EFFECTS OF CONCURRENT MENTAL ACTIVITY ON STATIC AND DYNAMIC ACCOMMODATION RESPONSES

By

FREDERICK VINCENT MALMSTROM

Bachelor of Science
United States Air Force Academy
Colorado
1964

Master of Aerospace and Operations Management
University of Southern California
Los Angeles, California
1970

Master of Science
Oklahoma State University
Stillwater, Oklahoma
1972

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of the Oklahoma State University
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Thesis Approved:

Robert J Weber
Thesis Adviser

Larry Hochhaus

Robert F Stanners

Robert Radtke

Norman N Durham
Dean of the Graduate College

PREFACE

This thesis originated from a small exploratory study performed nearly five years ago in the optometry laboratory at the National Aeronautics and Space Administration's Ames Research Center. At the time, Messrs. Randle, Weber, and I had noted that it was relatively easy to restrict a person's range of accommodation merely by instructing him to "think something" while, at the same time, have him attempt to maintain focus on a target. As time and funds have permitted, we have pursued both a description and an explanation of this phenomenon which has previously not, to the best of our knowledge, been adequately researched. The nature of this thesis is more nearly a grand exploratory study and will, I hope, serve as a small source of inspiration for other accommodation studies which will surely follow as objective optometers become more accessible to vision researchers.

Many generous people and institutions deserve recognition for the successful completion of this thesis. The optometry laboratory at the NASA/Ames Research Center was made available through my sometimes adviser, sometimes colleague, and always friend Robert J. Randle, NASA Research Scientist. Equally important for her understanding of subjects, computers, optometers, and me is our long-time assistant and co-worker, Ms. Donna L. Miller, who, together with fellow Guest Worker John S. Bendix, spent many curious and productive hours testing subjects.

I wish to thank my major adviser, Dr. Robert J. Weber, for his continuous and valuable time and advice during the lifetime of this experiment and for his allowing me the widest possible latitude in pursuing the associated problems. Also included in this appreciation are Dr. Robert F. Stanners and Dr. Larry Hochhaus for their liberal time and advice.

Away from the laboratory and academia, a most generous and loving support was provided by my parents, Mr. and Mrs. Vincent F. Malmstrom. The love and understanding provided by my wife and, incidentally, best friend, Susan Gates, has undoubtedly been the most important human element in this entire endeavor. And, although not directly involved, my new son, Carl, provided a great deal of encouragement to finish this thesis quickly and return to the taxpayer roles.

This entire study was funded by in-house support from the Man-Vehicle Systems Research Division, NASA/Ames Research Center, Moffett Field, California, and from the Reliability and Maintainability Testing Division, USAF/Rome Air Development Center, Griffiss AFB, New York, who generously granted me the time to pursue this thesis as an independent project.

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NOMENCLATURE

D	diopter (D = meters^{-1})
hz.	hertz; cycles per second
sec.	second
Sin	sine wave
Sq	square wave
STATS	statistical analysis of time series
OL	open loop; empty field conditions
0.0D	zero diopter; far target; optical infinity
3.0D	three diopters; near target; 1/3 meter target
1X	count backwards by ones
3X	count backwards by threes
7X	count backwards by sevens
NX	ignore the target movement, do not count

CHAPTER I

INTRODUCTION

The extent to which non-visual factors can affect visual accommodation are not well known nor easily studied. The difficulties in studying accommodation come both from historical misconceptions and inadequate objective measures. It has long been known that accommodation exhibits both reflexive and so-called higher-order responses; it is, especially, the higher-order responses which have not been well researched.

Historically, human accommodation has not been easy to observe. Buried below the cornea and aqueous humour, the lens and controlling zonule and ciliary muscles do not exhibit many changes which can be observed both objectively and unobtrusively. Hence, accommodation studies have necessarily been made subjectively. It has often been necessary to query the subject directly whether an image is in focus, for example, with a Badal optometer or a Snellen chart. Thus, it has often been impossible to separate the pure accommodation changes from the more subjective elements of perception.

There have been several elegant models of human accommodation as a reflexive or servo-model mechanism (Stark and Takahashi, 1965; Carter, 1962; Troelstra et al., 1964). In essence, most of these models state that the primary impetus to accommodation changes is a presence of retinal blur which will cause the eye to hunt for an in-focus image.

