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BRAIN ELECTROPHYSIOLOGICAL CONCOMITANTS OF HEMISPHERIC LATERALITY WHILE PROCESSING ALTIMETER DISPLAY INFORMATION

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BRAIN ELECTROPHYSIOLOGICAL CONCOMITANTS OF HEMISPHERIC LATERALITY WHILE PROCESSING ALTIMETER DISPLAY INFORMATION

by

George Harris Buckland

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Supervised by Dale W. McAdam, Ph.D.
Department of Psychology

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He attended Purdue University in Lafayette, Indiana from 1963 to 1967 and received a B.S. degree with a major in psychology. From 1967 to 1969 he attended the University of Rochester as a New York State Herbert H. Lehman Fellow. In 1969 he completed the M.A. degree in Psychology under the supervision of Dr. Jerome S. Schwartzbaum. He was on leave of absence from 1969 to 1973 while he served on active duty in the U. S. Air Force. In 1973 he returned to the University of Rochester as a USAF AFIT student. where he continued to major in Physiological Psychology under the supervision of Dr. Dale W. McAdam.

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ABSTRACT

Average evoked potential (AEP) concomitants of laterality of brain hemispheric function were measured in sixteen subjects while they processed altimeter display information. Three types of schematized altimeter displays were used, representing the counter (CT), counter pointer (CP) and three pointer (3P) altimeters. Two experimental conditions were employed. In Condition I the subject was required to read the altimeter display (2 sec. presentation) as rapidly as possible and generate an integrated verbal response without errors, pausing or stumbling during the response. In Condition II a same/different judgement was required by the subject in response to two brief (400 millisecond (msec)) presentations, which were separated by a two-second inter-stimulus interval, of the same type of altimeter display. The two experimental conditions were selected as standard behavioral paradigms which approximate two modes of altimeter display information processing used by pilots during actual aircraft flight. Condition I was repeated three times during two experimental sessions and Condition II was repeated twice.

The evoked potentials were recorded from left (P_3) and right (P_4) parietal scalp electrodes and averaged across the eighty trials for each altimeter display for each behavioral condition. AEP amplitude measures for the late positive component (LPC) were based on the measurement of a peak, or an average of two peaks,

within a restricted range of 300 to 500 msec after the stimulus display onset. The peak amplitude measures were converted to a logarithmic ratio of the right (P_4) amplitude over the left (P_3) amplitude, $Ln(P_4/P_3)$ or its equivalent LnP_4-LnP_3, in order to derive a numerical value representing the right/left asymmetry in AEP amplitude.

During the reading of the three altimeter displays in Condition I there was a significantly larger late positive component LnP_4-LnP_3 value for the CP and 3P displays than for the CT display. This greater right-more-positive effect was interpreted as an evoked potential concomitant of greater right hemisphere functional involvement in the processing of the CP and 3P altimeter information than the CT altimeter information.

The average verbal response latency was more than twice as long for the 3P (1596 msec) than for the CT (641 msec) or CP (604 msec) displays, with the CP having a significantly shorter reaction time (RT) than the CT display. Most subjects also reported that the CP was easier to read than the CT altimeter. The superiority of the CP over the CT altimeter was interpreted as an information processing facilitation possibly due to greater involvement of the right hemisphere in processing the CP display.

Neither the LPC LnP_4-LnP_3 values or the behavioral RT's were significantly different between the altimeter displays for Stimulus 1 or Stimulus 2 in Condition II. However, the LPC LnP_4-LnP_3 values were significantly different between Stimulus 1 and 2 for the 3P altimeter in Condition II. This was interpreted as a possible indication that Stimulus 1 is initially processed more by spatial mnemonic functions in the right hemisphere than Stimulus 2 is for the 3P display. And, that possibly Stimulus 2 is processed more by comparator functions in the left hemisphere than Stimulus 1 is for the 3P altimeter.

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BRAIN ELECTROPHYSIOLOGICAL CONCOMITANTS OF HEMISPHERIC LATERALITY WHILE PROCESSING ALTIMETER DISPLAY INFORMATION

Following the clinical observations of Broca in the 1860's and his conclusion that, "We speak with the left hemisphere," (Broca, 1865; Joynt and Goldstein, 1975) a variety of investigators have employed various behavioral and physiological techniques to investigate hemispheric functional asymmetries. The current study attempts to further the development of human factors engineering techniques by using three different altimeter displays to investigate averaged evoked potential concomitants of brain hemispheric functional asymmetries.

White (1969) reviewed much of the behavioral literature pertaining to hemispheric laterality differences, and a large number of studies have been reported since then. The purely behavioral studies have required the use of stimuli which were constructed or generated in such a way that they utilize anatomical or functional asymmetries of the visual or auditory sensory systems in order to lateralize the neuronal information processing. In general a right visual field or right ear superiority (left hemisphere) has been reported for linguistic stimuli and a left visual field or left ear superiority (right hemisphere) for spatial stimuli. Hilliard (1973) reported right visual field superiority for the recognition of linguistic trigrams and a left visual field superiority for the spatial task of facial recognition. Dee and Hanney (1973) have reported left visual field superiority for the recognition of random shapes in an experiment to control for expectancy effects. Using dichoptic presentation of word pairs MacKavey et al (1975) have reported a right hemifield recognition advantage across manipulations of word orientation, exposure duration and fixation control. Carmon et al (1975) used dichoptic presentations of pairs of digits and found fewer errors for digits in the right visual field than in the left visual field.

Darwin (1974) has reviewed recent studies employing dichoptic auditory tasks which generally show that verbal stimuli presented to the right ear tend to be more accurately reported than verbal stimuli presented to the left ear. Ingram (1975) has reported such right ear superiority in children as young as three years old. Perl and Haggard (1975) have reported that a significant right ear advantage for dichotically presented diphthong sounds only occurred after practice, indicating that is some instances hemispheric functional asymmetries become apparent only as the task is overlearned.

The clinical literature abounds with evidence indicating that gross insult to the left cerebral hemisphere in right handed patients is much more likely than right cerebral insult to produce deficits in language functions (Luria, 1974; Lenneberg, 1966; Whitaker, 1971a). The contemporary questions with regard to the neural substrates of language are not whether we speak with the left hemisphere, but rather how is language distributed within the left hemisphere and what additional roles does the right hemisphere play in the production of language (Dingwall and Whitaker, 1974; Geschwind et al, 1968; Whitaker, 1971b). Damage to the right cerebral hemisphere is much more likely than damage to the left cerebral hemisphere to produce deficits in spatial information processing functions (Benton, 1967, 1969; Benton and Van Allen, 1968; Benton et al, 1973; Joynt and Goldstein, 1975; Kohn and Dennis, 1974).

Behavioral studies in split brain patients have also extended our knowledge about hemispheric laterality in brain function. Gazzaniga (1970) surveyed much of the research in split brain humans and animals that started with Sperry's (1961, 1966) observations that the split brain behaves in many respects like two separate brains. In a 27 year follow-up of a split brain patient Goldstein and Joynt (1969) reported that she still displayed defects in the interhemispheric transfer of information. They concluded that it appeared unlikely that any major functional reorganization had taken place. Butler and Norrsell (1968) reported that in one split brain patient words presented to the right visual field were vocalized at once, and objects presented to either hemifield were correctly retrieved by touch. Images displayed in the left visual field were sometimes named also, but only after long exposure. Some three letter words presented to the left visual field could also be reported. In a dichotic listening study, Springer and Gazzaniga (1975) reported that two split brain patients failed to identify any syllables presented to the left ear, even under conditions designed to optimize processing and output in favor of that ear. In a recent review, Sperry (1974) has summarized the hemispheric laterality findings from a variety of behavioral tasks used with split brain patients. He reported results demonstrating that in right handed patients the left hemisphere is distinctly important for language functions and calculation, while the right hemisphere is important for spatial abilities and nonverbal ideation, and that it has only simple language comprehension.

Using electrophysiological techniques another area of scientific research has developed dynamic techniques for studying differential patterns of neuronal activity in the two hemispheres. Hemispheric asymmetries in both the EEG alpha rhythm and average evoked potentials (AEP's) have been investigated. Several researchers have reported asymmetries in the ratio of EEG alpha rhythm between the cerebral hemispheres during the performance of linguistic versus spatial tasks (Butler and Glass, 1974; Doyle et al, 1975; Dumas and Morgan, 1975; Galin and Ornstein, 1972; McKee et al, 1973; Morgan et al, 1971, 1974; Robbins and McAdam, 1974). The general finding is a reduced amplitude in the EEG alpha over the hemisphere (left or right) actively engaged in the task compared to the opposite hemisphere. In a different type of alpha study Schwartz et al (1975) trained subjects for EEG parietal asymmetry using biofeedback techniques. Analysis of post feedback questionnaires revealed that reduced alpha amplitude over the left hemisphere relative to the right hemisphere was significantly associated with verbal cognitions, while more visual cognitions produced the opposite alpha effect. Peper (1972) reported findings similar to those of Schwartz, but his subjective reports were not extensive enough to permit statistical analysis.

The evoked potential studies have investigated hemispheric asymmetries during both the generation of speech and the perception of verbal or non verbal stimuli. The studies involving speech generation have concentrated on the slow potential shifts and have typically found greater negativity over the left hemisphere, especially Broca's area, in right handed subjects preceding the production of speech (Levy, 1975; Low et al, 1973; McAdam and Whitaker, 1971 a and b; Morrell and Huntington, 1972; Zimmerman and Knott, 1973, 1974).

Using visual stimulation in both hemifields, and recording over both occipital areas Buchsbaum and Fedio (1969, 1970) have reported that verbal and non verbal dot patterns evoked potentials from the left occipital region which were more greatly different than similar evoked potentials from the right occipital area. They concluded that the greater evoked potential difference over the left hemisphere was consistent with evidence that the left hemisphere is dominant as a comparator mechanism. The smaller but still significant difference over the right hemisphere was interpreted as evidence for some participation of that hemisphere in speech function.

In an electrophysiological study employing measures of EEG alpha power, evoked potential power and evoked potential peak amplitude, Galin and Ellis (1975) reported that the evoked potential power and peak amplitude measures reflected hemispheric lateralization of cognitive processes. The alpha power measure reflects Fourier spectrum analysis power and the evoked potential power reflects the overall amplitude of the response. Thus, the right/left alpha power ratio was higher in the verbal task than the spatial task, and the evoked potential power or peak amplitude measures had higher right/left ratios for the verbal than for the spatial task. However, the EEG alpha power measures reflected the hemispheric laterality differences more consistently for the verbal and spatial tasks. The tasks lasted for three minutes each and the averaged alpha power was computed over the entire three minute period, while the evoked potentials were obtained from 30 ten millisecond (msec) flash stimuli given once every three seconds during each task. The flashes were superimposed on the background illumination and being irrelevant to the task they tended to evoke large AEP's when the alpha power amplitude was larger. This does not appear to be a fair test of the efficacy of EEG alpha power versus AEP measures as an indicator of laterality of brain hemispheric function, since AEP's are typically evoked by task relevant stimuli. With task relevant stimuli evoked potential amplitude typically increases as a function of increasing attention or involvement of the subject (Chapman, 1969; Roth et al, 1970; Smith et al, 1970; Sutton et al, 1967), while

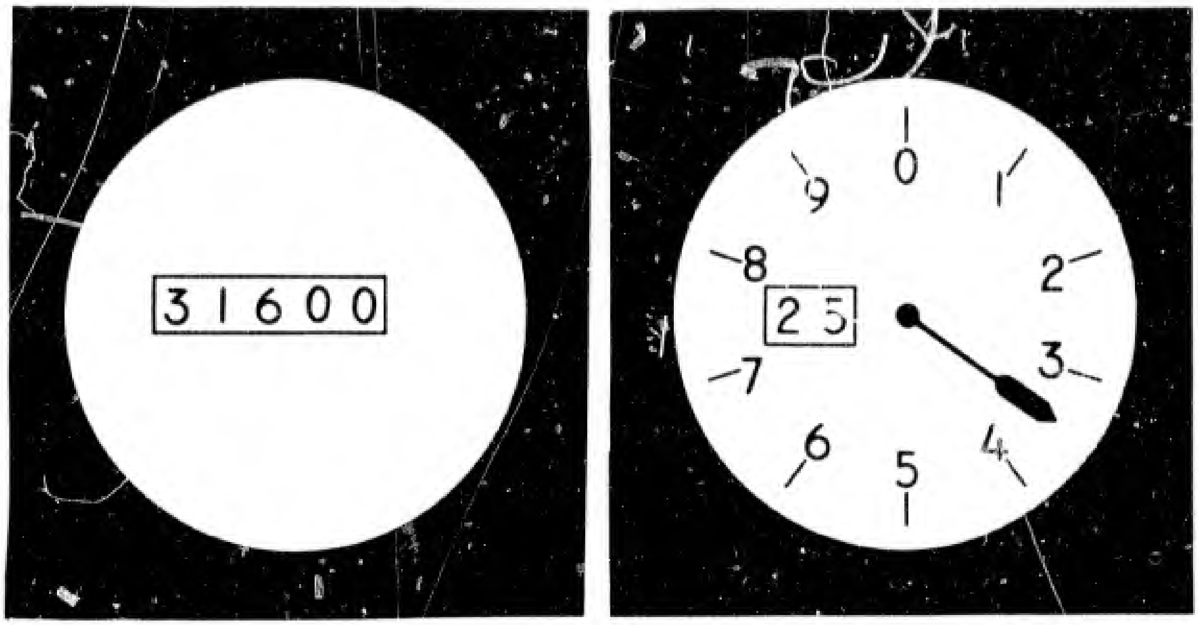
EEG alpha power decreases. The current study uses task relevant stimuli and assumes greater evoked potential amplitude for greater hemispheric involvement in the stimulus information processing.

