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ANALYTICAL COMPARISON OF TRANSIENT AND STEADY STATE VISUAL EVOKED CORTICAL POTENTIALS.

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To better describe the linear-dynamic properties of the human visual-cortical response system, transient and steady state Visual Evoked Response Potentials (VERP) were observed. The stimulus presentation device provided both the evoking stimulus (flickering or pulsing lights) and a video task display. The steady state stimulus was modulated by a complex, ten frequency, sum-of-sines, wave. The transient VERP was the time-locked average of the EEG to a series of narrow light pulses (pulse width of 10 msec). The Fourier transform of the averaged pulses had properties that approximate band limited white noise, i.e. a flat spectrum over the frequency region spanned by the 10 summed sines. The Fourier transform of both the steady state and the transient evoked potentials resulted in transfer functions that are equivalent and therefore comparable. To investigate the effects of task loading on evoked potentials, a grammatical reasoning task was provided. Results support the relevancy of continued application of a systems engineering approach for describing neurosensory functioning.

INTRODUCTION

A new methodology for analyzing and interpreting the dynamics of the brain's response system based upon sum of sines (SOS) stimulation and systems engineering analysis has been developed (Junker and Peio, 1984). This technology requires that the system being studied possess a significant degree of linearity for the measure to be of descriptive value. The question of linearity is considered in this paper by comparing systemic responses to two types of stimulation.

One of the greatest challenges in examining the brain's electrical potentials is the low signal to noise ratio. Evoked responses are so small in comparison to the background electrical activity of the brain that a method for enhancing the signal to noise ratio must be decided upon. There are two well developed techniques for accomplishing this. Steady state evoked response potentials (SSERP) are based on the frequency following phenomenon in the human response system. Using a repeating stimulus successive ERP's are elicited. It has been shown that the elicited response contains the repeating frequency of the stimulus. The brain does not have a chance to regain its resting, undisturbed state (Regan, 1973, 1975, 1979). With the aid of the Fast Fourier Transform (FFT) it can be demonstrated that the ERP is at exactly the same frequency as the stimulus. The other method, transient ERP, is based on " hitting" the system, with a pulse or a click, and then measuring the electrical potential. Each response to the pulse is considered a transient response. The amplitude of the transient response can be measured and then a series of responses can be averaged together. This is a time-locked average, that assumes the response always occurs at the same time relative to stimulus onset.

In the field of automatic control systems technology, an input/output relationship for the linear portion of a nonlinear system is defined as a describing function (Kochenburger, 1950). Manipulations of the FFT's of the response potential (output) and evoking stimulus (input) yield a describing function that is a complex measure of the output/input relationship of this sensory-response system (for a detailed description of guidlines for analysis of frequency response data see Levison, 1983). Prior to the development of the ten sine wave stimulation technique (Junker and Peio, 1984) most measurements were made with single sine waves, or at most three sine waves simultaneously (Regan, 1973, Wilson, 1979 and Wilson and O'Donnell, 1981). Construction of comprehensive describing functions were not often undertaken, and there is no data available from researchers showing task loading effects across a broad range of frequencies. Perhaps for this reason no one has taken on the task, until this time, of exploring the actual relationship between steady state and transient VER potentials. Regan (1979) stated that, "For a linear system the transient response has a fixed relationship to the steady-state response. Consequently, transient and steady state descriptions of a linear system's behavior are equivalent and can be regarded as alternative formulations of the same data...therefore, transient and steady- state stimulation can produce responses that provide complimentary information about the sensory system under test." Using our existing stimulus apparatus and computer generating capability, we incorporated into the system the ability to: accurately generate a narrow pulse stimulus, collect and time-lock average the data, FFT the results and compute describing functions from the transforms. These describing functions were used for comparison with steady state describing functions. This analysis has been applied to ERP's in taskloading (workload) and non-taskloading conditions. The task used was grammatical reasoning. This task was selected because it is highly engaging and it only requires a minimal of motor response. An explanation of the stimulation device, EEG data collection, and sum of sines methodology is presented in this paper. In addition the cognitive loading task, the transient stimulation methodology, the transient results, and comparisons between transient and steady state describing functons are given.