It is, of course, quite plausible that the reflexive portion of accommodation may be adequately described by a servo-mechanical model. However, the servo-model is not sufficient for describing all aspects of accommodation (Smithline, 1974; Randle, 1975). Campbell and Westheimer (1959) expressed doubts, for instance, that accommodation did not involve the visual cortex in some way. If it were the case that control of accommodation were, in part, influenced by higher processes, then accommodation might be described better by whole families of responses, each with its own operating characteristics. A reflexive, or servo-model would be only one of these families of responses.

The scope of this study is limited to non-visual factors affecting accommodation; therefore, discussion of the visual stimulus items which are believed to affect the servo-styled response, such as retinal blur and chromatic aberrations, must, of necessity, be bypassed.

Non-visual Factors Affecting Accommodation

In an early experiment, Olmsted and Morgan (1939) showed that exposure to a sudden, sharp stimulus, such as a tap on the nose, was accompanied by a brief change in the refractive state of the rabbit's eye. The suggestion was, and still is, that the reaction is the result of stimulation of the sympathetic nervous system. Further surgical experiments on rabbits, both stimulating sympathetic fibers and cutting the IIIrd Cranial (parasympathetic fibers) nerve tended to support this earlier finding (Morgan, Olmsted, and Watrous, 1940). Pathology also forms support for sympathetic action. Loss of sympathetic ganglion in the neck (Horner's disease) produces, in addition to constriction of the pupil, extreme difficulty in accommodating for distance. Dominance of the sympathetic system, as in some forms of Basedow's disease, is shown by difficulty in accommodating for near objects (Schober, 1954).

Conversely, parasympathetic activity causes an opposite accommodation response. For example, direct stimulation of the IIIrd Cranial will cause a myopic response, or a shift in refractive power of the lens to the near point (Davson, 1972, pp. 403).

Administration of drugs produce similar effects. Sympathetic activating or parasympathetic inhibiting drugs, like atropine or cocaine, produce difficulties in accommodating for near objects. Parasympathetic activating or sympathetic inhibiting drugs, like ergot or pilocarpin, produce difficulty for distant accommodation (Schober, 1954).

By this time, it should become increasingly clear that negative (far) accommodation is not merely the decay of positive (near) accommodation. For example, the velocity of the response in the far direction is much too rapid to be dependent upon the decay of some parasympathetic transmitter substance (Cogan, 1937). Thus, Schober (1954), Toates (1972), and others were led to describe the accommodation response as an opponent process in which the sympathetic and parasympathetic divisions tend to hold each other in equilibrium.

Furthermore, Schober (1954), mostly on theoretical grounds, proposed that the resting position of accommodation was not at the visual far point, but at some intermediate balance point between full sympathetic and full parasympathetic activation. The theory of Helmholtz in the 19th century had set forth the proposal that full negative (far) accommodation was a state of extreme relaxation. Bit by bit, the theory of Helmholtz is falling into disfavor. Indeed, empirical studies about a phenomenon known variously as "empty field myopia," "night myopia," and "instrument myopia," all seem to support an intermediate-resting-position hypothesis (Hennessy and Leibowitz, 1971; Leibowitz and Owens, 1975). All of these anomalous myopias occur when the eye is placed in a field of indeterminate focus, such as darkness, fog, or in front of a pinhole aperture. During the first half minute, accommodation will slowly drift towards a value of about one diopter (D; $D = m^{-1}$). The point of focus would then tend to wander slightly about this value. Such an intermediate-resting-position of accommodation value is quite in agreement with a "null" region between sympathetic and parasympathetic activity. It should also be added that the intermediate resting position is considered a <u>behavioral</u> resting position. Westheimer and Blair (1973) presented evidence from animal studies that accommodation assumes a 0.0D (infinity) value during anesthesia and death. Conversely, an excised lens assumes a thicker, or more spherical shape, indicating that, independently, the lens would be more adapted to near vision (Davson, 1972, pp. 400).