I also assumed that the brain may have a fair amount of latitude in its ability to process information in various ways. Rather than generate stimuli that were perhaps theoretically pure but somewhat artificial, I chose the altimeter display as an applied information display which might generate different patterns of hemispheric functional asymmetry, depending on the specific behavioral task employed. I hoped that by investigating evoked potential concomitants of laterality of brain function in response to these more applied stimuli that I would also gain information concerning the specific displays and behavioral tasks employed.

The aircraft altimeter has been a classic human factors engineering problem in terms of the optimal way to present this extended scale numerical information (Grether, 1948; Heininger, 1966). Until the mid 1960's, the most widely used altimeter display had three hands, one each for 10,000's, 1,000's and 100's of feet (Chernikoff and Ziegler, 1964; Reilly et al, 1964). See figure 1 for an example. However, studies as early as the 1940's (Grether, 1948) had shown that this display was difficult to read and in fact contributed to many critical flight incidents (Heininger, 1966; Hill and Chernikoff, 1965). Since the mid 1960's most military aircraft and many of the larger commercial aircraft have switched to displays employing counters plus a single pointer for hundreds. Some aircraft such as the F-15 have a full counter plus

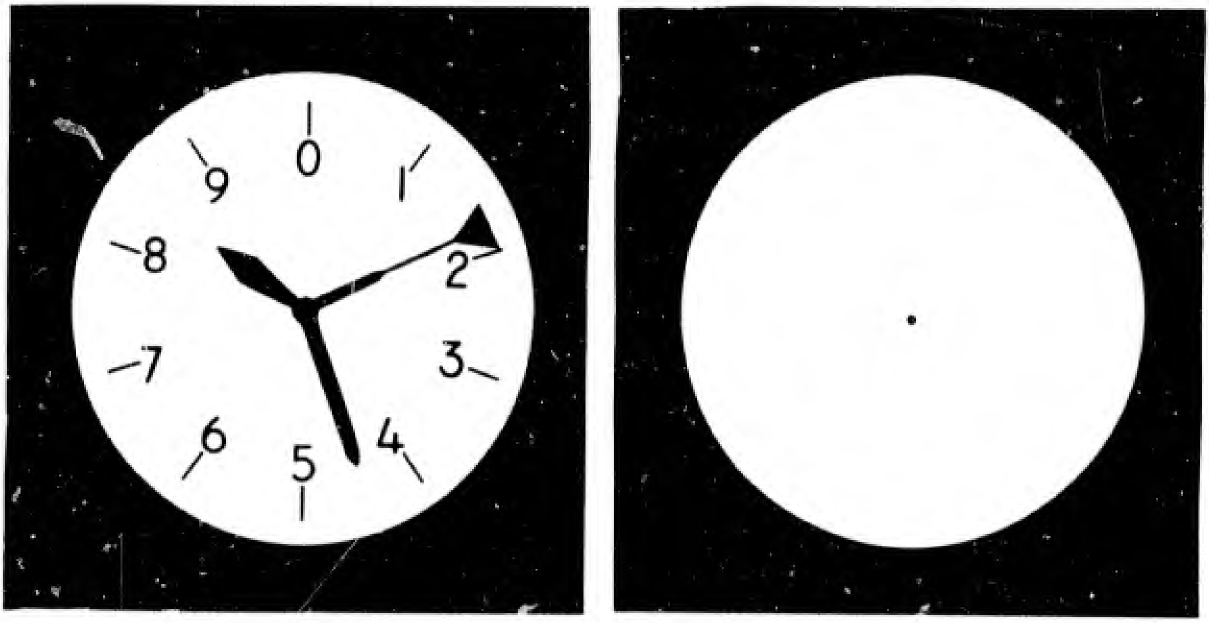
FIGURE 1

The three altimeter displays and fixation point as viewed by the subject. These photographic representations are not as large as the displays were in the experiment.



Counter (CT)
31,600

Counter Pointer (CP)
25,300



Three Pointer (3P)
18,400

Fixation Point

Figure 1

a pointer and the Federal Aviation Agency has also sponsored investigations of altimeter displays employing only digital counters (Pangburn et al, 1972).

The three pointer (3P) altimeter, with its dial face and pointers, appears to represent a numerical altitude setting in a geometric fashion which is more spatial in nature than the counter (CT) altimeter which is a straight forward number. Thus, the 3P altimeter should probably activate right hemispheric information processing functions more than the CT altimeter, which would be expected to activate principally left hemispheric information processing mechanisms. The counter pointer (CP) altimeter, being a combination of both types of information display, could be considered to fall inbetween the CT and 3P displays in terms of laterality of hemispheric function. It is not clear where moving tape type instruments would fit in this analysis. Counter drum pointer altimeters were also excluded because the 100's drum duplicates the pointer in an experimentally confounding way.

I decided to utilize the three schematic aircraft altimeters, the CT, CP and 3P, as information displays in a study of laterality of brain function and thereby also attempt to gain more insight into how the human brain processes this highly practical stimulus information. Insights and techniques developed from this research might contribute to future altimeter displays, and these research approaches should also contribute to the further development of human factors engineering techniques. In the future, more sensitive dynamic techniques for tracking human information processing will be required to optimize dynamic computer driven cathode ray tube and other electronic information displays.

It is apparent that pilots utilize altimeter information in two different ways. In one information processing mode they read the altimeter quantitatively to obtain a number representing their altitude. Experimental Condition I was designed to correspond to this mode of information processing. In a second processing mode pilots primarily scan the instruments looking for changes since the last scan, and they merely judge whether or not the altimeter setting has changed in order to determine if they are maintaining the same altitude. Experimental Condition II was designed to correspond to this mode of information processing.

The two modes of information processing differ substantially in the amount of time required for stimulus information input for the 3P altimeter. Studies by Reilly et al (1964) and Chernikoff and Ziegler (1964) indicate that average exposure times of 2.2 to 3.0 seconds are required for pilots and trained nonpilots to read a 3P altimeter. However, eye-point-of-regard studies (Fitts et al, 1950; Jones et al, 1949, 1950; Milton et al, 1949, 1952) indicate that during various aircraft maneuvers the pilot typically looks at the 3P altimeter for less than 500 msec from 3 to 15 times per minute, depending upon the maneuver. Similarly, preliminary behavioral pilot studies indicated that a two second display interval was required for most moderately trained subjects to read 3P altimeters without excessive errors or stumbling. But, a 400 msec display interval was quite adequate for making same/different judgements.

In the present study electroencephalographic (EEG) and electrooculographic (EOG) data were recorded using the two experimental conditions. Donchin (1973), Hillyard et al (1973), Regan (1972) and Shagass (1972) have surveyed the numerous studies that have related the late positive component (LPC), which is also referred to as the P_3 or P300 component, of the average evoked potential to a variety of perceptual concepts such as association cortex function (Ritter et al, 1972), consciousness (Posner et al, 1973), information delivery (Klinke et al, 1968; Sutton et al, 1967; Tueting and Sutton, 1973), information processing (Barlow, 1971), memory processes (Weinberg et al, 1970), reactive change (Karlin, 1970), selective attention (Nash and Singer, 1974) and task relevance (Donchin and Smith, 1970; Smith et al, 1970). In this study I hypothesized that perceptual differences between the CT and 3P altimeters which relate to linguistic versus spatial perceptual processing requirements should be especially prominent in the LPC. EEG's were recorded from the vertex (C_z) (Ten Twenty System, Jasper, 1958) where the maximal LPC is sometimes recorded (Donchin et al, 1973; Hillyard et al, 1973; McAdam and Rubin, 1971) and from left (P_3) and right (P_4) parietal areas as lateral placements, over what is presumably associative cortex, relative to the midline parietal area (Pz) which has also been reported to be a site of maximal amplitude for the LPC (Loveless, 1973; Marsh et al, 1973; Otto and Leifer, 1972;

Papakostopoulos, 1973; Picton and Hillyard, 1974; Vaughan and Ritter 1970). Vertical and horizontal EOG's were also recorded for the purpose of monitoring eye movements during altimeter reading and to permit the recording of eye movement and eye blink artifacts.

METHODS

Subjects

Sixteen right handed normal male adults, ranging in age from 16 to 40 years, served in two four-hour experimental sessions. Two subjects were unpaid volunteers and the other fourteen subjects were paid $3.00 per hour for their participation. The first hour of each session was used to test brain hemispheric dominance and to apply the EEG and EOG electrodes. The next three hours were used for training and testing. The two sessions were separated by a minimum of 6 days and a maximum of 62 days for different subjects.

A variety of indicators of brain hemispheric dominance were used. Two handedness questioneers were used, one originally developed by Crovitz and Zener (1962) and the other by Benton (1975). The Torque Test developed by Blau (1974) was also administered. Finally, all subjects were tested for eye dominance by requiring them to casually align a pencil tip, which was hand-held at about mid-arm's length, with a distant fixation point with both eyes open. Then they successively closed each eye a few times. The eye, which when closed, created misalignment of the pencil tip with the fixation point was the dominant eye. That is, the dominant eye was the eye actually used to align the pencil tip with both eyes open. The eye dominance was tested several times to insure that the subject was completely aware of the effect and was able to give an accurate report. One subject was never able to successfully complete this test due to problems with double images whenever it was tested.

Stimulus System

Visual stimuli (fixation point and three types of altimeter displays) were tachistoscopically presented by a custom made three channel slide projection system. The tachistoscopic projection system consisted of three Kodak model B-2 Ektagraphic slide projectors with lens mounted Vincent Associates 25 millimeter (mm) Uniblitz shutters. The slide projectors were mounted in a stand approximately 1 meter (m) from a rear projection glass screen (Polacoat Corp., model LS60NG-1/8), which was mounted on the inside surface of a glass window in a double wall Industrial Acoustics Corp. (IAC) sound attenuating room. The glass window was blocked off by black poster board except for a circular viewing port where the stimulus was projected. The viewing port measured 11.4 centimeters (cm) (4.5 inches) in diameter and was made from a thin aluminum plate painted flat black. A small green light emitting diode (LED) was mounted 7.6 cm (3 in.) above the viewing port for the purpose of signalling when a trial could be started. The three slide projectors were intensity balanced by adjustable iris diaphragms and Kodak neutral density Wratten filters mounted on the shutters. The luminance provided by the background lighting and the projected altimeter images or the fixation point measured 2.0 log foot-lamberts at the subject's side of the rear projection screen. The

IAC room was diffusely illuminated by shielded incandescent bulbs which provided 0.3 log foot-lamberts at the rear projection screen, with the slide projectors off. The illumination measurements were made with a Salford Electrical Instruments (SEI) Exposure Photometer.

The slide projectors and shutters were controlled by a custom-made six-channel digital timer, associated digital logic circuitry and electronic shutter drivers. The digital logic also provided event and response signals which were recorded on analog magnetic tape and a paper chart recorder.

The stimuli consisted of high contrast film transparencies (Kodak Super Speed Duplicating Film, type 2551) which were photographs of plastic and metal altimeter models that were fabricated by the author. These models were the same size as aircraft altimeters. The transparences were carefully registered and mounted in plastic and glass slide binders (Gepe Corp.) in order to maintain precise alignment during projection.

The three altimeter displays, shown in figure 1, are schematized versions of a digital counter (CT), counter pointer (CP) and three pointer (3P)altimeters abstracted from military CP and 3P altimeters. Military Specifications MIL-A-27198A and MIL-A-27229A were used for the 3P. MIL-A-83212 was used for the CP, which is a member of the more widely used counter drum pointer family of altimeters. Military Standard MS33585 was used for the pointers and MS33558 was used for the numerals. The CT altimeter was abstracted from the F-15 altimeter which includes a full five digit counter plus a pointer and dial. In order to control for differences in numerals, the same numerals (Letraset 24 point Engineering Standard, 51-24-CN) were used in all counter and dial locations on the altimeter models. These numerals were selected as a compromise between the various sizes which have been used on altimeters in the past. The first two numerals of the CT and the two counter numerals of the CP altimeter overlap exactly. The dial of the 3P and CP also correspond exactly.

Most aircraft altimeters use white numerals on a black background in order to enhance readability at night. However, the altimeter displays for this study used black numerals and markings on a clear or white background in order to minimize differences in projected luminance. The pointers were also painted entirely black in order to overlap the fixation point at the hub. The fixation point was 3mm (.12 in.) in diameter when projected and it was smaller than the pointer hubs in order to minimize distracting movement at that point. The projected size of the altimeter displays was 10.3 cm (4.1 in.) in diameter, subtending 5.6 degrees of visual angle for the subject. Normal altimeter size is 6.98 cm (2.75 in.) and the nominal cockpit viewing distance is 71.12 cm (28 in.) (Military Standard-1472A, p 27), with the altimeter subtending 5.6 degrees of visual angle. However, the subject chair required an average eye distance of 105.4 cm (41.5 in.) thus necessitating a larger altimeter display. The center of the display was approximately 15 degrees below the horizon, the normal line of sight for individuals (McCormick, 1970, p 427). This location was chosen to maximize the convenience of viewing and scanning the altimeter displays.