METHODS

Apparatus

The test chamber simultaneously delivers the evoking stimulus (flickering lights) and a video task display (Figure 1). This presentation was achieved by combining the two images via an 18 cm x 26 cm half-silvered mirror at 45 degrees to the two images. The evoking stimulus was produced by two 26 cm xenon/fluorescent light tubes hung horizontally 5 cm apart and mounted 4 cm behind a 25 cm x 27 cm transluscent, diffusing screen; which distributed the light, as evenly as possible, over the visual field. The average intensity of the lights were 40 FL, as measured, by a United Detector,model PIN 10D, high speed photo cell, placed at the subject's viewing point. This average intensity was sufficiently low such that a subject could still comfortably discern the video task-display within the same visual field. The video task was displayed on an Audiometrix 11 in x 11 in video monitor.

Beckman silver/silver chloride electrodes were used with the Grass model P511 AC amplifiers, with amplification x50,000 and bandpass of 0.1 to 300 Hz, to record the EEG. The sum-of-sines (SOS) wave and transient pulse were generated, and data collected, on a Digital Equipment Corp.(DEC) PDP 11/60 computer. Signals from the 11/60 were low pass filtered on a Krohn-Hite model 3750 filter (cut off at 40 hz) and then fed into a Scientific Prototype, model GB, tachistiscope/light driver, which was modified so that average intensity and depth of modulation could be adjusted. The grammatical reasoning task was generated by a Commodore model VIC computer. The software and the response-box hardware, for this task, were developed by Systems Research Laboratories Inc. The two channels of data (photo cell and EEG) were fed through General Radio low pass filters (cut off at 25 Hz) to prevent high frequency aliasing. The filtered signals were then digitized and stored for analysis on the PDP 11/60. The collected data was fast fourier transformed, ensemble averaged and plotted using a DEC PDP 11/34 computer and a Printronix model P300 printer.

Stimulus

To better elucidate the linear properties of the visual-cortical response system the experiment was designed to collect describing function measures with different forms of inputs. The modulated light served as the driving stimulus. For steady state stimulation the lights were modulated using a complex SOS wave composed of 10 harmonically non-related frequencies. All 10 of the frequencies were multiples of the fundamental frequency of 0.0244 hz. The component frequencies range from approximately 6.25 to 21.75 Hz, with intermediate frequencies at 7.75, 9.50, 11.50, 13.25, 14.75, 16.50, 18.25, and 20.25 Hz. None of these component frequencies contained a sum or difference of any of the other component frequencies; this restriction on sine wave selection was implemented to avoid the possible corruptions at the selected frequencies by nonlinearities of the flickering light generator and possible nonlinear evoked potential responses. Appropriate input selection insured that nonlinear harmonic effects would not occur at the component frequencies.

For every data collecting trial the starting phase values for each of the 10 component sine waves were randomized with a uniform random number generator, insuring that the time sequence of flickering light presentation was random from trial to trial. By utilizing randomized phase with the summing of the 10 sinusoids a maximum depth of modulation of 13%, per sinusoid was possible. The lights were sinusoidally modulated about an average luminance of 40 ft-lamberts. Previous work (Junker and Peio, 1984) had shown 6.5% to be sufficient for obtaining VER's. Regan and Beverley (1973) in looking at the effects of the percent depth of modulation on the VER demonstrated a straight line relationship between VER volts and percent depth of modulation over a limited range (10% to 30%) of modulation. Over 30% a saturation-like effect occurred indicating nonlinear behavior in the VER data. Thus our stimulus depth of modulation minimized nonlinear overdriving while still assuring an adequate VER.

For comparison purposes we created our transient stimulus to have power spectral properties similar to the spectral properties of the sum of sines stimulus. The sum of sines consisted of 10 sine waves ranging from 6.25 to 21.75 Hz, with equal power for each of the component sinusoids. The power spectrum of the transient pulse was adjusted to have a flat spectrum over the same frequency range. The transient stimulus was a narrow (.01 sec duration) computer generated pulse driven through the low pass filter and fed into our light driving circuit. Interstimulus time was varied between 1.28 and 1.38 sec, the variability (0 to 0.1 sec) was generated with a uniform random number generator for each stimulation segment. One run, or trial, consisted of 40 stimulus segments.