Volitional Control of Accommodation

In the absence of all other depth information (object size, brightness, overlap, texture, etc.), the eye is as likely to begin its accommodative hunting in the wrong direction as well as the correct direction (Campbell and Westheimer, 1959). Therefore, it may be properly questioned as to whether the subject has any volitional control over accommodation, or is the control of accommodation purely due to a trial-and-error process of eliminating retinal blur? In an extended study, Randle (1970) reported that subjects were able to alter their accommodation both in fixed-focus and empty fields after extensive feedback training. Part of the feedback training included accommodating a specific distance to a specific tone. In this instance, the pure tone varied in frequency as a function of the refractive state of the subjects' eye; high frequencies were associated with high dioptric values (close targets). Later in the experiment, subjects also learned the specific task of accommodation to, or near to, infinity, without using the tone. In a less elegant experiment, Provine and Enoch (1975) demonstrated that four subjects could learn to exhibit as much as 9.0D volitional control of accommodation while wearing a soft contact lens. In both instances, it was not reported that the subjects knew how they effected the accommodation changes, but only that they could effect the change. Although it may not be clear how volitional control of accommodation is effected, it is certainly possible to interfere with this process. Randle (personal communication, 1978) cites personal knowledge of a subject who, after an altercation with his professor, was unable to exercise volitional control of accommodation for an entire day. This subject, otherwise, was a most reliable performer both prior to and after the incident. Whether this subject's difficulty was because of a sympathetic or parasympathetic inhibition is, however, entirely speculative.

Visual Imagery

It has been hypothesized that "thinking near" and "thinking far" would be sufficient impetus to effect the volitional control of accommodation. However, the role of imagery has had a history of contradictory evidence. Westheimer (1957) reported that two subjects instructed to "think near" and "think far" in an empty field were only able to effect a small (less than 0.5D) and transient (unspecified) change in accommodation. Later, Cornsweet and Crane (1973) reported that the imagery technique was not useful in altering accommodation; and Provine and Enoch (1975) reported ambiguous results. In 1976, Malmstrom and Randle reported that subjects could effect significant and appropriate changes in accommodation (about 0.5D) by "thinking near" and "thinking far," but only about an empty-field 1.0D resting state of accommodation. Apparently, there is some component of volitional control, namely imagery, which can be useful in altering accommodation in a desired direction; but the effect is so small that its usefulness may be of questionable value in locating actual targets.

Parasympathetic Activity

The "experimental" evidence on the presumably parasympathetic activity of accommodation is, more correctly, a listing of anecdotes and clinical observations. Westheimer (1957) probably has the only personally documented case of two subjects who were intentionally insulted while being observed in empty field conditions. In this study, both subjects experienced an increase in myopia of over 1.0D with residual effects lasting for over five minutes. Skeffington (1957) also reported a study where subjects who read progressively more difficult material also showed an increase in accommodation values. Nevertheless, if the increase was in the positive direction, it might more correctly reflect a negative attitude (parasympathetic response) to the material being presented rather than a general (sympathetic) arousal response.

Sympathetic Activity

Olmsted, in addition to his experiments with animals (cf. Olmsted and Morgan, 1939) had also noted a strong dioptric change in the "direction of hypermetropia" (the far direction) in humans who were exposed to electric shocks, horns, and pistol shots (Olmsted, 1944). Cogan (1937) cited the case of a student who, nearing the time for a final examination, was unable to effect near accommodation. A more recent study by Randle, Roscoe, and Pettit (in preparation) examined 20 commercial airline pilots over about a six-week period. In this study, the pilots were required to make several decisions during a simulated night landing task while viewing the display through various magnifications of the landing field. Results revealed an unexpected significant main effect; the importance of the decision influenced the accommodative state, always towards the visual far point. Presumably, all the above cited cases would indicate that a far accommodative shift would be due to a general increased sympathetic arousal. It should also be quite obvious that this sort of response has not been well documented.

Tunnel Vision

In 1975, Malmstrom, Randle, and Weber had observed that subjects instructed to perform a secondary backwards counting task during a dynamic accommodation experiment produced an apparent "clipping" or shortening of their total accommodation range. At the time, it was thought that this restricted accommodation range might be a third-dimensional analogue to the well-documented perceptual "tunnel vision" response to mental loading (Leibowitz, 1973; Ikeda and Takeuchi, 1975;

Leibowitz and Appelle, 1969; Mackworth, 1965). It has been known for some time that the physical environmental conditions, such as body position, positive-g acceleration, or hypoxia can cause a decreased retinal blood supply, and, hence, tunnel vision (e.g., Gillingham and McNaughton, 1977). Curiously, there do not seem to be any physiological models which describe the mental loading tunnel vision. That is, other than some passing reference to a "central processing deficit," the discussion seems to avoid whether the narrowing of the visual field could be primarily sympathetic or parasympathetic in origin, or a combination of both.

