a special class of orienting response which is resistant to habituation. One of the basic characteristics of the CNV is the persistence of the waveform as long as subjects remain interested in the imposed task. In fact, Walter (1964) devised this paradigm to circumvent the problem of habituation during a study of intermodal evoked responses in nonspecific cortex. An important question raised in the present study, then, is why frontal negativity habituates in the sustained, but not the delayed response task.

Walter and his colleagues (1964) found that CNV persists as long as a "significant association" is maintained between a warning (S1) and imperative (S2) stimulus. A progressive diminution of the CNV was demonstrated during "equivocation" in which S2 was withheld on a proportion of trials. Complete habituation of the CNV in normal subjects occurred when the "probability of association" was reduced to chance level. Results of the present experiment demonstrate that the maintenance of CNV cannot be accounted for strictly in terms of the probability of stimulus association since the stimulus contingencies were identical in both response tasks. The difference in CNV magnitude between the two tasks must be due, therefore, to response parameters. This conclusion is consistent with the finding of Donchin _et al_ (1971) that the postcentral pattern in monkeys is response dependent.

Failure to observe an analagous postcentral pattern in humans may be due to differences in recording technique and electrode location. Scalp electrodes reflect a diffuse spatial average of volume-conducted potentials, whereas transcortical indwelling electrodes reflect more localized differences. Furthermore, the midline placement of frontal, central, and postcentral electrodes in the present study differed considerably from the lateral postion of electrodes in the left hemisphere of monkeys. Somatotopic representation of the body in the postcentral gyrus is well-documented (eg. Woolsey, 1958). The largest postcentral TNVs in monkeys were found over parietal regions somatotopically appropriate to the responding musculature (Otto, 1974). The standard midline position (Pz) used in this study, however, was both posterior and medial to the appropriate somatosensory region.

Habituation patterns observed in anterior frontal cortex of man and monkey also depend on response parameters. Habituation occurred only in the sustained double response task. The motor inhibition theory of frontal lobe function proposed by Ferrier (1886) and reviewed by Brutkowski (1965) provides a possible explanation. If the anterior frontal cortex exercises an inhibitory role in the regulation of motor activity, one would expect to find electrical activation during the foreperiod of a delayed

response task, but not a waiting interval which entails sustained motor discharge.

Hemispheric asymmetry. The finding of larger negative shifts over the motor cortex contralateral to movement contrasts sharply with previous reports that CNV is bilaterally symmetrical (Low et al, 1966; Cohen, 1969). Marsh and Thompson (1972) were unable to generate hemispheric differences even though stimulus presentation was carefully segregated in the left and right visual fields. Hillyard (1972) also described a dramatic inability to lateralize CNV in human split-brain subjects. Butler and Glass (1971), however, recently found larger CNVs over the dominant hemisphere during numeric operations.

The motor area was chosen in the present study as the most likely region to exhibit lateralization because considerable evidence of hemispheric asymmetry of the "readiness potential" (RP) has accrued (Kornhuber and Deecke, 1965; Vaughan et al, 1968; McAdam and Seales, 1969). A careful effort was made to locate precentral electrodes over cortex somatotopically appropriate to the responding limb. The laterality effect reached statistical significance, however, only when data were pooled across response and feedback conditions.

Rebert et al (1967) noted that the amplitude of CNV increased in proportion to the physical effort of response. Button pressing in the present experiment required minimal effort. Whether increased effort would have enhanced or effaced the hemispheric asymmetry over the motor cortex is an important question for future study.

Performance feedback. Visual feedback increased the magnitude of CNV in the single, but not appreciably in the double response task. Comments of subjects suggested that feedback served as a motivating factor which increased the "interest" or "challenge" of the task. The apparent ineffectiveness of feedback in the double response task may be due to pretrial negative shifts which occurred in many subjects, primarily in the double response condition. The baseline value used to compute area measurements in such cases tended to reflect a negative ceiling reached during the pretrial epoch. This circumstance explains, in part, why the CNV was consistently less in the double than single response task.

A number of investigators (Irwin et al, 1966; Rebert et al, 1967; Cant and Bickford, 1967; Waszak and Obrist, 1969; Borda, 1970) have shown that CNV is a reliable indicator of changes in general drive or motivation level. Shock, difficult signal detection, increased muscular effort, and food deprivation tend to increase the amplitude of CNV. Perceptual feedback in this study appeared to serve a similar motivating function.