Task

The task loading condition used was the grammatical reasoning task from the Criterion Task Set (Shingledecker, et. al., 1983). This task is based on the original grammatical reasoning task developed by Baddeley (1968). The task is designed to impose variable processing demands on resources used for the manipulation of grammatical information. Stimulus items are two sentences of varying syntactic structure accompanied by sets of three symbols. The sentences must be analyzed to determine whether they correctly describe the ordering of the characters in the symbol set. This version used two sentence items worded either actively/negatively or passively/positively and described three symbols. This was considered the high demand level. The object for the subject was to determine whether both sentences match in their correctness. If both sentences correctly described the ordering of the three symbols, or if neither correctly described the symbols, the appropriate response was positive. If one sentence was correct but the other was not the appropriate response was negative. There was a 7.5 sec time limit for responding. Binary responses were entered manually on two labeled keys, of a four button keypad, placed on the right arm of the subject's chair.

Procedure

Subjects were seated in a darkened IAC chamber facing a 15 cm x 15 cm window. Behind the window was the stimulus presentation device. For the lights only condition the subjects were instructed to "relax and fixate on a small square at the center of the display", for the cognitive loading condition the subjects were instructed to concentrate on the task. Each trial lasted 82 sec. and after every three trials the experimenter entered the booth to inquire about the status of the subject (alertness, fatigue etc); every sixth trial the subjects were given a 3-6 min. break. Sessions were either 12 or 18 trials long. Subjects were advised that the session could be terminated at any time upon their request.

Transient data was collected from subjects at the end of the same sessions in which steady state data was collected. Data was collected for four trials of lights only (no task load) and then for four trials in which subjects performed the grammatical reasoning task (task loading).

Analysis

Manipulations of the fast fourier transforms of the photo cell signal (input) and the evoked response potential signal (output) yields a describing function which is a complex measure of the output-input relationship of this system. The focus of this project was on the amplitude ratio and the phase angle measures obtained from these computations.

For SOS stimulation we were interested in estimates of mean values for the gain and phase computations across replications. For indication of mean variability we calculated the standard error by computing the standard deviation across replications and dividing by the square root of the number of replications. If the data had been normally distributed these computations would have, in fact, been a measure of standard error.

For transient stimulation collected data was analyzed with a DEC 11/34 computer. Time lock averaging of each of the 40 segments for each trial was done first, then averaging across trials for each condition (4 trials per condition) was performed. Time responses were plotted for lights only and task loading conditions. In addition, time responses were Fast Fourier Transformed and describing function gain and phase values were computed. The describing functions were plotted, for comparison, with sum of sines generated describing functions.

Recording

Recording was done with Beckman silver/silver chloride electrodes at Oz, with linked mastoids as ground and reference according to the 10-20 International System. The resistance between the electrodes was less than 5 K ohms.

RESULTS and DISCUSSION

Time locked average responses to the pulse stimulus, for both lights only and task loading are presented in Fig 2 for four subjects. Strong effects from task loading, namely overall decreases in response peaks are present for subjects 02, 03, and 05. An opposite trend, a slight increase in response peaks with task loading, can be seen for subject 15. Typically time locked averaged data, such as this, is analyzed using component analysis techniques or principal factor analysis (Regan 1973, John et.al. 1973). It is possible to take this data a step further, into the frequency domain, by computing decribing functions as was done for steady state ERP data.

Corresponding describing function results are given in Fig 3. An important relationship to observe is the mapping between transient time average changes, related to task loading effects (from Fig 2) and corresponding describing function changes, in the frequency domain (Fig 3). Subjects 02, 03, and 05, who exhibited amplitude decrements in their average time responses with task loading, showed a concomitant decrease in describing function gain curves. It is interesting to note where the greatest gain changes occured. For subjects 02 and 05 these changes were in the lower frequency range (centered about the alpha frequency band, 10 Hz), while for subject 03 a reduction in gain, with task loading, occured within a higher frequency range (the beta band, 16 Hz). In contrast the gain curve for subject 15 showed an increase, with task loading, above and below 10 Hz with a noticable decrease at 10 Hz, corresponding to time averaged amplitude increases.