Other Considerations

It is obvious that there are probably distinct parallels between accommodative and pupillary responses (Hess and Polt, 1960; Hess and Polt, 1964) when used as a measure of interest, attitude, and cognitive loading. Although it may be an oversimplified case, parasympathetic activity is taken to be the primary pupillary contraction controller, and sympathetic activity is taken to be the dilation pupillary controller (Lowenstein and Lowenfeld, 1950). The fact that the pupillary, accommodative, and oculomotor responses are closely allied can be seen in the well-known _near reflex_. The near reflex consists of an associated pupillary contraction, accommodation increase, and ocular convergence (all mediated by N III) when the visual system looks at a near object. Lest it be thought that all three responses are dependent upon each other, it should be stressed that any one of the responses can be made to act independently under special conditions. Drugs such as atropine will paralyze both the pupillary and accommodation response;

phenylephrine (Neo-synephrine) will dilate the pupil but leave accommodation and convergence virtually unchanged (Sabin and Ogle, 1958). Similarly, it is possible to use prisms to "fool" the visual system into positive accommodation and pupillary constriction while convergence remains at infinity (parallel) (Toates, 1972). Clark, Randle, and Stewart (1975) reported a vestibular-ocular accommodation reflex in man which does not affect the pupillary response appreciably. Although the pupillary response was not measured in this experiment, a large pupillary response would render the optometer signals unreadable. (This was an equipment limitation.)

Nevertheless, it would seem that, under normal circumstances, accommodation might be an indicator equally as sensitive to attitude and interest as the pupillary response. To date, this possibility has not been investigated, although the evidence suggesting a parallel activity is tantalizing. Hess and Polt (1960, 1964) in two landmark papers describing effects of interest and mental loading on the pupillary response, claimed that accommodation was not a factor in their experiments; no accommodation measurements were made, as they assumed only distance cues affect accommodation. The assumption of these authors, while certainly not fatal to their discovery, may have been bypassing another indicator of the effects of information processing on the visual system. For example, Kahneman and Beatty (1966) found that differing fixation points produced different baseline values for the pupillary response; subjects focusing at larger distances produced relatively larger pupillary responses.

Problem and Hypotheses

To date, the literature describing the effects of non-visual factors affecting visual accommodation has been mostly confined to a scattering of animal studies, clinical observations, and anecdotes. A review paper discussing the non-visual effects on visual accommodation by Randle (1975) stresses that non-visual factors should no longer be ignored. Furthermore, recent availability of sophisticated monitoring equipment allows for the study of the _dynamic_ responses of accommodation to its total environment. Neither the physical world nor the mental state of the subject is motionless; yet, most studies about accommodation totally ignore the issue of dynamics.

The Search for a Model

The original paper by Malmstrom, Randle, and Weber (1975) is the starting point for the present study. It was observed during a dynamic accommodation tracking task that a shortened range of tracking ability resulted from the introduction of a concurrent backwards counting task. It appeared that the range of tracking ability was impaired, but the effect was especially prevalent as the target approached the near point. Because of the exploratory nature of the original study, however, certain questions were never answered.

It was originally suggested that such a clipping of accommodation peaks pointed to a diversion of central attentional processing capacity from the primary task; hence, there was the possible source of cortical mediation of the accommodation process. Such a diversion of central processing capacity would tend to support a Capacity Model of information processing proposed by Kahnemann (1973). In this model, it is assumed that almost any conscious activity places demands on the available capacity, and concurrent activities which require attention tend to interfere with one another. The Capacity Model would suggest the following effects on accommodation during a concurrent mental task:

(1) Both the near and far points would tend to be clipped, assuming that both positive and negative accommodation require central processing capacity.

(2) Over an extended period of practice or familiarity, the range of accommodation would return to normal; increased familiarity with the same accommodation and concurrent mental task would lessen the demands on central capacity.

(3) A more difficult concurrent mental task would create an even more restricted range of accommodation because of the increased demand on capacity.