In designing the CNV paradigm, Walter (1964) was keenly aware of the need for motivational incentives to engage the cooperation of subjects. He found that trains

of clicks and flashes terminated by button pressing were more effective reinforcers than single clicks or flashes. Peters et al (1970) confirmed this finding and suggested that termination of the stimulus train provided informational feedback which enhanced motivation. Results of this study provide direct evidence that informational feedback increases the amplitude of CNV, consistent with the speculation of Peters et al.

Multiprocess conception. This study has shown that the CNV can be reversibly lateralized over the left or right motor cortex and that the magnitude of CNV varies in relation to response and performance feedback parameters. Donchin et al (1971) and Otto (1972) have shown that the topographical distribution of surface-negative shifts in the cortex of monkeys is dependent on imposed stimulus-response parameters and the stage of training. Borda (1970) and Jarvilehto and Frustorfer (1970) have differentiated frontal and central-dominant negative shifts which appear to summate in human scalp-recorded CNV. Cant and Bickford (1967) noted that the locus of maximal CNV shifted from the vertex to frontal region when the experimental contingencies were modified so that an inescapable shock could be avoided.

These findings suggest that contingent negative variation does not represent a single neuronal process nor originate in any single cortical region. Haider (1969) and Rebert (1972), furthermore, have observed negative shifts in several subcortical nuclei during the reaction-time foreperiod which indicates that CNV is not exclusively a cortical phenomenon. As recorded from the human scalp, CNV reflects a multiplicity of psychological and physiological processes occurring at a variety of locations in the brain preparatory to motor or mental action. The configuration of participating neural structures depends on the precise stimulus, response, and reinforcement contingencies operative in the experimental situation. This general multiprocess conception provides a parsimonious explanation of the bewildering list of psychophysiological processes with which the CNV has been associated.

SUMMARY

The effect on the CNV of sustained and delayed motor response with the dominant and nondominant hand in the presence and absence of visual performance feedback was studied in 15 male adults. Monopolar scalp recordings were obtained at Fz, Cz, Pz, and bilaterally over the motor hand area. Results indicated that the magnitude of the CNV was greater in the delayed than sustained response task, greater in the presence than absence of feedback, and greater over the motor hand area contralateral to movement. Frontal CNV habituated in the sustained, but not the delayed response task, suggesting that frontal negative variations in the former case signify an orienting response to

novelty or uncertainty. The absence of habituation in the delay condition was interpreted in terms of the motor inhibitory function of frontal association cortex. Performance feedback appeared to enhance CNV indirectly by increasing the motivation of subjects. A multiprocess conception of CNV was proposed in which vertex-negative slow potentials reflect a multiplicity of psychophysiological processes occurring at a variety of cortical and subcortical locations in the brain preparatory to a motor or mental action.

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TABLE I

MEAN NEGATIVE VOLTAGE-TIME INTEGRALS (uVsecs) AT 5 SCALP LOCATIONS

	Fz	Cz	Pz	LMC	RMC	MEAN
SRF	372.5	566.1	427.8	496.9	472.7	467.3
SRNF	252.5	385.5	313.7	333.5	292.0	315.5
DRF	267.1	306.5	226.9	233.6	180.9	243.0
DRNF	221.8	261.2	175.1	294.8	208.7	232.3
MEAN	278.5	379.8	285.9	339.7	288.6	

Topographical distribution of CNV under varying conditions of response and feedback during performance with dominant hand. DR=double response task; SR=single response task; F=with feedback; NF=without feedback; LMC=left motor cortex; RMC=right motor cortex.

FOOTNOTES

[1]This paper is based on a dissertation submitted by the senior author to the Department of Psychology, Stanford University, in partial fulfilment of the Ph.D. degree. The study was conducted in the Human Performance Branch, NASA-Ames Research Center. The authors are indebted to Drs. R.M. Patton, K.H. Pribram, and E. Donchin for advice and support. D. Otto held an NIMH Predoctoral Fellowship and L. Leifer, a National Research Council Associateship.

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LEGENDS

Fig. 1 Superimposed averages of slow potential patterns during single (SR) and double response (DR) tasks with (F) and without feedback (NF). CNV magnitude was larger in task SR than DR and in condition F than NF. Calibration: 25 uV EEG and 125 uV EOG. Negative up.