Results of task loading effects for the same four subjects, but with SOS stimulation, are shown in figure 4. Data plotted here represents the averages from six 40-second replications for each condition for each subject. Standard error about the mean is represented by the vertical lines at each data point on the plots. Referring to fig 4, properties of these curves to observe are the uniqueness or 'signature' of the pair of describing functions for each subject. For initial analysis applied to task-loading vs. no task-load conditions we have found the effects of task-load to be related to this signature. Subject 05 exhibits a large resonant peak at 10 Hz (alpha band), which decreases during task loading. There is a commensurate decrease in steepness of the phase curve about 10 Hz, indicating a reduction in resonance. This resonance reduction can be considered, in systems engineering terms, an increase in the damping coefficient of the dynamic system. Subject 02 also exhibits alpha band resonance properties. Unlike subject 05, however, there is an increase in gain at the higher frequency region (in the 14 Hz, beta band) with task-loading. Subject 03 shows beta band resonance and with task-loading exhibits a gain reduction in the resonance region, similar to subject 05, but in the beta band. Only minor effects from task loading were exhibited by subject 15, in terms of a slight increase in higher frequency sensitivity. Thus it seems that subjects that are alpha responders (subjects that show an alpha-band resonance, e.g. sub 05) show an alpha decrement. Nonalpha responders (those that lack the alpha resonance peak e.g., sub 15) tend not to show this alpha-band decrement with task loading.

Figure 5 shows, combined on each of the four plots, task and no task results for both transient stimulation and steady state stimulation. The thicker solid lines and the thicker dashed lines are the describing functions resulting from transient time averages (repeated from Fig 3). The circles and triangles represent the describing function values at each of the ten component frequencies from the SOS stimulation (from figure 4).

The correspondance between steady state and transient describing function curves is noteworthy. Describing functions for subject 05 show corresponding regions of peak gain sensitivity for transient and steady state stimulation and show similar gain reduction with task loading. Subject 03 shows similar changes across stimuli in the beta range of the gain curve. Thus for both subjects the effects due to task loading, as indicated by describing function changes, are much the same across stimulus conditions. Furthermore the phase curves have a similar shape, across stimuli and across task conditions for all subjects. The overall correspondance between describing function data for transient and steady state stimulation is remarkable for all four subjects.

One condition that seems to be significant, but the effect of which is not yet accounted for, is arousal level. This is suggested by the responses of subject 02. For the transient stimulus, time responses show a marked change between no load and task loading (fig 2) with a correspondingly significant change in the frequency domain in the alpha region (fig. 3). From this data we would conclude that with transient stimulation subject 02 is a strong alpha producer. Past results indicate that this subject is a strong alpha producer with steady state stimulation as well (see data for subject "RP" in Junker and Peio, 1984). Referring to fig. 5 for subject 02, however, this is not indicated by the steady state gain curves. In fact little change occurred in the alpha band with task loading. There was however an increase in steady state ERP gain sensitivity within the beta band. This subject's steady state ERP data with no task loading does not show the usual alpha band resonance (high gain) and has measures with large variability (indicated by standard error) which may be an indication of lowered level of arousal; i.e. high variability may be an indicator of lowered arousal. Further, given a condition of lowered arousal, it could be argued that task loading was sufficiently engaging to increase the subjects attention level to the task, as indicated by gain increase in the beta region. These hypotheses suggest that general arousal level and/or attention to a specific task may be observed seperately in ERP describing functions.

From working with both transient and steady state ERP's we have found it quite useful to use both stimulation techniques. As hypothesized by Regan, results do in fact compliment one another. Describing functions obtained by transient stimulation span a wide frequency range (0-50 Hz in this study). Thus they provide overall spectral response for modeling and provide clues to phase unwrapping beginning at 0 Hz. In contrast steady state stimulation provides the ability to concentrate stimulus at selected frequencies. As a result steady state stimulation yields ERP measures and background EEG simultaneously.

The most important point of our results, at this time, is the fact that the forms of the describing functions are remarkably similar across stimuli. From this we conclude that we are justified in continuing with the application of a systems engineering perspective in describing neurosensory functioning. In fact, due to observed subject differences, a systems engineering model structure may be the only way to capture the individual differences in a useful and quantitative manner.

We believe the next step in applying our systems engineering methodology will be "closing the loop". By allowing the human operator VERP feedback, issues of attention and arousal could be controlled. This system, without feedback, has no 'reason' to respond. Through the use of feedback displays the full power of systems engineering analysis could be applied to these human response mechanisms.