An alternative hypothesis is that the clipping of accommodation peaks is an indicator of a general model of sympathetic arousal, not unlike the pupillary response. In this instance, the accommodation response could be viewed as an autonomic response, more an indicator of the mental state of the subject than as a processing deficiency. The Sympathetic Model would suggest the following effects on accommodation during a concurrent mental task:

(1) The accommodation shift would be in the negative (far) direction during the concurrent task.

(2) Over an extended period of practice or familiarity, the range of accommodation would remain shifted to the far point. Some degree of habituation might occur, tending to return the range

of accommodation to the original value; however, the accommodation far shift which is indicative of concurrent mental activity would not be subject to learning effects.

(3) Similar to the pupillary response, more severe demands of the secondary task would be reflected in greater arousal; hence, there would be a greater accommodative shift to the far direction.

(4) During empty-field conditions, the accommodative shift to the far direction would be exaggerated, to the extent that empty-field equilibrium would not retard accommodation.

(5) The time required for the accommodation range to return to normal from the far shift would be proportional to the amount of general sympathetic arousal. That is, recovery might not be instantaneous, but would require several seconds.

Finally, there is a third hypothesis that the clipping of accommodation peaks is an indicator of a general parasympathetic arousal model. Such a model would suggest more of an attitude change towards the secondary task and would incorporate many of the predictions of the Sympathetic Arousal Model. The Parasympathetic Arousal Model would suggest the following effects on accommodation during a concurrent mental task:

(1) The accommodation shift would be in the positive (near) direction during the concurrent task.

(2) The accommodation range would tend to increase or decrease as the subject altered his attitude towards the tasks. However, as an indicator of autonomic parasympathetic arousal, the near accommodation shift would not show learning effects, although

some degree of habituation might occur.

(3) Similar to the pupillary response, the more severe degree of arousal, the more severe the accommodative shift to the near direction.

(4) During empty-field conditions, the accommodative shift to the near direction would be exaggerated to the extent that empty-field equilibrium would not retard accommodation.

(5) The time required for the accommodation range to return to normal from the near shift would be proportional to the amount of general parasympathetic arousal. That is, recovery might not be instantaneous, but would require several seconds.

It is obvious that many of the predictions are not exclusive of a specific hypothesis. However, the critical dependent variables which ought to support one hypothesis over another are the Direction and Magnitude of the accommodation shift and the effects of learning over Days. As will be seen, there are certain "bonus" dependent variables, Phase Lag, Latency, and Velocity of accommodation. Although these variables are not mentioned directly in the original hypotheses, the particular analyses and computer programs the data were subjected to made it possible to analyze and discuss these variables, too. Because Phase Lag, Latency, and Velocity of accommodation were not central to the issues brought forth in this study, they should be treated as items of exploratory interest. It is hoped that the treatment of these items will serve as impetus for others to continue further research in a largely unknown area.

CHAPTER II

METHODOLOGY

Subjects

The subjects for this study were four adult males ranging in age from twenty-one to twenty-three years. These four subjects were screened from a pool of sixteen volunteers on the basis of their ability to track targets reliably on the optometer focus stimulator (Crane and Cornsweet, 1970). All subjects had normal vision as measured by the Bausch and Lomb orthorater, and the age requirement was to insure that all subjects had a wide range of accommodation. All subjects were paid $3 per hour for participating in five consecutive daily sessions which lasted about two hours each.

Apparatus

All measurements were taken with the Cornsweet and Crane (1970) objective optometer at the NASA/Ames Research Center and built under contract by Stanford Research Institute. The optometer is an infrared, continuously nulling (servocontrolled) device based on the familiar Scheiner principle (ref. Davson, 1972, pp. 397). A retinally reflected rectangular aperture is made to fall on a splitfield photosensor. A difference in focus between the optometer and the subject's eye results in a lateral displacement (motion) of the rectangle and on the photosensor from which an error signal of appropriate sign and magnitude is developed. This error signal drives a small high-speed servo on the optometer to a new position that nulls the error signal and, thus, the difference in focus. For full details of the operation of the optometer, the reader is directed to Cornsweet and Crane (1970).

The subject's head was held in place by a hot-wax molded bite-board affixed to the optometer chassis. Hence, any intelligible conversation by the subject was impossible unless he first pulled away from the optometer.