The numerical settings of the altimeter displays consisted of 100 randomly selected numbers with several limitations. The ones and tens digits were always zero in order to limit the number of meaningful digits to three or one digit for each pointer of the 3P altimeter without requiring interpolation. Seven was never used as a hundreds digit in order to avoid having the pointer of the CP altimeter overlap the counter portion of that display. All digits from zero to nine were equally used in the ten thousands place. That is, of the 80 settings used for testing, eight started with zero's, eight with ones, etc., in the ten thousands place. All three meaningful digits were required to be different, thus excluding the possibility of repeated digits as this would have caused difficulty with the 3P altimeter and might have otherwise influenced neuronal information processing times. Finally, in each group of settings starting with the same ten thousands digit, the same number could only appear twice in the hundreds and twice in the thousands place. See the Appendix for lists of the numbers. Of the 100 settings, 80 (1 slide tray) were used for testing and the other 20 were used for training. The same set of 80 numbers was used for testing the three different altimeters, but the order of presentation was separately randomized for each type of display.

Subject Chair

The subject was seated in a modified barber chair which had a more comfortable seat, adjustable wooden arms and a wooden platform for the feet. The foot platform was adjusted to allow for comfortable positioning of a microswitch which was activated by slightly lifting the right foot. The subject was trained to initiate each trial by momentarilly raising his right foot to close the normally closed microswitch and thus start the digital timer. After a one second pretrial delay the tachistoscopic projector system changed from the fixation point in channel 3 to the altimeter display in channel 1. The fixation point was on at all times except when a display was presented in channel 1 or 2. The adjustable wooden arms had custom-made two way lever activated dual microswitches mounted on the ends. The levers on these switches could be conveniently moved in or out by the thumb and forefinger of each hand. A slight inward movement activated one microswitch and an outward movement activated a second microswitch. Both lever switches were connected to the digital control logic via AND gate circuitry so that both levers had to be simultaneously switched in or out in order to indicate a same or different response for Condition II and stop a digital stopwatch.

Two microphones were mounted on adjustable goose neck extensions next to the subject chair in order to provide input for the voice activated relay and tape recorder.

Recording System

EEG and EOG signals were recorded from the scalp and area around the eyes using AgAgCl electrodes (Beckman Instruments) on nonhairy skin and gold cup electrodes (Grass Instruments) on normally hairy skin. One pair of electrodes was placed on the superior (noninverting or G_1 amplifier input) versus the inferior (inverting or G_2 amplifier input) orbital ridge of the right eye for the vertical EOG (EOGV) channel. Another electrode pair was placed across both eyes on the right (G_1) versus the left (G_2) outer canthus of the eyes for the horizontal EOG (EOGH) channel. Hooking up EOG electrodes in this manner produces a positive voltage deflection for upward and for rightward eye movements. Gold cup electrodes (Grass Instruments) placed on Cz, P_3 and P_4 were used as the G_1 inputs for three EEG channels referenced to linked mastoids (M_1-M_2). The system ground (GND) electrode was placed at Fpz.

The skin was cleaned with alcohol and Offner Paste (Beckman Instruments) was used in all electrodes. Nonhairy skin was abraided with a typewriter eraser which had been cleaned in alcohol, and hairy skin under gold cup electrodes was rubbed with the blunt 18 gauge hypodermic needle used for placing electrode paste. The skin was abraided in order to minimize and match electrode impedances. The electrode impedance was checked before and after the recording session with a Grass model TIM1B tissue impedance meter. Impedance readings were noted between C_z, P_3 and P_4 referenced to each other and to GND; M_1 and M_2 referenced to each other and to GND; and all EOG electrodes referenced to GND. In all subjects electrode impedance for all EEG electrodes was below 3 kilohms and in most subjects below two kilohms. The impedances for the EEG electrodes and for the mastoid electrodes were always carefully matched and differences greater than 200 ohms were not permitted. The electrode impedance for all EOG electrodes was below 5 kilohms and was typically below 3 kilohms. In many subjects the skin under the GND and especially under M_1 and M_2 was abraided to the point of slightly breaking the skin, definitely excluding the possibility of skin potential effects which have been reported by Picton and Hillyard (1972) and Corby et al (1974). The skin breakage was noted by visual inspection after removal of the electrodes, and slight scab formation noted the next day. Not all subjects could be carefully examined in this regard, but the electrode impedances did not differ greatly across subjects.

The recording electrodes were plugged into a small custom-made electrode box which hung on a strap around the subject's neck. A short cable leading from the electrode box connected to a long cable leading out of the IAC room to the polygraph, allowing for rapid convenient connection of the subject's electrodes.

A Grass model 78 polygraph with 7P511 AC coupled amplifiers was used to amplify the electrophysiological signals and produce a paper chart recording. The amplifiers were set at 5 microvolts per mm for EEG recording and 7.5 microvolts per mm for EOG recording. The filter settings were the same for all channels, with a high pass setting of 0.1 Hz (TC = 600ms), low pass setting of 1 kilohertz and no 60 cycle filter. All the electrophysiological signals plus the event signals and a verbal response channel were recorded on an eight channel Precision Instrument model PI-6208 instrumentation tape recorder. Off line response averaging was done on a Nuclear Chicago Data Retrieval Computer model 7100 and the averages were written out on a Leeds and Northrup Speedomax model XL strip chart recorder.

Experimental Procedure

Condition I. In this condition the subject was required to read an altimeter display as rapidly as possible after it was presented. The verbal response had to be in the form of an integrated number without pausing. The word thousand had to be inserted also, as in "thirteen thousand, two hundred." The hundreds pointer for the CP and 3P altimeters was always read to the lower hundreds digit without interpolation for the tens and ones digits. Verbal responses which were inaccurate or included pauses or stumbling were scored as errors, and all errors were discouraged.

The altimeter display was presented for two seconds and the verbal reaction time was measured from the onset of the display to the onset of the verbal report using a digital stopwatch and a Scientific Prototype Audio Threshold Detection Relay model 761-G. The relay was typically triggered by the first puff of air as the subject began to speak. Eighty such display trials were presented for each type of altimeter (CT, CP or 3P), with a minimum intertrial interval (ITI) of four seconds. The altimeter display slide projector was advanced during the ITI. The end of the four second ITI was signaled by the onset of the green LED and then the subject could begin another trial by initiating the one second pretrial interval with his foot switch. Condition I consisted of three blocks of eighty trials (one slide tray each), with only one type of altimeter display being used for each stimulus block. The order of presentation of altimeter types was completely counterbalanced across the sixteen subjects using the six possible orders of the three altimeter types more than twice. Thus, some subjects received the block of CT altimeters first and others got the CP or 3P first.

Condition II. This condition required that the subjects make a same/different judgement between two successively presented altimeter displays. The first display was presented exactly the same as in Condition I, except that it was on for only 400 msec. After the first display or Stimulus 1 there was a two-second interstimulus interval (ISI) followed by the second display which was presented for 400 msec by projector channel 2. The subject was required to judge whether Stimulus 2 was the same or different than Stimulus 1 and respond using both lever switches as rapidly as possible without making errors. Response direction for the lever switches was also counterbalanced across subjects and display block order. Thus, half of the subjects moved the levers in for same and out for different while the other half responded in the opposite direction. A three second minimum ITI was used for Condition II with the same altimeter display order (same slide trays) being used for Stimulus 1 as for Condition I, and the same order of the blocks of altimeter displays. Half of the displays for Stimulus 2 were the same as Stimulus 1 while the other half were selected to differ only slightly from Stimulus 1. Typically these different second stimuli had one or sometimes two digits which were one unit removed from Stimulus 1, or two digits were reversed in position, etc. The different second stimuli were selected from the total group of 100 altimeter settings, without any stimuli being repeated or overlapping with the same stimuli. The same and different stimuli were randomly distributed except that no more than four trials in a row could require the same response. See the Appendix for a list of the altimeter settings used in Condition I and II.

Each block of eighty altimeter display trials required from ten to fifteen minutes to complete depending upon the speed of the subject. All subjects were required to get out of the subject chair after each block of eighty trials and exercise a little in order to maintain their vigilance levels and to attenuate any effects of a previous block of trials on a successive block of trials.

Experimental Sessions. Two experimental sessions were used in order to permit adequate training of the subjects and to promote stabilization of the behavioral and physiological data. The same experimental conditions, altimeter displays and order of presentation of displays were used for both experimental sessions. However, the first session employed more training and the second session repeated Condition I fully after Condition II. Thus, the first session involved only one complete run of Condition I and Condition II.

After completing Condition II, subjects without previous behavioral training received further training on reading 3P altimeters by doing one more Condition I run on 3P altimeters. Due to an equipment failure only 15 of the subjects participated in Condition II for the second session.

Initial Training. After the subject was seated in the subject chair and the electrode junction box was plugged in, he was trained to initiate trials by only momentarilly lifting his foot. In order to minimize unnecessary eye movements he was instructed to fixate consistently, as he preferred either on the fixation point or to the left where the counter digits would appear, for each type of altimeter display. Thus, the subject was instructed to avoid all eye movements except those necessary to actually read the altimeter display, until he had completed his verbal response. He was further instructed to avoid any eyeblinks, other muscle movements, or mouth movements such as blowing out or lip smacking, starting just before the initiation of the pretrial interval until after the verbal response. He was encouraged to blink more often during the pretrial interval. Since the subject controlled the beginning of the pretrial interval he was instructed to pause when necessary in order to avoid eyeblinks, to regain his composure after stumbling on a trial, to fidget, or simply to rest his eyes for a moment.

The training for Condition I primarily involved acquainting the subject with the three types of displays, developing the proper verbal response and giving the subject practice primarily in reading the 3P altimeter. The CT and CP were easy to read, but the 3P was much more difficult, typically requiring more than twenty trials until the criterion of more than three successive 3P displays had been read correctly. Training and subject competance on the 3P altimeter really continued to progress until the second testing session for many subjects. Three subjects had received additional training in previous sessions involving behavioral testing.

The subject was trained on Condition II after testing on Condition I. Training for Condition II primarily involved establishing smooth use of the response levers. The subject was again cautioned to avoid eyeblinks, eye movements or extraneous muscle movements, starting before the initiation of the pretrial interval until a few moments after responding to Stimulus 2.

Analysis of EEG and EOG Data

The three channels of EEG and two channels of EOG data were played back off line and averaged using four-second analysis epochs. The eighty trials for each type of altimeter display (data block) were used to form one average evoked potential (AEP) for each run. The four second epochs started with the onset of the one second pretrial interval for Condition I and 500 ms after the onset of the pretrial interval for Condition II. Averages were also computed for 20 microvolt calibration signals from a Grass Instrument model SWC1B Square Wave Calibrator, which had been recorded on tape via the entire electrophysiological system at the end of the testing session.

The AEP's for the EEG and EOG data were quantified by measuring the strip chart write outs and converting the measures to microvolts for amplitude and msec for latency. These measures were performed in three latency segments for Condition I as illustrated by figure 2. The first segment ran from 100 msec to 300 msec and was referred to as the early positive component (EPC). The second or late positive component (LPC) segment ran from 300 to 500 msec, and the last or very late positive component (VLPC) ran from 500 to 700 msec. Within these three segments, the prominent peak or peaks (two maximum) or inflection point in the AEP curve was used as a measurement point for amplitude and latency. In the case of two distinct peaks, an average was computed for further data analysis procedures. Whenever multiple peaks were measured, the same characteristic points were used for P_3 and P_4. Only the LPC was measured for Condition II as illustrated in figure 3. The peaks or inflection points in the AEP curves were considered to be characteristic points and were used for comparison purposes across altimeter display types, experimental conditions, condition runs and subjects. Since the temporal resolution of the measurement was no better than ± 25 msec, the characteristic points were allowed to vary in latency by as much as 50 msec in the entire span for the EEG measures from C_z, P_3 and P_4. The EOGH and EOGV AEP curves were measured at exactly the same latency points, with the measurement

FIGURE 2

A representative AEP for Condition I showing the method of measuring amplitude and latency for the three measurement segments; the early positive component (EPC), the late positive component (LPC) and the very late positive component (VLPC).