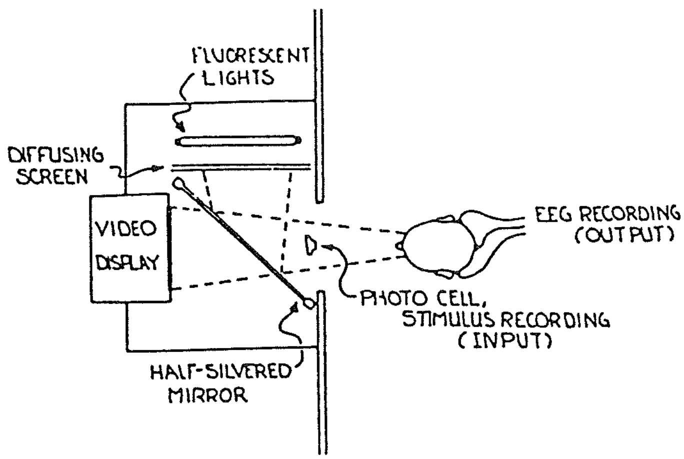

Figure 1. Experimental Setup

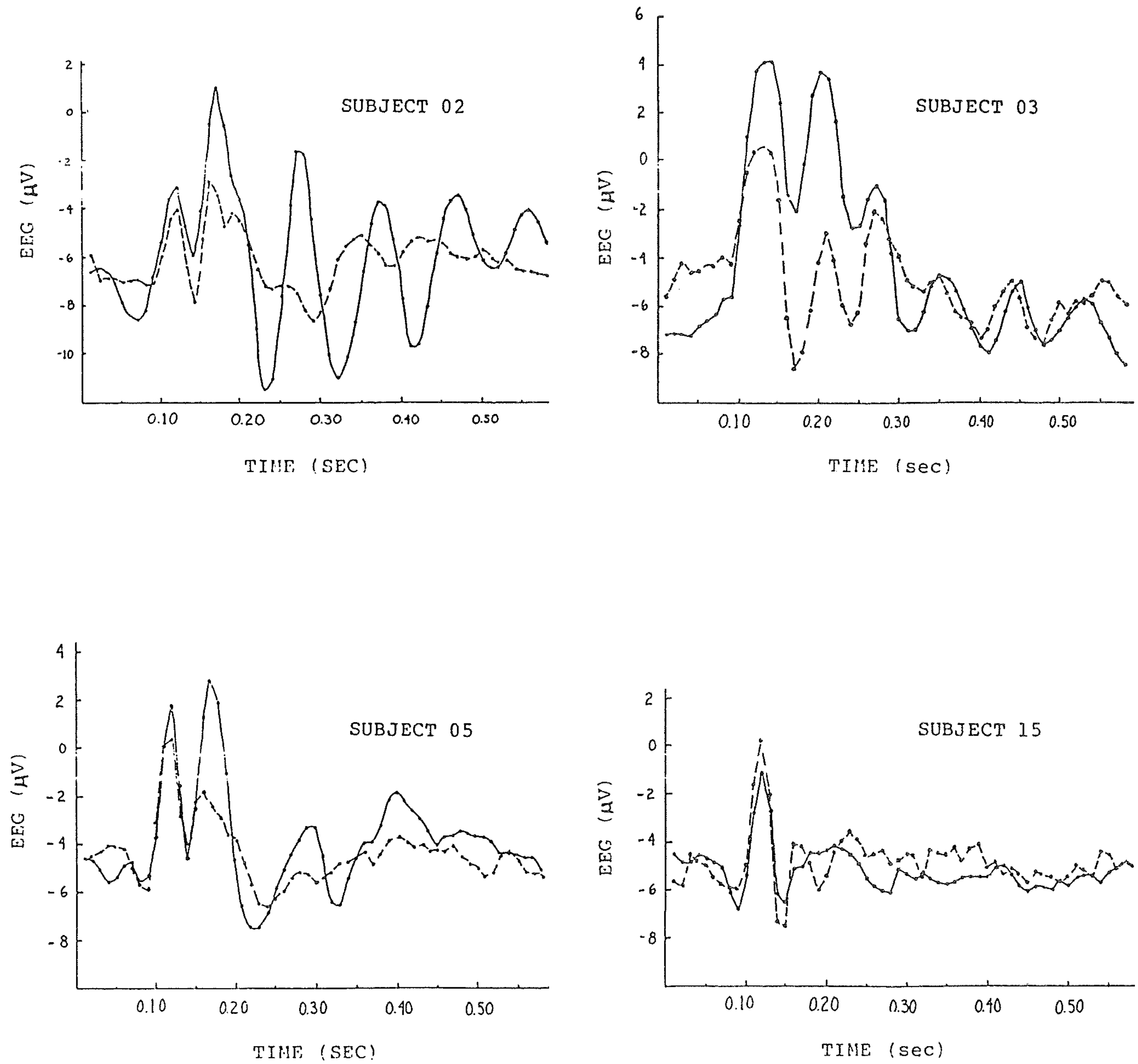

FIGURE 2. AVERAGED TIME RESPONSE TO TRANSIENT STIMULUS.