Fig. 2 Both sets of averages were computed from the same data. Solid areas in the left column correspond to interstimulus measurements. Shaded areas in the right column correspond to pretrial measurements. Extended epoch calculations included both shaded and solid segments. 8-sec averages indicate that negative shifts commenced about 1.5 sec prior to S1 in this double response series, a fact that cannot be ascertained in the 4-sec averages, but which profoundly influences the baseline estimate. Negative up.

Fig. 3 Response data, pooled across feedback and laterality conditions and plotted in terms of the serial order of performance, indicates that frontal CNV habituated in the double, but not the single response task.

TYPICAL CNV PATTERNS RECORDED FROM
RIGHT-HANDED SUBJECT
AVERAGES OF 20 TRIALS

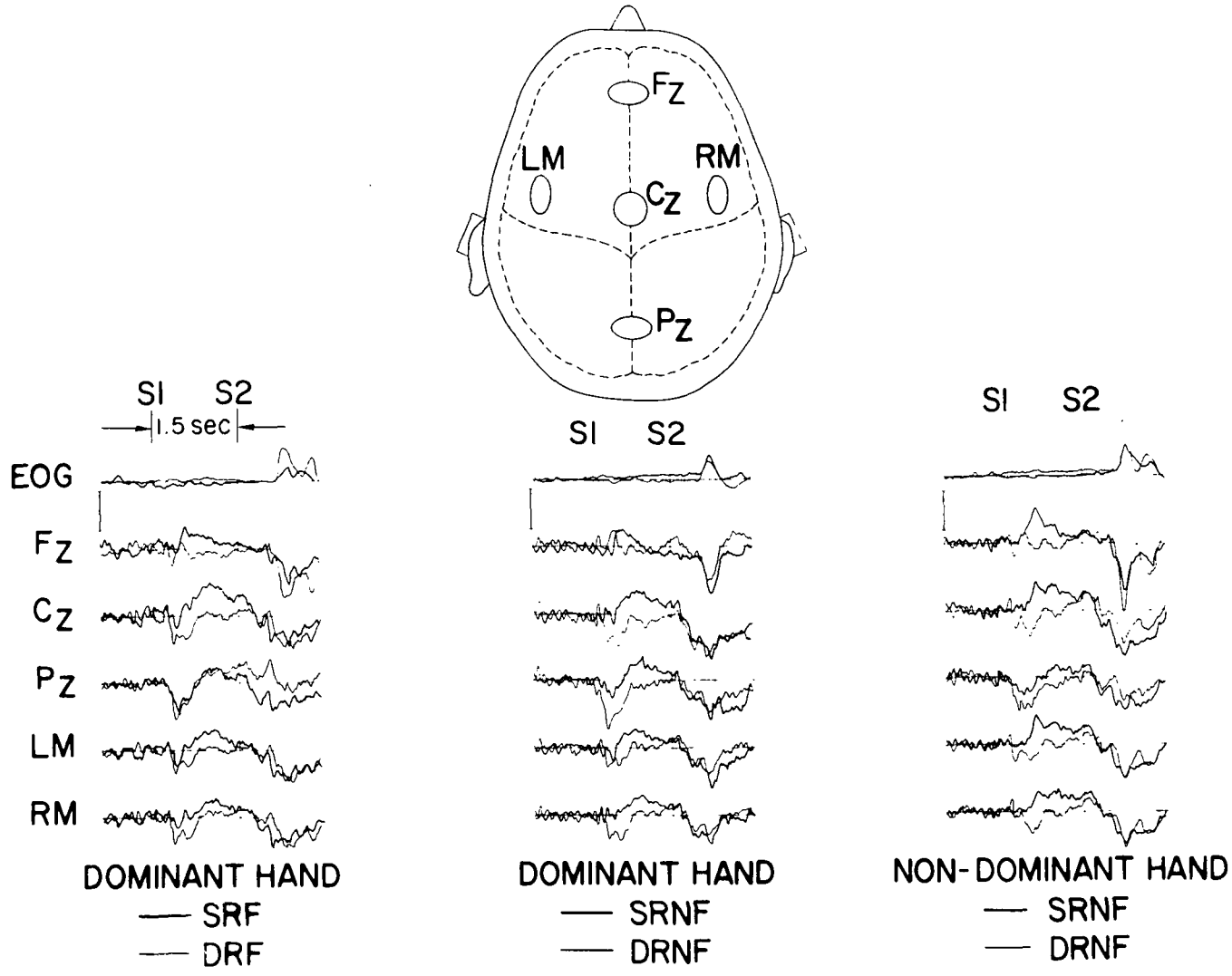

Fig. 1