CONDITION I AEP

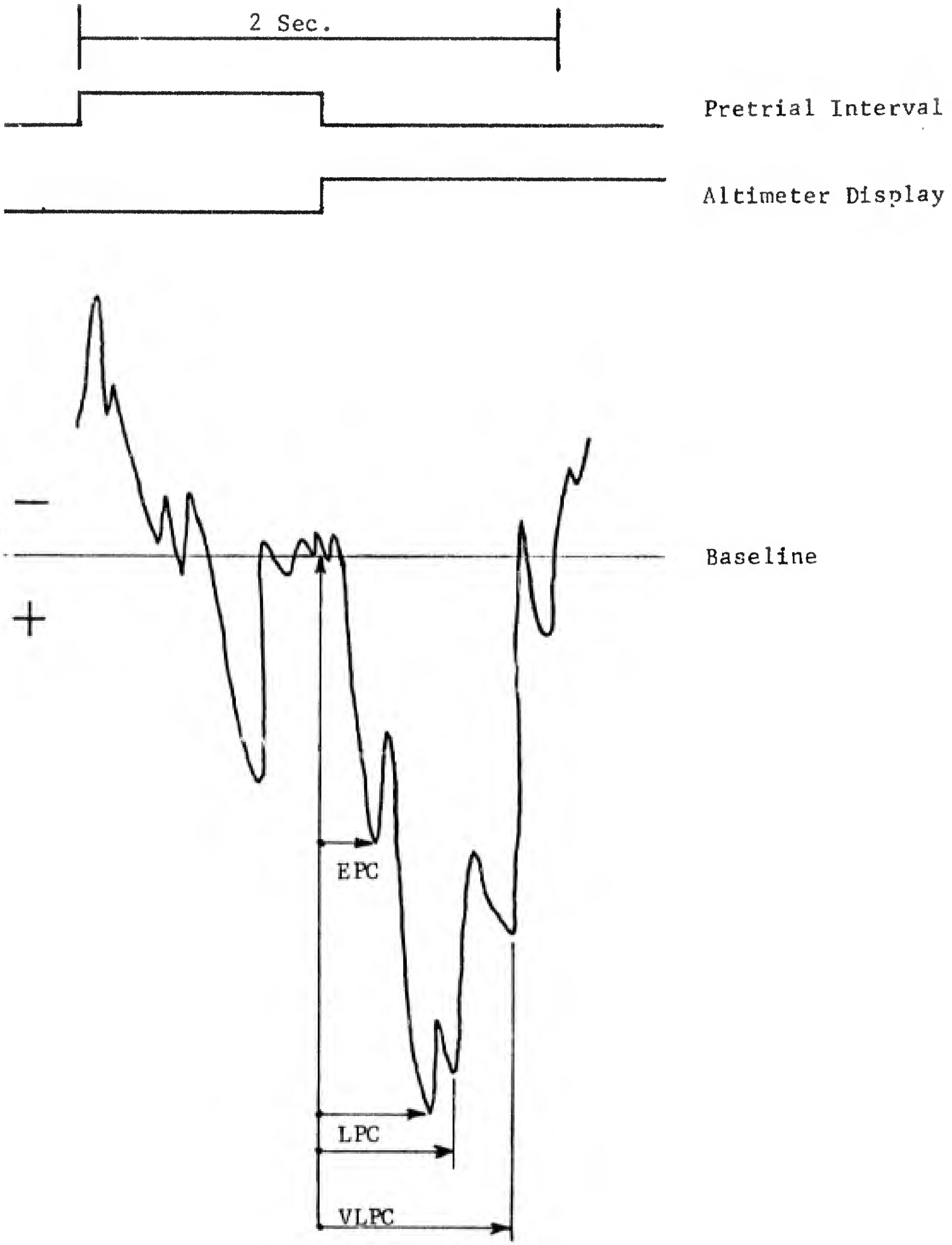


Figure 2

FIGURE 3

A representative AEP for Condition II showing the method of measuring amplitude and latency for the late positive component (LPC) to both Stimulus 1 (S1) and Stimulus 2 (S2).

CONDITION II AEP

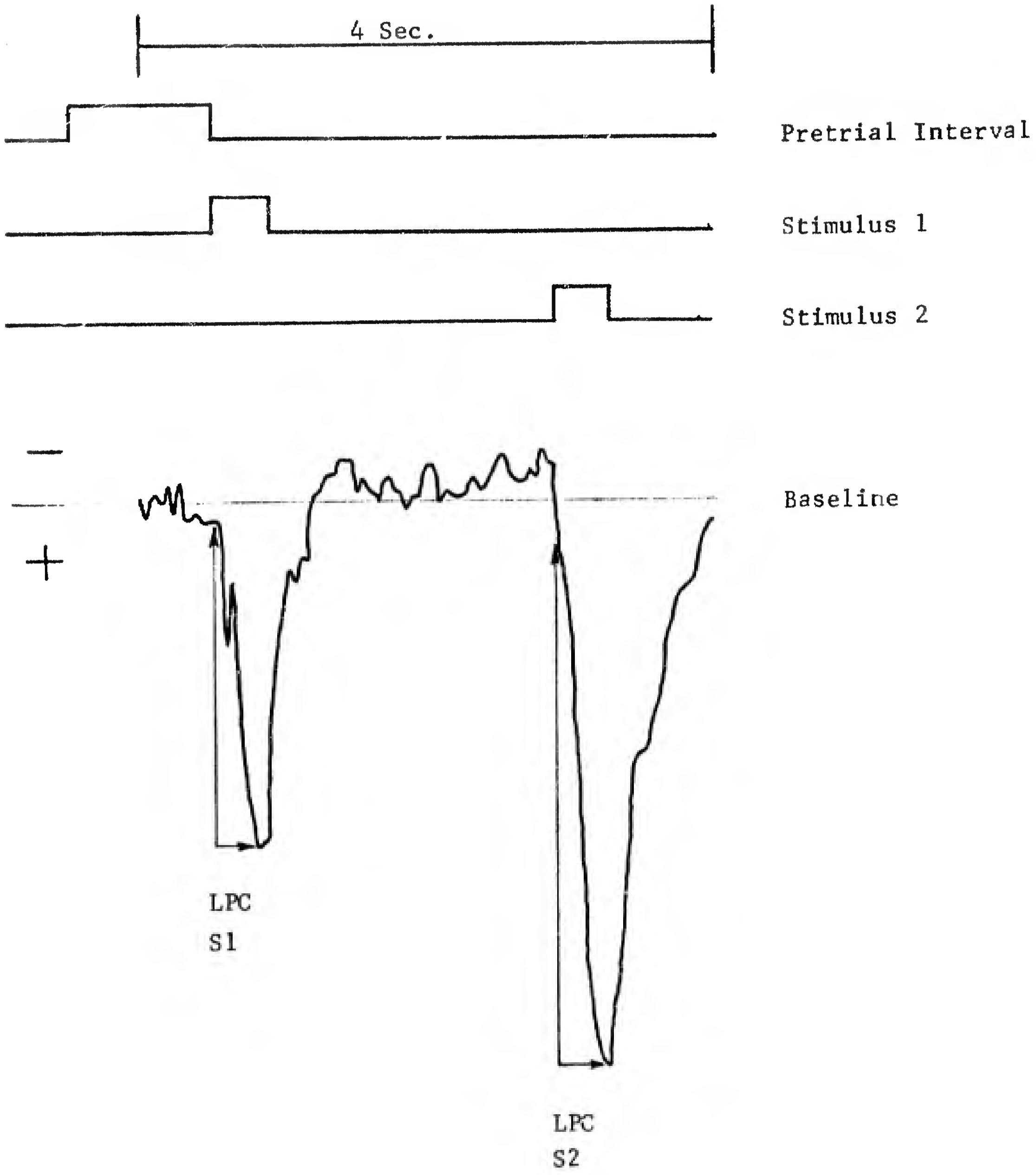


Figure 3

points chosen to correspond to the characteristic points for C_z, P_3 or P_4. In general, obviously corresponding characteristic points were apparent for the EEG data but not for the EOG data.

Behavioral Data Analysis

The behavioral data were analyzed in terms of errors and average behavioral reaction times for each block of trials for each altimeter display. The onset of the verbal response was used for Condition I and the onset of the lever response was used for Condition II in determining the average reaction time. Obviously spurious early reaction times due to lip smacking or breathing out before the verbal response, and very late responses due to excessive stumbling were deleted from the averages. A median of less than 2% of the trials were deleted across all subjects and all blocks of trials, with less than 4% being deleted for almost any individual block of trials. Typically more trials were deleted for the 3P than for the CT or CP altimeter displays.

RESULTS

Behavioral Data

Tables 1 and 2 present the reaction time (RT) and error rate data averaged across subjects for Conditions I and II. The average standard deviation (SD) is the mean across subjects of the individual SD's which were computed for each subject's average RT. Two types of errors were scored. The first type of error was a completely incorrect or wrong response. The second type of error was a response which was ultimately correct but involved a correction, pause or stumble for Condition I, and an observed correction or a response of both same and different for Condition II. In many instances corrections for Condition II were executed so rapidly that the experimenter could only observe that both response indicator lights were on.

In Condition I it was apparent from the reaction time data that the 3P altimeter has a much longer verbal response latency than either the CT or CP altimeters ($F(2,30) = 135.86$, $P < .001$) (Myers, 1966, Chapter 7). The reaction time for the CP altimeter was also slightly shorter than the RT for the CT altimeter ($F(1,15) = 5.65$, $P < .05$). All subjects reported that the 3P was much more difficult to read than either the CT or the CP altimeter. Most subjects also reported that the CP altimeter was easier to read than the CT and that they typically did not have to look at the single pointer in order to read it. This is in contrast to the 3P altimeter which

TABLE 1

Behavioral reaction time (RT) and error (as a % of the total number of trials) data for Condition I. The average RT (in msec) and average standard deviation (SD) is an average across subjects of each subject's individual RT and SD. The errors are classified as either completely wrong responses (WR) or as an ultimately correct response involving a correction, pause or stumble (CPS).

TABLE 1

CONDITION I BEHAVIORAL DATA

	Latency (msec)						Errors (%)					
	CT		CP		3P		CT		CP		3P	
	RT	SD	RT	SD	RT	SD	WR	CPS	WR	CPS	WR	CPS
First Run Ave.	659	116	623	93	1753	421	.31	1.56	.15	1.32	12.50	7.65
Second Run Ave.	628	97	601	84	1553	343	.48	1.01	.08	.24	6.95	5.00
Third Run Ave.	637	103	589	80	1481	320	.15	1.01	.48	.31	6.25	5.70
Over All Ave.	641	105	604	86	1596	361	.31	1.19	.24	.62	8.57	6.12

TABLE 2

Behavioral reaction time (RT) and error (as a % of the total number of trials) data for Condition II. The average RT (in msec) and average standard deviation (SD) is an average across subjects of each subject's individual RT and SD. The errors are classified as either completely wrong responses (WR), or as a response involving either a correction or an execution of both responses (CB).

TABLE 2

CONDITION II BEHAVIORAL DATA

	Latency (msec)						Errors (%)					
	CT		CP		3P		CT		CP		3P	
	RT	SD	RT	SD	RT	SD	WR	CB	WR	CB	WR	CB
First Run Ave.	746	229	808	240	781	247	.39	3.82	.94	5.24	1.12	4.76
Second Run Ave.	653	190	700	208	761	234	.09	3.91	.16	3.16	.91	3.34
Over All Ave.	700	210	754	224	771	240	.24	3.86	.55	4.20	1.02	4.05

which all subjects reported required eye movements unless the pointers happened to be closely grouped together. Subjects reported that it was necessary to sort out visually the three pointers, typically starting with the 10,000's hand first. No such visual sorting appeared necessary with the CP altimeter.

The faster subjects often reported response strategies such that they would read the 10,000's and 1,000's hand on the 3P altimeter and then begin their verbal response while reading the 100's pointer. Likewise, they would read the two digits of the CP or the first two digits of the CT and begin responding while reading the pointer or the third CT digit.

Visual inspection of the EOG records in order to detect eye movements around the altimeter displays was hampered by the small size of the eye movements, which were always less than 5.6 degrees and often only 2 or 3 degrees of visual angle. Background EEG activity or noise also often obscured the smaller eye movements. In the subjects with the cleanest EOG records very few or no eye movements were observed while the subjects read the CT or CP altimeters. However, two or three eye movements were often observed while the subjects read the 3P altimeter, before they reported the number.

The error rate data for Condition I indicates an obviously larger error rate for the 3P altimeter than for the CT or CP altimeters. These data were not statistically analyzed due to the much greater error rate and variability for the 3P data versus the CT or CP data, which would thus compromise any statistical analysis.

The reaction times for Condition II do not differ significantly across altimeter display types (F(2,30) = 2.28). Similarly, the average error rate for the 3P is closer to the average error rate for the CT and CP for Condition II, when the two conditions are compared. The average error rate differences between Condition I and Condition II were not statistically analyzed due to the lack of homogeniety of variance across the different displays for the two conditions. Also, eye movements were not observed in the EOG records while the subjects looked at the brief presentations of Stimulus 1 or Stimulus 2, and the subjects did not report that eye movements were necessary.

Most subjects reported that they read the numbers for Stimulus 1 and compared them to Stimulus 2 for the CT altimeter. For the CP altimeter the subjects typically reported that they read the counter digits and judged pointer sameness by position. However, some subjects reported reading the entire Stimulus 1 for the CP display. Preliminary pilot work indicated that 50 msec is more than enough time to read either the CT or CP displays, but not the 3P display. None of the subjects reported successfully reading all of the 3P digits for Stimulus 1 or 2. All of the subjects reported the use of visual pattern matching for same/different judgements for the 3P altimeter. Most of the subjects said that they ignored the 3P dial numbers. A few subjects also indicated some use of visual pattern matching for the digits in the CT and CP displays in Condition II.