Solid lines: lights only, dashed line: task.

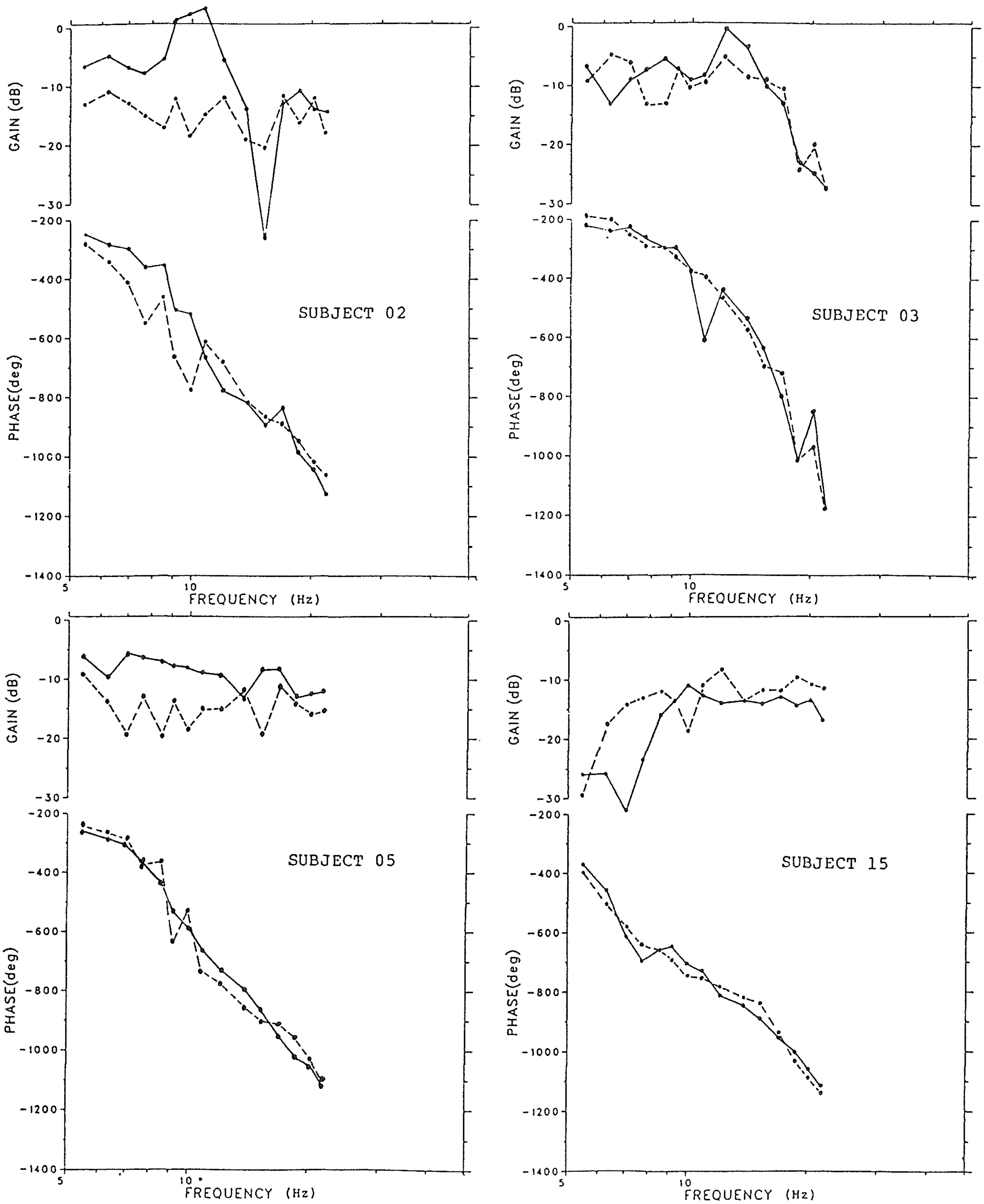

FIGURE 3. DESCRIBING FUNCTIONS FOR TRANSIENT STIMULUS.
Solid lines: lights only, dashed line: task.