COMPARISON OF STANDARD AND EXTENDED EPOCH AVERAGES

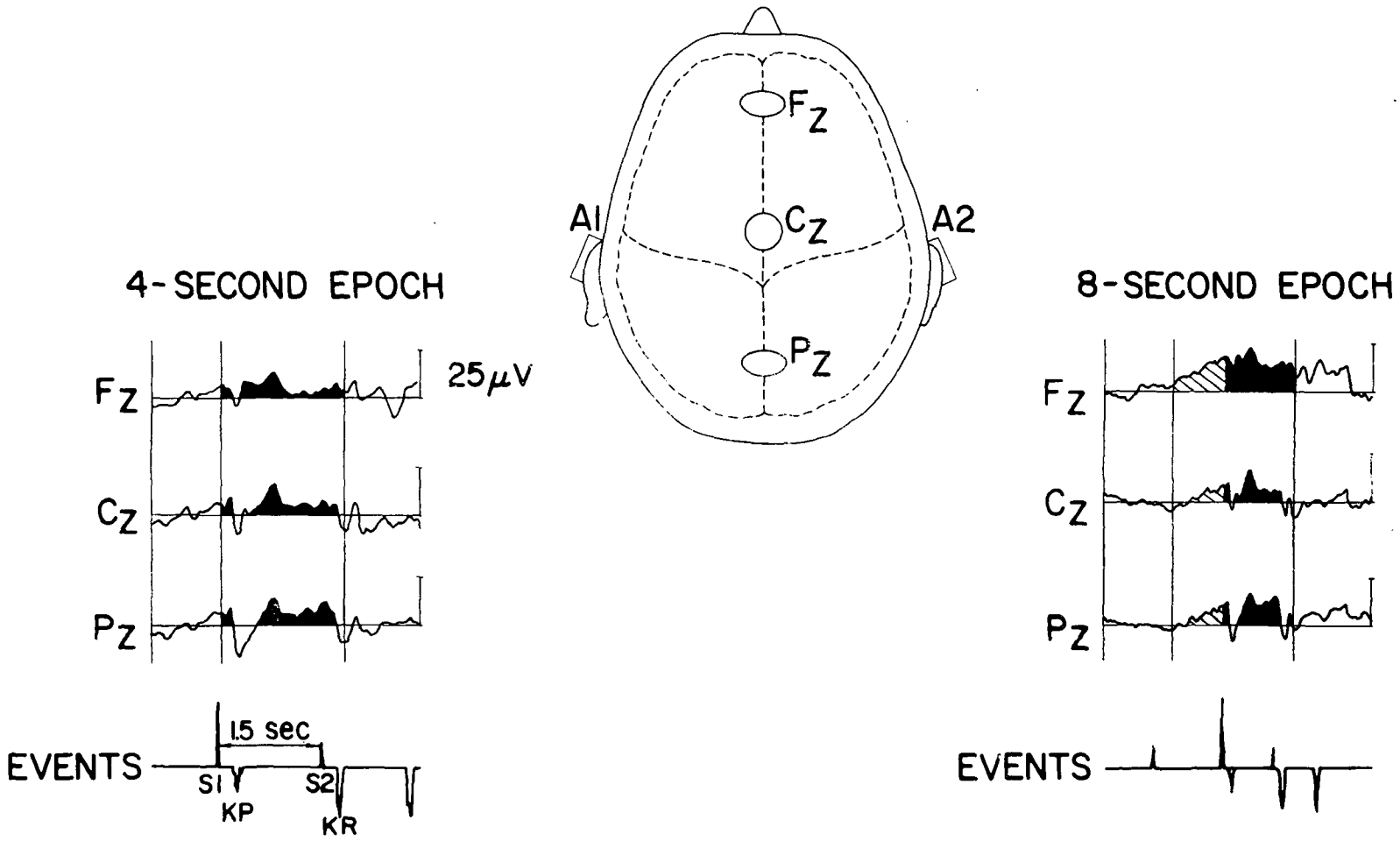

Fig. 2

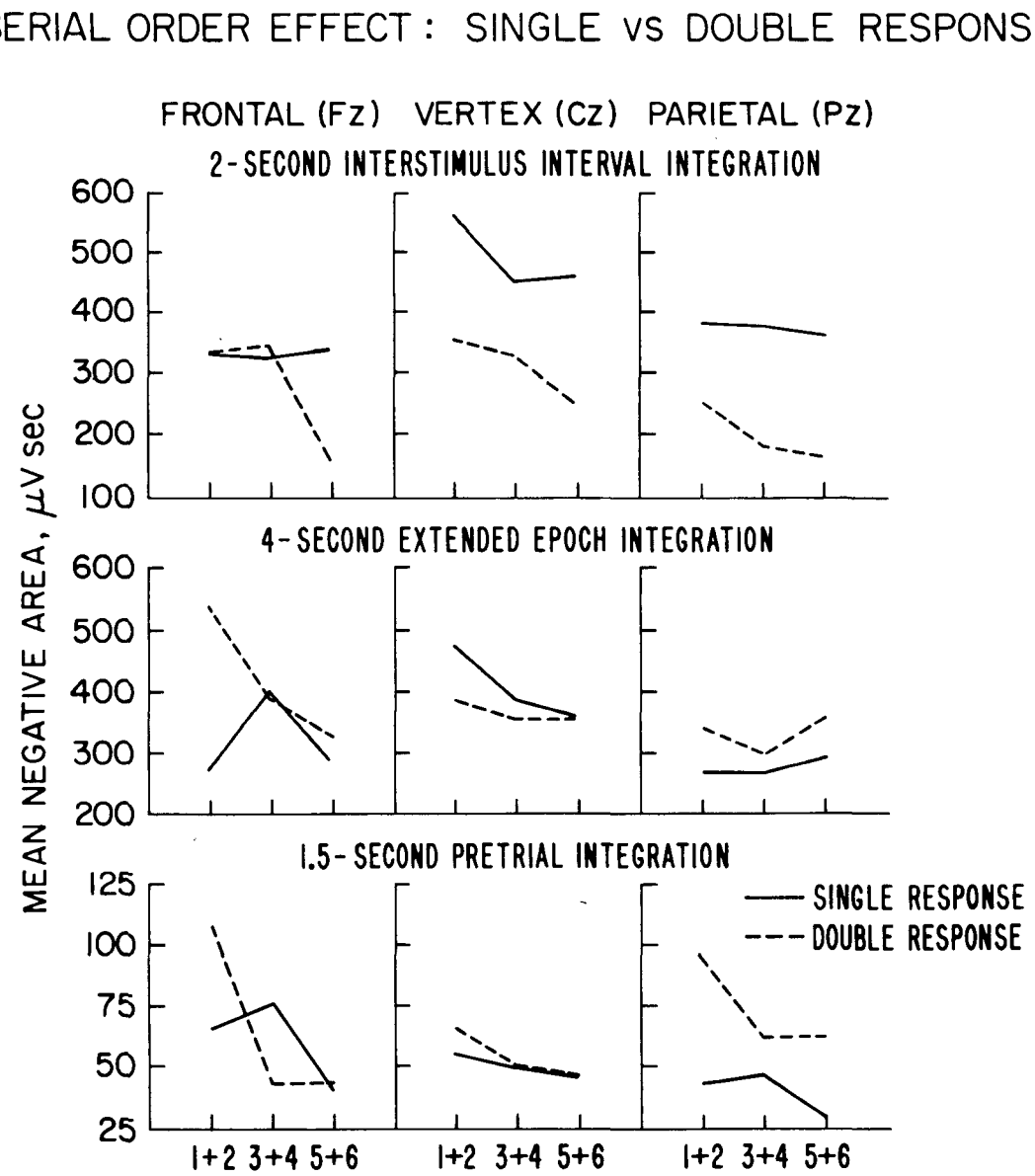
SERIAL ORDER EFFECT: SINGLE vs DOUBLE RESPONSE
FRONTAL (Fz)
VERTEX (Cz)
PARIETAL (Pz)
2-SECOND INTERSTIMULUS INTERVAL INTEGRATION
4-SECOND EXTENDED EPOCH INTEGRATION
1.5-SECOND PRETRIAL INTEGRATION
MEAN NEGATIVE AREA, μV sec
600
500
400
300
200
100
125
100
75
50
25
1+2 3+4 5+6
SINGLE RESPONSE
DOUBLE RESPONSE

Fig. 3