The CT and CP altimeter reaction time data were compared for Condition I and II, excluding the 3P data which was obviously different across the two conditions. The average RT and SD for each condition were determined by averaging together the CT and CP RT's and SD's for each condition. Both the RT's ($F(1,15) = 7.06$, $P < .05$) and the SD's ($F(1,15) = 31.10$, $P < .001$) were significantly different across subjects between the two conditions. The average SD for Condition I was less than half the SD for Condition II, and the average RT was, at the most, 150 msec shorter.

Averaged Evoked Potential Data

Condition I EEG Measures. Table 3 presents the average amplitude and latency data for the three measurement segments and the three electrodes averaged across subjects for each run, and then across the three replicated Condition I runs. The Δ column between the P_3 and P_4 columns indicates the difference in microvolts (µv) between the P_4 electrode and the P_3 electrode ($P_4 - P_3$). It can be seen that in all three measurement segments the average $\Delta(P_4 - P_3)$ amplitude is greater for the CP and 3P altimeter than for the CT altimeter, suggesting that the right hemisphere AEP relative to the left hemisphere AEP was more positive (right-more-positive) for the altimeters employing dials. These differences were not statistically tested.

Evoked potential amplitude measures vary widely across subjects due to a variety of mostly unknown anatomical, physiological, and

TABLE 3

Condition I AEP amplitude data (in µv) and latency (in msec) for the three EEG electrodes (P_3, P_4 and C_z) at the three measurement segments; the late positive component (LPC), early positive component (EPC) and the very late positive component (VLPC). The △ column expresses the difference in µv between P_4 and P_3 (P_4-P_3). The average amplitude and latency is an average across subjects for each run, and then across the three replicated runs. The standard deviation (SD) is an average of the three SD's for the three runs.

TABLE 3

CONDITION I EEG AEP MEASURES

		Amplitude (µv)												Latency (msec)								
		CT				CP				3P				CT			CP			3P		
		P_3	(Δ)	P_4	Cz	P_3	(Δ)	P_4	Cz	P_3	(Δ)	P_4	Cz	P_3	P_4	Cz	P_3	P_4	Cz	P_3	P_4	Cz
LPC	Ave.	10.0	(+ .9)	10.9	12.3	9.7	(+1.7)	11.4	13.3	7.0	(+1.5)	8.5	9.1	391	393	397	378	378	381	380	382	389
	SD	6.71		6.22	7.77	6.10		5.32	7.79	4.18		4.00	5.03	47	47	48	47	41	48	36	40	38
EPC	Ave.	7.1	(+ .1)	7.2	10.9	6.2	(+ .6)	6.8	10.5	5.3	(+ .6)	5.9	9.3	196	197	196	188	186	186	199	203	196
	SD	4.84		4.23	5.04	3.55		3.21	4.42	3.38		3.05	4.38	39	37	32	38	36	30	39	41	33
VLPC	Ave.	10.2	(+1.0)	11.2	15.1	9.7	(+1.6)	11.3	15.7	5.5	(+1.3)	6.8	8.3	585	588	594	586	587	592	578	586	587
	SD	6.74		6.55	8.06	6.93		6.68	8.35	4.76		3.30	5.65	48	48	50	51	52	51	54	54	57

other volume conduction factors. Because the right and left AEP's tended to covary in amplitude it was decided to characterize this hemispheric comparison data as a ratio of the P_4 (right) over the P_3 (left) AEP amplitude in order to derive a more stable index of laterality, for the purpose of making comparisons across subjects between the three altimeter displays. Such a relative method for comparing right/left amplitudes is also useful, because a greater amplitude in the AEP recorded over the right hemisphere versus the left hemisphere does not necessarily mean that the right hemisphere is more actively engaged in processing the evoking stimulus. As with between subject AEP amplitude measures, many factors can influence the size of the AEP over one hemisphere versus the opposite hemisphere. Rhodes (1975) has summarized his own findings plus those of several other researchers, and concluded that the evidence supports a consistent tendency for right hemisphere visual evoked potentials to be larger than left hemisphere visual evoked potentials. Thus, it is the shift in AEP amplitude asymmetry which is important in comparing between different types of stimuli rather than the actual asymmetry of the AEP amplitudes to any particular stimulus display.

A simple P_4/P_3 ratio was not completely adequate either, however, because it produced a statistical distribution of data points which was skewed due to nearby lower limit of zero and the distant upper limit of infinity. Therefore, a logarithmic transformation consisting of the natural log of P_4/P_3 ($\mathrm{Ln}(P_4/P_3)$) or its equivalent $\mathrm{Ln}P_4 - \mathrm{Ln}P_3$ was employed to produce a normal distribution of data points and to attenuate spuriously high ratios.

Figures 4, 5 and 6 display the LnP_4-LnP_3 values for the LPC, EPC and VLPC for the three separate Condition I runs plus an average line for each of the three measurement segments. The data are protrayed as a three point line function running from the CT to the 3P altimeter. While no such simple unidimensional continuum is implied or appropriately justifiable, the line graph does satisfy the need for a visual presentation of the data.

Repeated measures analysis of variance tests which were performed on the three run average LnP_4-LnP_3 amplitudes for each measurement segment indicated that only the LPC measures were significantly different across altimeter display types ($F(2,30) = 6.32$ $P < .01$). Although the means point to a larger CP and 3P than CT right-more-positive effect for the EPC ($F(2,30) = 1.16$) and VLPC ($F(2,30) = .60$) measures, the much greater across subject variability for these two measurement segments does not support a statistically significant difference. The LPC differences were further tested using Scheffe's method for multiple comparisons (Kirk, 1968, pp 144-145). The CP and 3P equally weighted were significantly different from the CT ($F(2,30) = 12.06$, $P < .01$). The CP and 3P were not significantly different from each other ($F(2,30) = .58$).

Condition II EEG Measures. Table 4 presents the average amplitude and latency LPC measures which were averaged across subjects, and then across the two replicated runs for Condition II. Figures 7 and 8 graphically present the LnP_4-LnP_3 values for the LPC's to

FIGURE 4

Increased values for LnP_4-LnP_3 for the counter pointer (CP) and three pointer (3P) altimeter displays versus the counter (CT) altimeter for the late positive component (LPC) in Condition I. The average for the three replicated runs is plotted along with the runs.

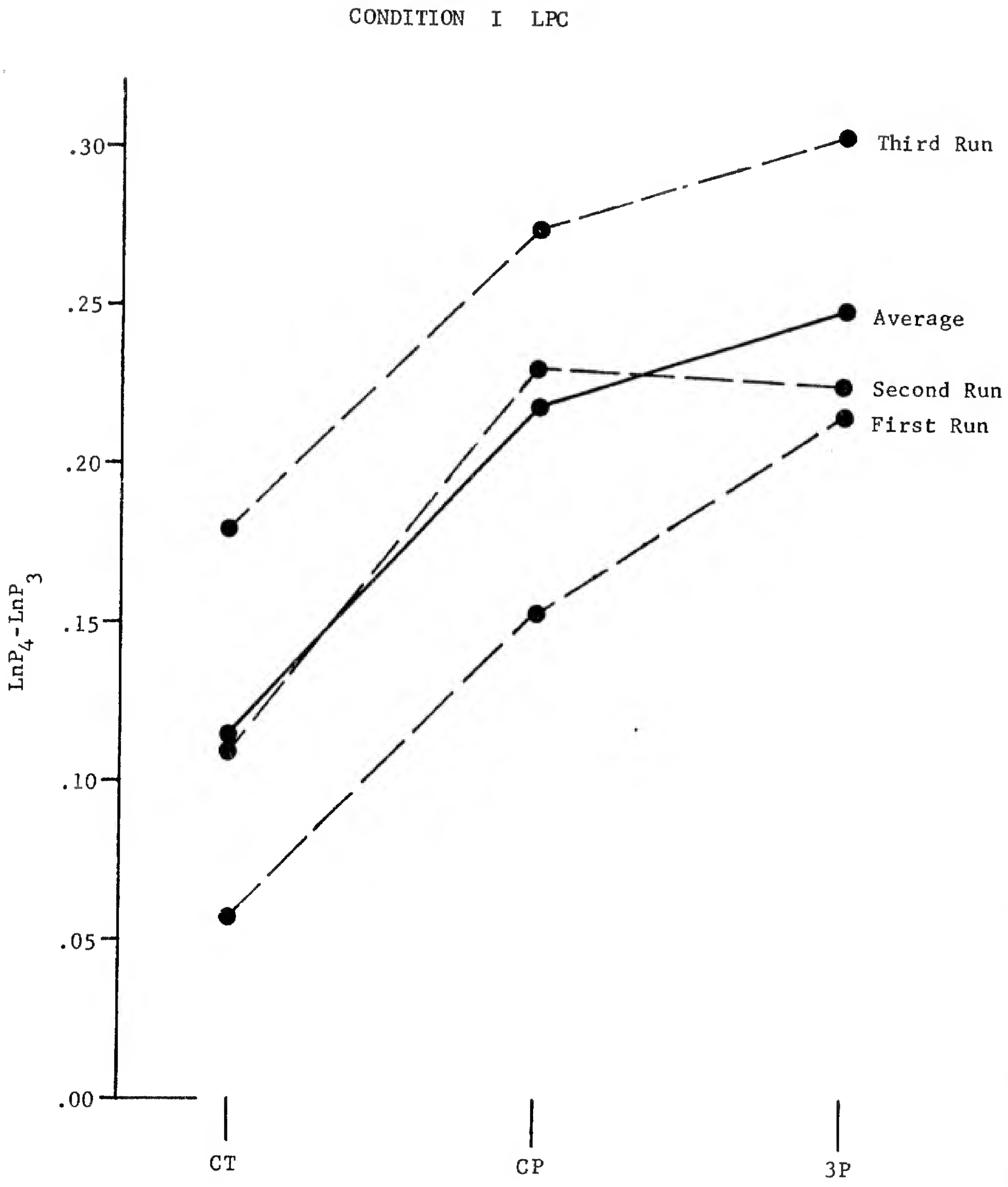

CONDITION I LPC
LnP$_4$-LnP$_3$
.30
.25
.20
.15
.10
.05
.00
CT
CP
3P
Third Run
Average
Second Run
First Run

Figure 4

FIGURE 5

LnP_4-LnP_3 values for the early positive component (EPC) in Condition I for the counter (CT), counter pointer (CP) and three pointer (3P) altimeter displays. The average for the three replicated runs is plotted along with the runs.

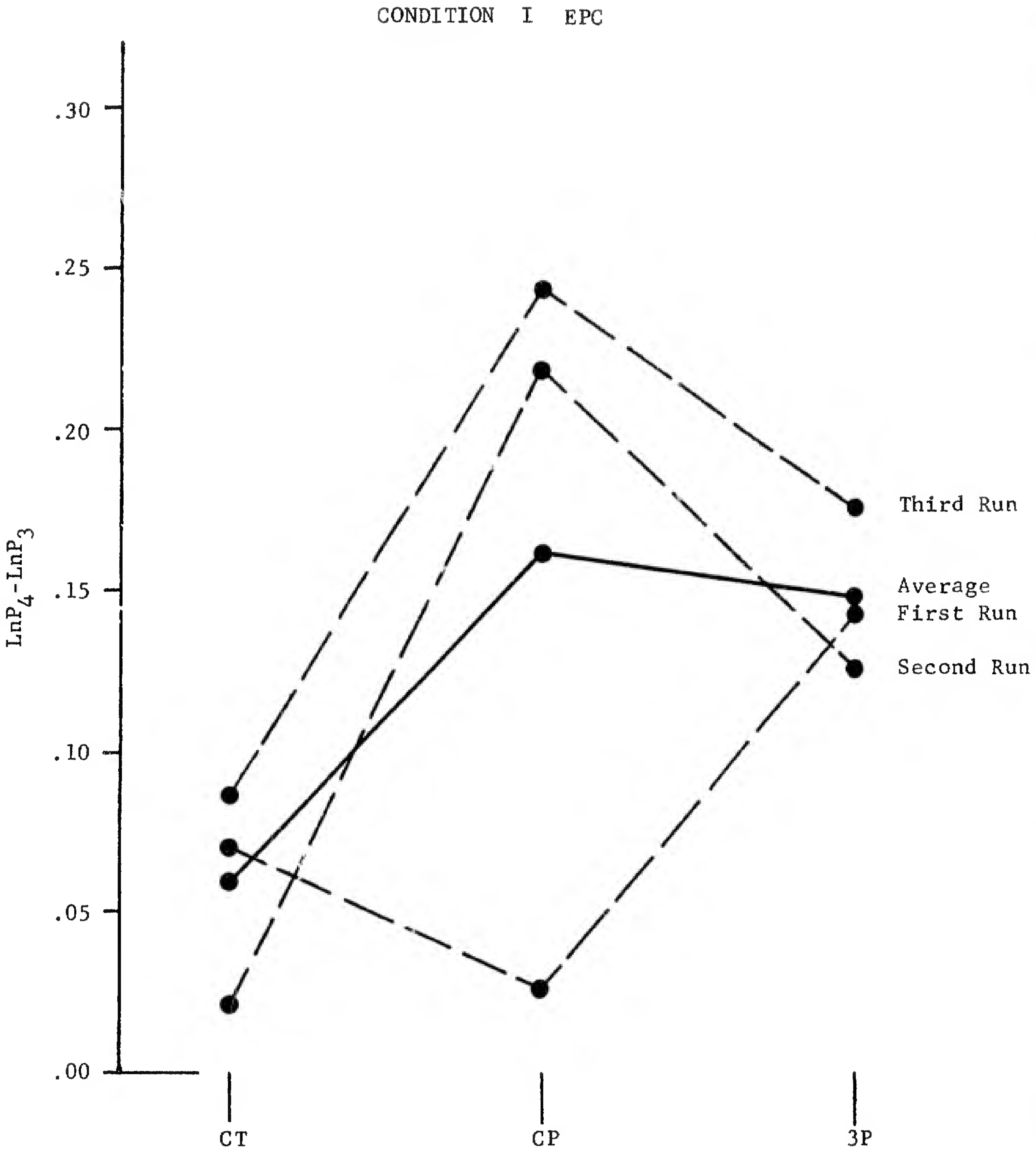

CONDITION I EPC
.30
.25
.20
.15
.10
.05
.00
LnP_4-LnP_3
CT
CP
3P
Third Run
Average
First Run
Second Run

Figure 5

FIGURE 6

LnP_4-LnP_3 values for the very late positive component (VLPC) in Condition I for the counter (CT), counter pointer (CP) and three pointer (3P) altimeter displays. The average for the three replicated runs is plotted along with the three runs.