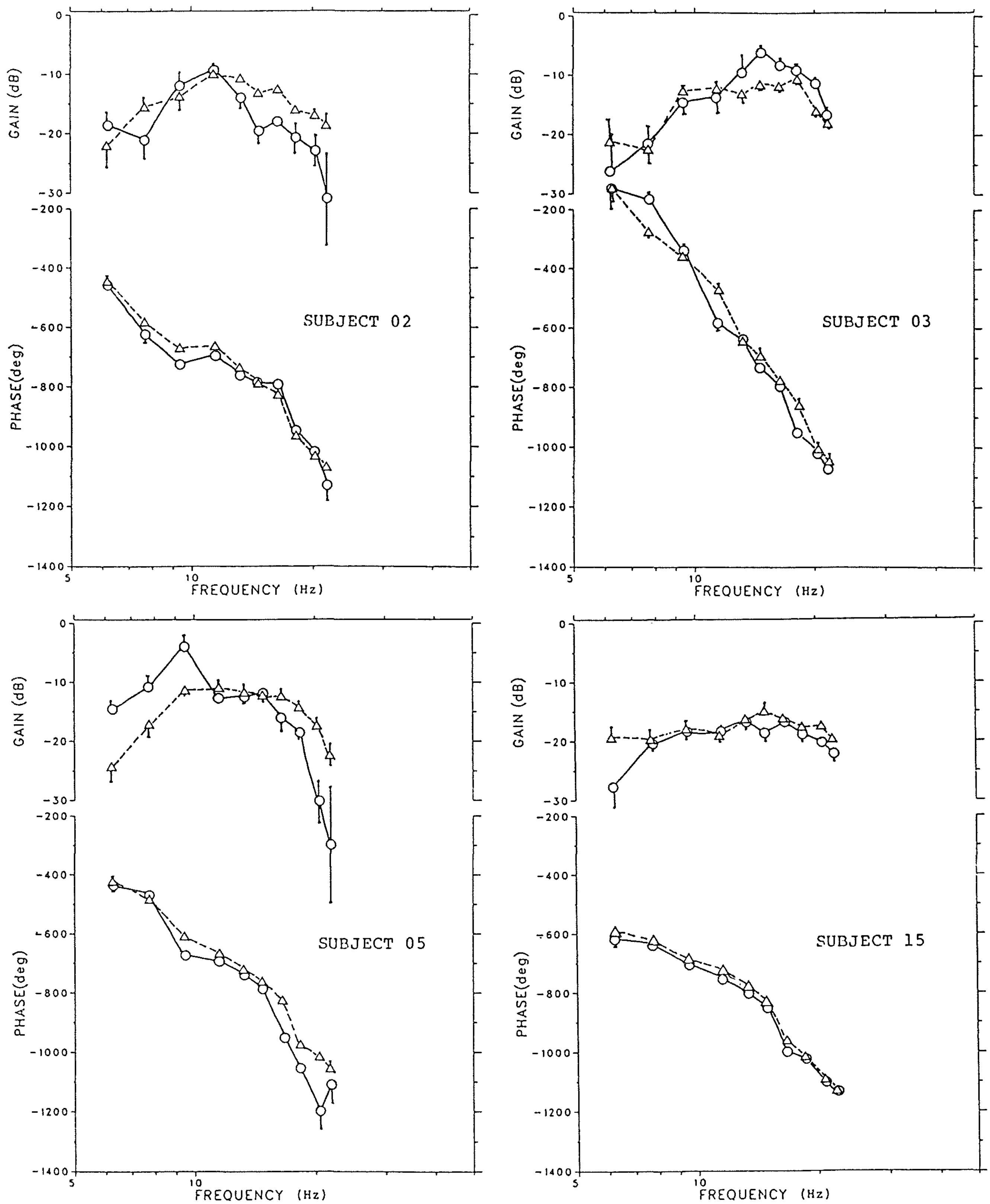

Figure 4. VER Describing Functions. Solid Lines: Lts Only
Dashed Lines: Grammatical Reasoning (Task-Loading)