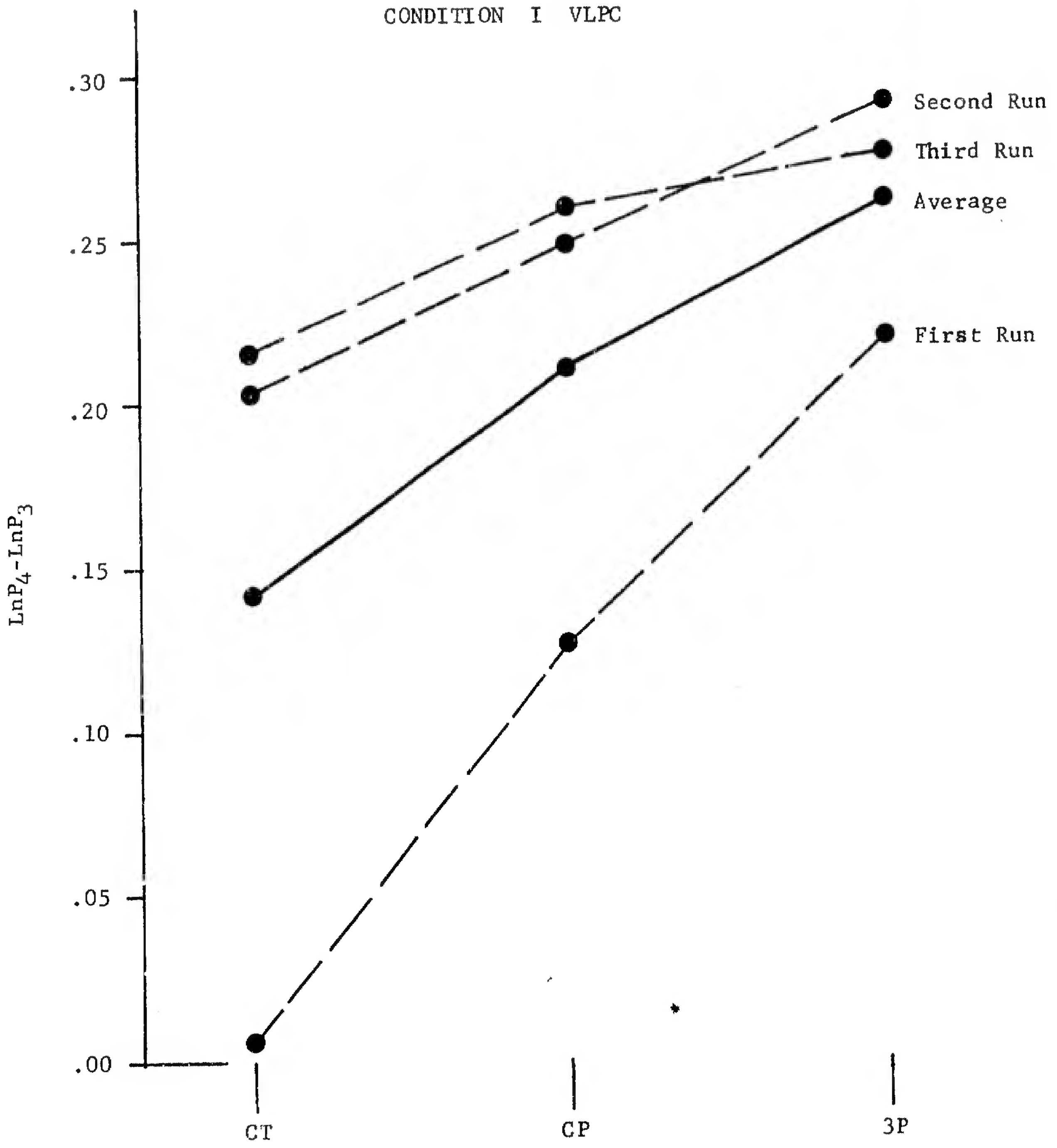

CONDITION I VLPC
.30
.25
.20
.15
.10
.05
.00
LnP_4-LnP_3
Second Run
Third Run
Average
First Run
CT
CP
3P

Figure 6

TABLE 4

Condition II EEG amplitude (in µv) and latency (in msec) data for the AEP late positive component (LPC) evoked by Stimulus 1 and Stimulus 2 at the three EEG electrodes (P_3, P_4 and C_z). The Δ column expresses the difference in µv between P_4 and P_3 (P_4-P_3). The average amplitude and latency is an average across subjects for each run, and then across the two replicated runs. The standard deviation (SD) is an average of the two SD's for the two runs.

TABLE 4

CONDITION II EEG AEP MEASURES

		Amplitude (µv)												Latency (msec)								
		CT				CP				3P				CT			CP			3P		
		P_3	(Δ)	P_4	Cz	P_3	(Δ)	P_4	Cz	P_3	(Δ)	P_4	Cz	P_3	P_4	Cz	P_3	P_4	Cz	P_3	P_4	Cz
Stimulus 1	Ave.	7.3	(-.1)	7.2	6.8	7.2	(+.3)	7.5	7.6	7.2	(+.6)	7.8	8.0	379	384	390	368	367	374	367	368	372
	SD	4.28		3.84	4.38	4.24		3.12	4.22	4.05		3.46	4.38	42	46	46	44	42	44	38	37	40
Stimulus 2	Ave.	10.7	(-.5)	10.2	7.0	10.3	(-.2)	10.1	7.2	11.8	(-1.0)	10.8	9.4	394	390	390	402	394	395	394	397	392
	SD	4.82		4.88	4.92	5.58		5.02	5.56	6.44		6.02	5.82	34	34	31	34	32	38	44	42	52

FIGURE 7

LnP_4-LnP_3 values for the AEP late positive component (LPC) to Stimulus 1 in Condition II for the counter (CT), counter pointer (CP) and three pointer (3P) altimeter displays. The average for the two replicated runs is plotted along with the runs.

CONDITION II STIMULUS 1 LPC

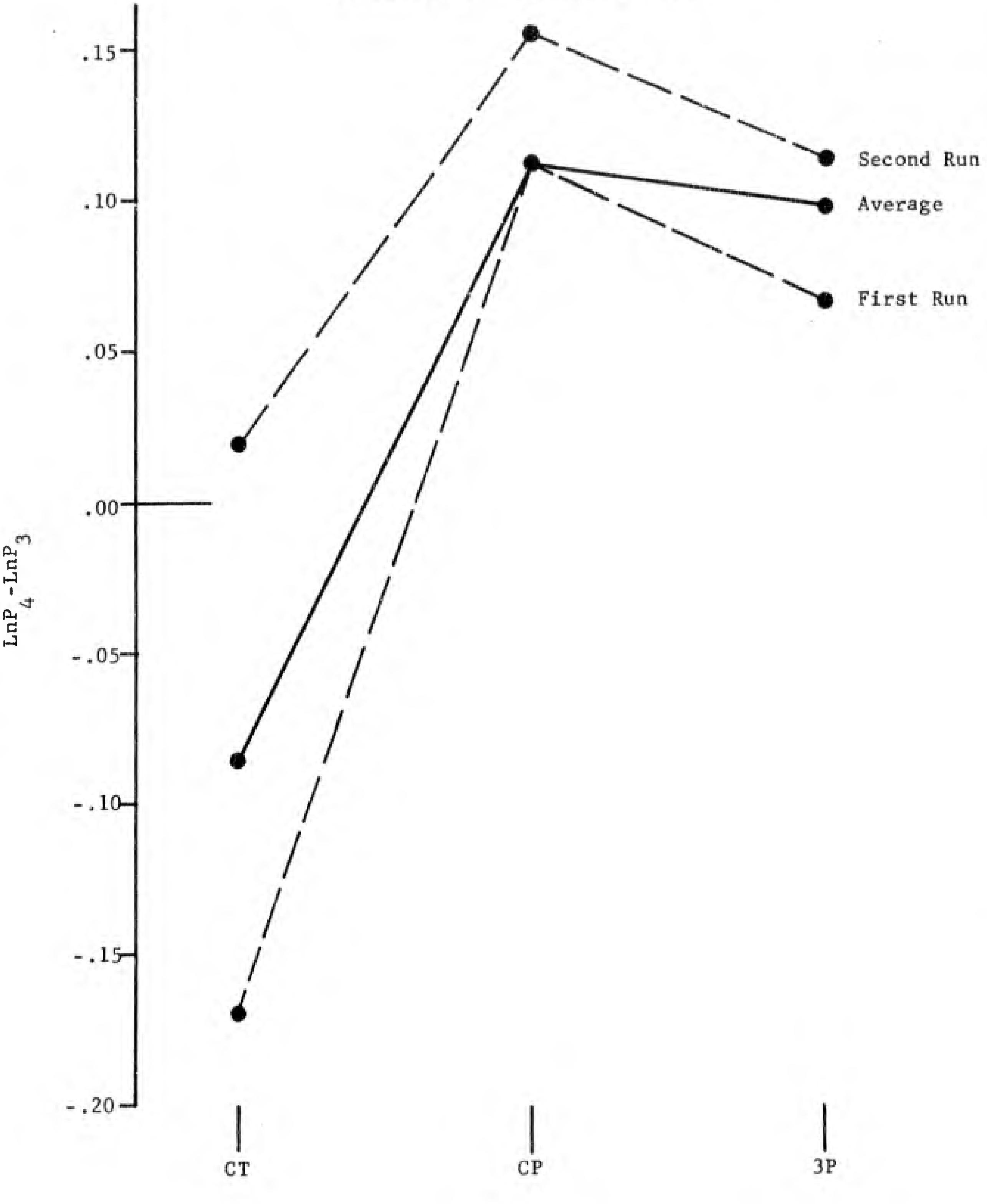


Figure 7

FIGURE 8

LnP_4-LnP_3 values for the AEP late positive component (LPC) to Stimulus 2 in Condition II for the counter (CT), counter pointer (CP) and three pointer (3P) altimeter displays. The average for the two replicated runs is plotted along with the runs.