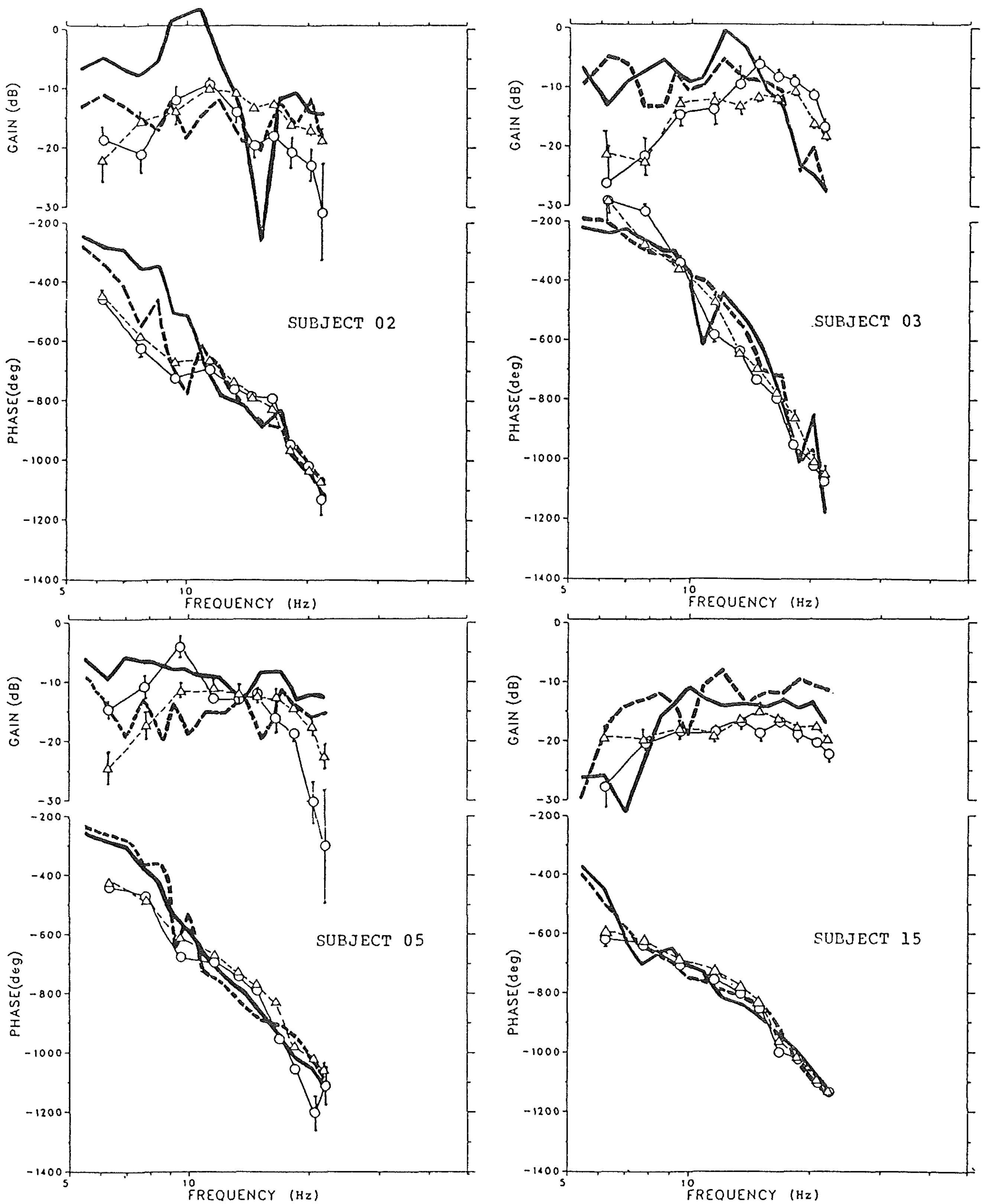

FIGURE 5. DESCRIBING FUNCTIONS FOR TRANSIENT AND STEADY STATE STIMULATION.
Transient: thick solid-no task, thick dashed-task
Steady State: circles-no task, triangles-task

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