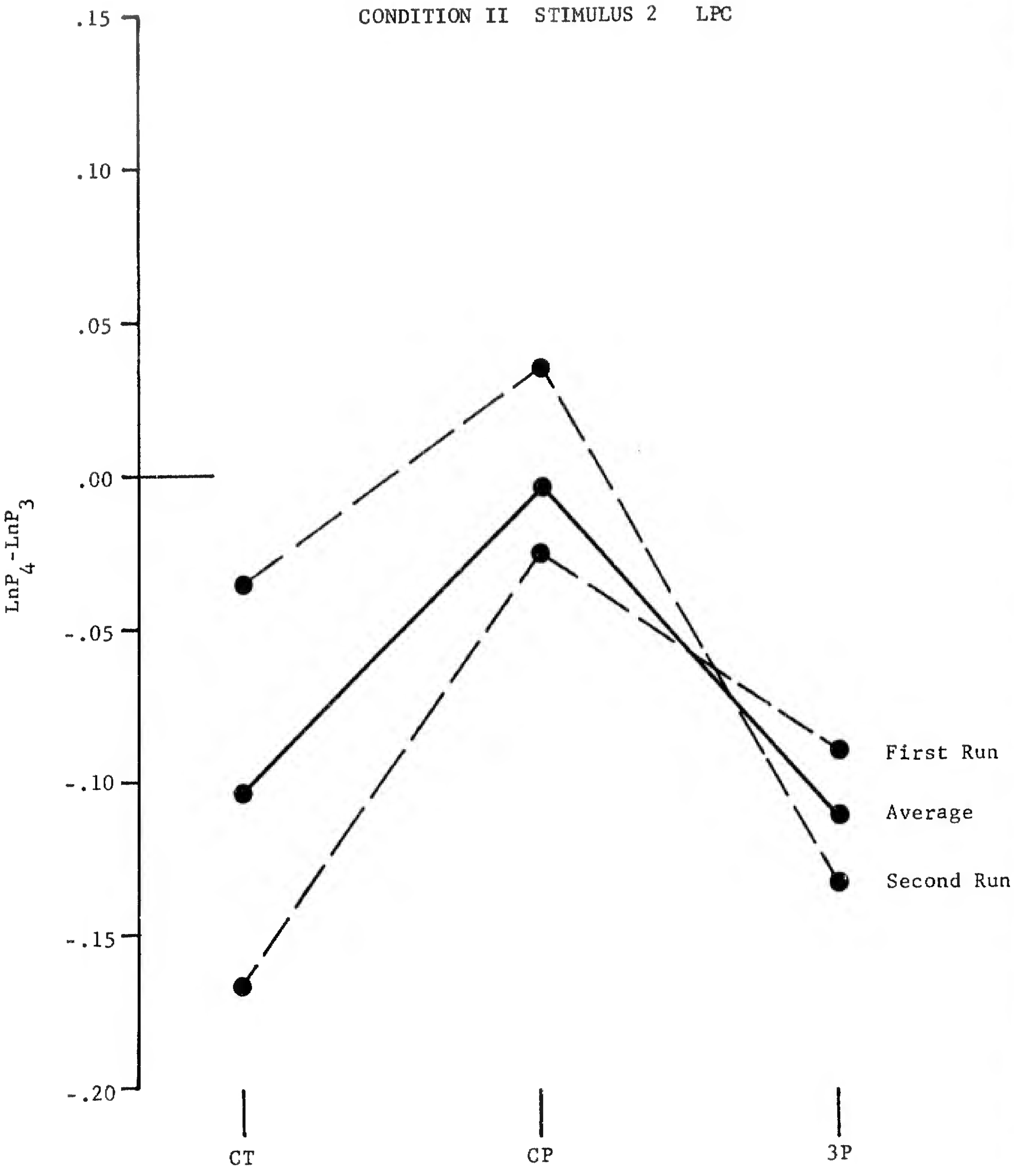

CONDITION II STIMULUS 2 LPC
.15
.10
.05
.00
-.05
-.10
-.15
-.20
$LnP_4 - LnP_3$
First Run
Average
Second Run
CT
CP
3P

Figure 8

Stimulus 1 and Stimulus 2 in Condition II. While the average (P_4-P_3) amplitude measures and the LnP_4-LnP_3 values suggest a possible right-more-positive difference for the CP and 3P versus the CT altimeter for Stimulus 1, neither the Stimulus 1 ($F(2,30) = 2.47$) or Stimulus 2 ($F(2,30) = 2.28$) average LnP_4-LnP_3 values are significantly different, again due to across subject variability.

There appears to be a shift in the AEP interhemispheric asymmetry from Stimulus 1 to Stimulus 2 for Condition II. The LnP_4-LnP_3 values were statistically tested for Stimulus 1 versus Stimulus 2 for the CT ($F(1,15) = .11$), CP ($F(1,15) = 1.18$) and the 3P ($F(1,15) = 11.47$, $P < .005$) altimeters, indicating that only the values for the 3P altimeter are significantly different. The average LnP_4-LnP_3 values for Stimulus 2 for the 3P altimeter are negative. Apparently for Stimulus 2 the average AEP interhemispheric laterality difference for the 3P altimeter is a left-more-positive effect, at least in comparison to Stimulus 1.

EOG Measures

Tables 5 and 6 present the vertical (V) and horizontal (H) EOG measures for the three altimeter types and the three measurement segments averaged across subjects, and then across the three runs for Condition I or two runs for Condition II. Both the EOGV and EOGH measures indicated consistently smaller AEP amplitude in the area around the eyes than at the vertex or parietal EEG electrodes. Most of the average EOG measures were substantially smaller than

TABLE 5

Condition I AEP amplitude data (in µv) and latency (in msec) for the vertical (V) and horizontal (H) EOG channels at the three measurement segments; the late positive component (LPC), the early positive component (EPC) and the very late positive component (VLPC). The average amplitude and latency is an average across subjects for each run, and then across the three replicated runs. The standard deviation (SD) is an average of the three SD's for the three runs.

TABLE 5

CONDITION I EOG AEP MEASURES

		Amplitude (µv)						Latency (msec)					
		CT		CP		3P		CT		CP		3P	
		V	H	V	H	V	H	V	H	V	H	V	H
LPC	Ave.	4.9	-.3	6.7	2.3	2.3	2.7	394	394	381	381	383	383
	SD	10.01	5.63	9.26	7.41	9.99	3.41	47	47	46	46	37	37
EPC	Ave.	3.7	-2.5	4.4	1.4	5.8	-.3	197	197	189	189	199	199
	SD	4.28	4.28	4.21	4.39	6.43	2.60	34	34	31	31	33	33
VLPC	Ave.	-4.9	5.5	-4.2	11.2	0.8	4.5	591	591	588	588	585	585
	SD	12.92	8.03	11.54	9.68	13.85	5.60	49	49	51	51	55	55

TABLE 6

Condition II EOG amplitude (in µv) and latency (in msec) data for the AEP late positive component (LPC) evoked by Stimulus 1 and Stimulus 2 in the vertical (V) and horizontal (H) EOG channels. The average amplitude, and latency is an average across subjects for each run, and then across the two replicated runs. The standard deviation (SD) is an average of the two SD's for the two runs.

TABLE 6

CONDITION II EOG AEP MEASURES

		Amplitude (µv)						Latency (msec)					
		CT		CP		3P		CT		CP		3P	
		V	H	V	H	V	H	V	H	V	H	V	H
Stimulus 1 LPC	Ave.	4.2	0.3	5.8	-.5	6.6	2.2	384	384	370	370	370	370
	SD	5.28	4.88	5.62	8.04	5.92	2.27	44	44	44	44	37	37
Stimulus 2 LPC	Ave.	7.5	0.6	6.2	3.7	9.2	-.4	394	394	400	400	396	396
	SD	9.20	3.22	9.64	6.62	12.40	3.92	32	32	34	34	42	42

their corresponding EEG measures. Also, the variability of the EOG data (SD) relative to the mean amplitudes was much greater than for the EEG data. In 16 out of 18 instances for Condition I and 10 out of 12 instances for Condition II the EOG amplitude SD's were even greater than the average amplitudes. No consistent trends were observed in the EOG data except that the EOGH measures were in most cases smaller than the EOGV measures, further reducing any case for EOG contamination of the EEG laterality data. The EOG data might be viewed as portraying noisey or poor quality EEG data, which have been recorded from electrodes that are distant from the active brain site and are contaminated by EOG artifacts. The EOGH LPC amplitudes were averaged across the three runs for Condition I and were not found to be significantly different across subjects between the three altimeter display types ($F(2,30) = 2.79$).

Hemispheric Dominance Data

Table 7 presents the results of the various indicators of brain dominance which were used. The individual subjects are arranged in order of decreasing AEP laterality composite scores for Condition I. The AEP laterality composite scores were determined by averaging the LnP_4-LnP_3 amplitudes for the CP and 3P for the Condition I LPC and subtracting the CT LnP_4-LnP_3 amplitude ((CP (LnP_4-LnP_3) + 3P(LnP_4-LnP_3))/2 - CT(LnP_4-LnP_3)). The right handed column indicates whether the subjects considered themselves to be strongly or moderately right handed, with a moderate report

TABLE 7

Subjects' scores on the various indicators of hemispheric dominance. The subjects are arranged in order of decreasing AEP laterality composite score. The derivation and scoring of the various indicators and composite scores are explained in the text.

TABLE 7

HEMISPHERIC DOMINANCE DATA

Subject Order	Right Handed	Crovitz & Zener	Benton	Torque Test	Eye Dominance	Indicators Composite Score	AEP Laterality Composite Score
1.	S	14	0	3	R	17	.430
2.	S	15	2	0	R	17	.336
3.	M	24	1	0	R	26	.270
4.	M	25	3	0	R	29	.250
5.	S	16	1	3	R	20	.180
6.	S	16	2	3	R	21	.176
7.	S	17	0	0	R	17	.160
8.	S	14	0	0	L	16	.090
9.	S	16	6	3	L	27	.072
10.	S	17	0	3	R	20	.048
11.	S	17	0	3	R	20	.036
12.	S	20	4	0	R	24	-.010
13.	S	17	0	3	R	20	-.015
14.	S	18	3	3	R	24	-.034
15.	S	19	1	0	R	20	-.034
16.	S	22	4	3	?	30	-.053
Composite Score Contribution	0,1	Abs.	Abs.	Abs.	0,1,2	------	---------

contributing one point to the indicators composite score. The Crovitz and Zener scores were tallied according to their procedure (1962). Benton's handedness inventory did not include a numerical scoring key, so the experimenter assigned one point for answers in the "both" column and two points for each answer in the "left" column. The Torque Test was scored according to Blau's procedure (1974). Findings of left eye dominance contributed two points to the indicators composite score. For the one subject unable to determine his eye dominance a one was contributed to his composite score.

Pearson r correlation coefficients were determined between the Crovitz and Zener scores and the AEP laterality composite scores (r = -.13), and the indicators composite scores and the AEP laterality composite scores (r = -.27). Apparently the other indicators of hemispheric dominance did contribute additional information to the Crovitz and Zener scores, but the correlation coefficient (-.27) is still rather low as the variance in the composite indicator scores will only account for 7% of the variance in the AEP laterality composite scores. Due to the restricted range of this data, the use of left handed subjects also would possibly have increased this correlation coefficient.

DISCUSSION

The significant differences between the LPC's for the three types of altimeters in Condition I supported the initial experimental hypothesis that the LPC would be larger over the right hemisphere relative to the left hemisphere for the more spatial altimeter displays. The EPC and VLPC were also measured because it seemed appropriate to impose some temporal limits on which AEP components were compared across subjects. The LPC was not always the largest positive peak for any individual subject. Sometimes the EPC or VLPC was larger. Adopting a criterion of measuring only the largest positive AEP component would have resulted in too much latency variability between subjects. Therefore, it was decided to adopt a measurement technique which incorporated both the classical concepts of distinct evoked potential components such as the P2 (P200) and P_3 (P300) components (Picton et al, 1974; Regan, 1972) as well as more rigid latency measurement points such as those used by Chapman (1973).

The existence of separate peaks and troughs in the AEP does not guarantee that there are separate underlying neuronal processes for each peak and trough. Chapman (1973) and Chapman et al (1975) have taken a multivariate statistical approach to the analysis of AEP data resulting in the identification of 15 orthogonal components. Eight of the components together accounted for 96.4% of the total original variance. Components 1 and 2 were similar to the contingent negative variation (CNV) and the P300 in time course and response to experimental conditions. Chapman reported that component 2 (P300) did incorporate a high percentage of the variance of the data and it was a prominent, strong, late component which would affect any overall measure of evoked potential amplitude. It certainly seems possible that the LPC in the present study also affected the evoked potential measures at the EPC and VLPC.

Other separate processes probably also occurred at the early and very late time segments. The EPC seems to be more variable in general. Donald (1973) has reported large fluctuations in the P200 at the vertex as subjects became highly overpracticed. The VLPC for the CT and CP may be contaminated with articulatory artifacts such as the glossokinetic potentials (Klass and Bickford, 1960) and other artifacts related to vocalization (Grozinger et al, 1973, 1975), since the average onset to verbal response was 641 msec for the CT and 604 msec for the CP. However, the average onset to verbalization was 1596 msec for the 3P altimeter making verbalization onset quite distant from the VLPC segment.

The VLPC occurs at a time when motoric and glossokinetic artifacts are quite likely for the CT and CP, and it is not significantly different across altimeter display types. This makes it difficult to postulate that articulatory artifacts are a source of the LPC laterality effects observed between the CT and CP. The greatly different CP and 3P verbal RT's further discount such an hypothesis. Finally, lateralized pickup by symmetrically placed electrodes is not expected to result from the articulatory musculature or the centrally located tongue (glossokinetic potentials).

The CP display differs from the CT by only one number which is represented by a pointer and dial. Apparently the inclusion of the pointer and dial is quite sufficient to produce a greater right-more-positive effect for the CP than the CT. Since the left hemispheric linguistic functions of the brain would be required for a verbal response to all three altimeters the greater right-more-positive effect for the CP and 3P altimeters is probably due to increased utilization of spatial information processing functions in the right hemisphere. If the right hemisphere is more greatly used for the CP altimeter, such contiguous use of both hemispheres for the CP might explain the apparent superiority of the CP versus the CT altimeter in terms of shorter verbal response RT's and subjective reports of greater ease in reading the CP altimeter.

A behavioral study by Yeni-Komshian et al (1975), of hemispheric function versus reading skill, may provide additional information for the interpretation of the CP superiority over the CT altimeter. Behavioral tests of laterality of hemispheric function were studied in good and poor readers enrolled in grades five through seven. The poor readers were more lateralized than the good readers on tests employing visual half field presentations of numbers and words. That is, the poor readers made a significantly larger number of errors for words and numbers in the left visual half-field (right hemisphere) than the good readers. This effect was even larger for numbers than for words. Apparently the right hemisphere may contribute to the superior reading performance of the good readers. Possibly this right hemispheric contribution to reading performance is similar to the contributions of the right hemisphere in contributing to the readability superiority of the CP altimeter over the CT altimeter.

Following the above interpretation, the greater difficulty in reading the 3P altimeter would have to be explained in terms of requiring eye movements and visual sorting of the three numbers read from the three pointers, plus some type of correct ordering of the numbers read from the three pointers. The shorter 3P response latencies and lack of eye movements for Condition II do support the hypothesis that visual sorting of pointers via eye movements is a major factor in the time consumed during quantitative reading of the 3P altimeter. In Condition II the subjects reported that they judged whether Stimulus 1 and 2 were the same or different for the 3P altimeter by using the entire visual pattern of the pointers without attending to the numbers. In Condition I, however, it was necessary to attend to the individual pointers one at a time in order to read the numbers in the correct order. It is of course not possible to prove from my data that the subjects actually fixated on each pointer of the 3P altimeter while reading it. More sensitive eye-point-of-regard techniques would be required for that purpose.

Preliminary behavioral pilot studies indicated that for short exposures (less than 400 msec) the verbal response RT was shorter for reading the entire CP display than for just one pointer (10,000's) of the 3P display, also suggesting a visual sorting requirement for the 3P but not for the CP altimeter.

While the correct ordering of the three digits is fairly rigidly structured for the CT and CP altimeters, the 3P digits appear to be read one at a time allowing for interposition of digits in short term memory before the verbal response is executed. Maintaining the correct order of these digits prior to the execution of the long latency verbal response probably ties up additional information processing capabilities. Possibly this factor could be better understood through studies forcing much higher error rates, by such methods as greatly reduced display exposure time.

The AEP's for Condition II were only measured for the LPC segment because these AEP's often did not have prominent EPC's and VLPC's, and because the right-more-positive effect for Condition I was only found for the LPC. The reason for the lack of a significant right-more-positive effect between the different altimeter displays for Condition II is not readily apparent. The greater variability of the RT's for Condition II and the introspective reports of the subjects may indicate a lack of consistency in the manner in which the subjects processed the stimulus information for Condition II.

Using purely behavioral techniques of hemifield visual presentation, Dee and Fontenot (1973) have reported that a statistically significant left visual field superiority for complex random forms only occured if a memory interval of 10 or 20 seconds was used.

Memory intervals of zero or five seconds did not produce a significant difference. Dee and Fontenot concluded that possibly the right hemisphere is specialized for spatial mnemonic functions rather than for purely perceptual processes. They suggested that such spatial mnemonic functions were probably not adequately taxed with their shorter memory intervals, while the perceptual differences did still exist at the short intervals.

Dee and Fontenot's memory interval was comparable to the ISI in Condition II, in that it was the time between a brief presentation of a test stimulus and the longer presentation of a target or an incorrect (same or different) stimulus to which the subject was required to respond either same or different. Since the present experiment only used two second ISI's it may not have sufficiently loaded memory processes to produce a laterality effect between altimeter displays. Preliminary pilot studies however, indicated that a longer ISI would have been more tedious and boring for the subjects. Many subjects found Condition II to be somewhat tedious and boring even with only the two second ISI. Thus, a longer ISI would probably have required the use of secondary tasks during the ISI in order to maintain the subject's interest and vigilance.

White and White (1975) also used both hands to indicate same or different responses in a behavioral study employing visual hemifield stimuli. Half of the subjects used both index fingers to make a same response and both middle fingers to make a different response, while the other half of the subjects used both index fingers for different and both middle fingers for same. In this study groups of two to four geometric or letter stimuli were presented to either the left or right visual hemifield and the subjects were required to indicate whether the stimuli were all the same, or were different. Both the geometric and the letter stimuli produced significantly faster reaction times when they were directed to the right hemisphere (left visual field) rather than to the left hemisphere. The RT's did not increase with increasing number of stimuli. White and White concluded that possibly the hemispheric effect was somehow tied up with response and pattern configuration effects which preempted any effects due to the type of stimulus employed. For example, the subjects may have been using nominal matching for the letters to the left hemisphere and pattern matching for the letters to the right hemisphere. This study provides further evidence of the various hidden complexities in experimental Condition II.

In Condition II, the significant difference between the Stimulus 1 and Stimulus 2 LnP_4-LnP_3 values for the 3P altimeter suggests a shift in the laterality of hemispheric processing for the two stimuli, as indicated by this AEP concomitant of hemispheric function. Possibly the 3P Stimulus 1 requires spatial mnemonic functions in the right hemisphere in accordance with Dee and Fontenot's (1973) hypothesis of such a right hemispheric specialization for spatial stimuli. But, Stimulus 2 requires comparator functions which may be more localized in the left hemisphere as hypothesized by Buchbaum and Fedio (1969, 1970). The average LnP_4-LnP_3 values for the CT altimeter suggest no such laterality shift between Stimulus 1 and Stimulus 2. The average LnP_4-LnP_3 values for the CP altimeter suggest a small shift but it is not statistically significant. Possibly such a shift for the CP is attenuated by the counter digits which might, for many subjects, already be processed primarily in the left hemisphere for Stimulus 1. Since the three altimeter display LPC LnP_4-LnP_3 values were not significantly different between altimeter displays for Stimulus 1 or 2, this interpretation might be plausible for the CP. Otherwise, it would seem necessary to postulate that the CP Stimulus 2 information is processed more by right hemispheric mechanisms than is the 3P Stimulus 2 information.

It is apparent that, in terms of human information processing, Condition II is not a concise easily defined task. Condition I requires a complex verbal response in contrast to the simple motoric response of Condition II, but fewer options for and less variability in human information processing may actually have occurred in Condition I. The significantly shorter RT's and SD's for the CT and CP in Condition I versus Condition II tend to indicate that at least the initial information processing was quicker and less variable for Condition I.

Condition II also may not be a completely accurate operational definition of the pilot's task while briefly scanning the instruments. In the pilot's task, each glance at the altimeter represents both a Stimulus 2 in terms of the previous glance and a Stimulus 1 in terms of the next glance. Condition II completely separates Stimulus 1 and 2. Perhaps a study involving a succession of altimeter displays with a same/different judgment being required for each one, in terms of the previous display, would provide a more accurate comparison to the pilot's task. Possibly this same criticism concerning applicability should also be directed at many of the reaction time studies in the literature which have used same/different judgements for pairs of stimuli. A more complete understanding of my Condition II results would certainly seem to require an experiment employing a string of successive altimeter display stimuli.

More statistically sophisticated approaches to evoked potential analysis, based on such multivariate statistical analysis procedures as those of Chapman (1973) and Chapman et al (1975), should be more effective than measures of peak amplitude alone in the more reliable dissection of future electrophysiological data. If such electrophysiological techniques are also used in conjunction with more sensitive technologies for tracking eye movements, such as the infrared photo-electric techniques of Gauthier and Volle (1975), then the ability to pursue dynamic human information processing should be greatly enhanced. The flexibility of, and the ability to change future computer driven electronic displays rapidly will require that human factors engineers use just such electrophysiological and eye movement techniques to pursue and optimize dynamic human information processing.

In conclusion, this study has produced significant electrophysiological results indicating that the dial type altimeter displays (CP and 3P) evoke greater right hemisphere AEP amplitude in a reading task. This AEP effect occurs in a latency period which has been related to a variety of perceptual and information processing constructs by a variety of researchers. Assuming that this greater right hemispheric AEP LPC amplitude is indeed indicative of greater involvement of that hemisphere in the neuronal information processing related to the task, then the small but significant superiority of the CP versus the CT altimeter is probably due to greater interhemispheric sharing of the total information processing load. Future attempts to optimize dynamic highly flexible man-machine information displays will probably find such subtle but moment to moment information processing effects to be important in the total dynamic optimization of the human information processing requirements.

SUMMARY

During the reading of the three altimeter displays in Condition I there was a significantly larger late positive component LnP_4-LnP_3 value for the CP and 3P displays than for the CT display. This greater right-more-positive effect was interpreted as an evoked potential concomitant of greater right hemisphere functional involvement in the processing of the CP and 3P altimeter information than the CT altimeter information.

The average verbal response latency was more than twice as long for the 3P (1596 msec) than for the CT (641 msec) or CP (604 msec) displays, with the CP having a significantly shorter reaction time (RT) than the CT display. Most subjects also reported that the CP was easier to read than the CT altimeter. The superiority of the CP over the CT altimeter was interpreted as an information processing facilitation possibly due to greater involvement of the right hemisphere in processing the CP display.

Neither the LPC LnP_4-LnP_3 values or the behavioral RT's were significantly different between the altimeter displays for Stimulus 1 or Stimulus 2 in Condition II. However, the LPC LnP_4-LnP_3 values were significantly different between Stimulus 1 and 2 for the 3P altimeter in Condition II. This was interpreted as a possible indication that Stimulus 1 is initially processed more by spatial mnemonic functions in the right hemisphere than Stimulus 2 is for the 3P display. And, that possibly Stimulus 2 is processed more by comparator functions in the left hemisphere than Stimulus 1 is for the 3P altimeter.

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APPENDIX

Counter Altimeter Settings in Order of Presentation During Testing

	Condition			Condition	
	I	II		I	II
1.	015	015	41.	513	605
2.	268	058	42.	082	172
3.	430	430	43.	184	184
4.	841	741	44.	370	279
5.	058	158	45.	823	823
6.	962	962	46.	759	670
7.	839	839	47.	921	921
8.	856	765	48.	291	391
9.	659	759	49.	423	423
10.	741	732	50.	209	209
11.	624	624	51.	724	841
12.	324	342	52.	605	504
13.	481	481	53.	534	534
14.	635	635	54.	342	345
15.	603	603	55.	568	469
16.	172	074	56.	018	108
17.	961	961	57.	870	870
18.	132	132	58.	301	201
19.	560	659	59.	083	082
20.	452	452	60.	253	254
21.	904	904	61.	780	780
22.	180	018	62.	825	825
23.	236	236	63.	316	406
24.	723	724	64.	936	936
25.	305	305	65.	036	036
26.	648	648	66.	802	802
27.	143	143	67.	254	324
28.	539	539	68.	213	213
29.	158	268	69.	391	301
30.	621	621	70.	034	034
31.	415	316	71.	579	568
32.	715	715	72.	472	472
33.	389	370	73.	124	124
34.	918	918	74.	489	579
35.	074	063	75.	854	945
36.	108	180	76.	504	513
37.	765	865	77.	930	930
38.	689	560	78.	201	291
39.	586	586	79.	953	854
40.	783	783	80.	450	450

Counter Pointer Altimeter Settings in Order of Presentation During Testing

	Condition	
	I	II
1.	648	648
2.	841	741
3.	918	918
4.	741	732
5.	603	603
6.	715	715
7.	253	254
8.	415	316
9.	534	534
10.	184	184
11.	724	841
12.	504	513
13.	108	180
14.	605	504
15.	452	452
16.	854	945
17.	586	586
18.	324	342
19.	723	724
20.	659	759
21.	209	209
22.	316	406
23.	201	291
24.	481	481
25.	780	780
26.	489	579
27.	539	539
28.	839	839
29.	936	936
30.	389	370
31.	759	670
32.	802	802
33.	472	472
34.	172	074
35.	823	823
36.	083	082
37.	430	430
38.	579	568
39.	635	635
40.	450	450
41.	034	034
42.	082	172
43.	213	213
44.	268	058
45.	305	305
46.	921	921
47.	856	765
48.	621	621
49.	825	825
50.	689	689
51.	058	158
52.	930	930
53.	870	870
54.	036	036
55.	158	268
56.	143	143
57.	513	605
58.	953	854
59.	765	865
60.	015	015
61.	074	063
62.	236	236
63.	391	301
64.	254	324
65.	904	904
66.	018	108
67.	568	469
68.	962	962
69.	180	018
70.	783	783
71.	124	124
72.	291	391
73.	961	961
74.	301	201
75.	132	132
76.	560	659
77.	624	624
78.	423	423
79.	342	345
80.	370	279

Three Pointer Altimeter Settings in Order of Presentation During Testing

	Condition	
	I	II
1.	268	058
2.	605	504
3.	481	481
4.	823	823
5.	172	074
6.	870	870
7.	472	472
8.	316	406
9.	083	082
10.	513	605
11.	132	132
12.	254	324
13.	854	945
14.	568	469
15.	621	621
16.	074	063
17.	741	732
18.	921	921
19.	415	316
20.	143	143
21.	058	158
22.	184	184
23.	180	018
24.	936	936
25.	082	172
26.	659	759
27.	158	268
28.	034	034
29.	108	180
30.	534	534
31.	539	539
32.	783	783
33.	953	854
34.	715	715
35.	253	254
36.	765	865
37.	301	201
38.	648	648
39.	918	918
40.	015	015
41.	370	279
42.	430	430
43.	213	213
44.	825	825
45.	389	370
46.	423	423
47.	018	108
48.	839	839
49.	305	305
50.	391	301
51.	579	568
52.	856	765
53.	036	036
54.	624	624
55.	930	930
56.	841	741
57.	124	124
58.	291	391
59.	802	802
60.	689	560
61.	780	780
62.	209	209
63.	489	579
64.	724	841
65.	586	586
66.	560	659
67.	324	342
68.	450	450
69.	962	962
70.	635	635
71.	342	345
72.	961	961
73.	504	513
74.	759	670
75.	201	291
76.	904	904
77.	236	236
78.	452	452
79.	603	603
80.	723	724