Stimuli

All subjects were presented a black "X" target subtending a visual angle of 2.9 degrees. The target was presented under both Static (steady fixed-focus) and Dynamic (cyclical changing-focus) conditions.

The Static target was presented at diopter setting of 0.0D (zero diopters), 3.0D (three diopters), and OL (open loop or empty-field) conditions. During the OL conditions, a selsyn-operated 0.3 mm. aperture was dropped into place at a plane in the optical system such that it was imaged in the plane of the entrance pupil of the subject's eye. Concurrently, the "X" target background brightness was increased to maintain constant target illumination. The eye's entrance pupil thus became 0.3 mm., a condition which increased the depth of field to an extent that the target was always in clear focus. Retinal blur and blur changes were now absent, and accommodation was not required. This was called the "open loop" mode and is analogous to empty-field viewing in that accommodation is independent of the stimulus field. The effect is identical to the aperture used in a pinhole camera; each image, regardless of its apparent distance, is in clear focus. This pinhole clarity of focus, however, is achieved at a cost of a limited field of view.

The Dynamic target was presented at speeds of 0.1, 0.2, and 0.4 hz. (hertz, cycles per second), both as a Sine wave and as a Square wave. All Dynamic targets ranged continuously back and forth through an apparent optical distance of 0.0D (infinity) and 3.0D (1/3 meter); however, the focus stimulator is designed so that the target did not vary in either size or brightness, so these factors could not be used as distance cues. The focus stimulator is based on the principle of the Badal optometer, which maintains targets at constant size and brightness. For further details on the Badal optometer, the reader is directed to Ogle (1961).

The focal change of the target and subsequent accommodation responses of the subject was fed continuously onto a Brush chart recorder and concurrently into magnetic tape for digital conversion on a PDP-12 computer. Analog-to-digital conversion was accomplished at a sampling of 20 data points per second. Thus, each 30-second period of data consisted of 600 data points. The analysis of optometer digital data was accomplished using an in-house "STATS" (Statistical Analysis of Time Series) computer program at the Ames Research Center. Appendix C, which is reproduced from Randle (1972) presents the specific procedures used in the data conversion. Figures 21 and 22, also listed in Appendix C, show a schematic of the parameters measured in this study. Sine wave analysis included two parameters: Amplitude gain and Phase Lag. Square wave analysis included seven parameters: zero tracking level, near target tracking level (Pulse), response Magnitude, and

Latency and response Velocity for both receding and approaching targets.

Design

Overall, the series of experiments was divided into two separate parts of equal importance, Static and Dynamic accommodation experiments. Both Static and Dynamic accommodation experiments were run concurrently over a five-day period. Every trial of each experiment, whether Static or Dynamic, was divided into four Time Blocks, a base (T_1) 30 sec. of target tracking, 30 sec. of target tracking plus a paced backwards counting task (T_2), and two more consecutive 30 sec. periods of rebase or recovery (T_3 and T_4). Keeping the target in focus, or tracking, was considered the Primary task; counting backwards was considered the Secondary task.

Static Accommodation Experiment

Because the Static accommodation experiment is, perhaps, the simplest to follow, this is where the study will begin. The Static experiment was divided into two separate phases. Phase 1 was a design of three target Distances (0.0D, 3.0D, OL) × five Days × four Time Blocks. The purpose of Phase 1 was to determine the effect of a single counting task on the ability of a subject to maintain focus on a stationary target. During this phase, the subjects were required to perform a Secondary task counting backwards by ones (1X) only. Distances were presented in random order.

Phase 2 was performed on days 4 and 5 only, and its purpose was to determine the effects of varying the Difficulty of the Secondary task on the subject's ability to maintain focus on a stationary target. The design was three target Distances (0.0D, 3.0D, OL) × two Days × three levels of Secondary task Difficulty (1X, 3X, 7X) × four Time Blocks. Figure 1 shows a schematic of the presentation of different phases of the Static accommodation experiments.

Dynamic Accommodation Experiment

The Dynamic accommodation experiment was divided into two target stimulus categories, Sine and Square waves. There were four distinct Phases to the Dynamic accommodation experiment. The first two Phases varied only in the type of target stimuli presented, Sine and Square. The purpose of Phase 1 and Phase 2 was to determine the effects of a constant Secondary task on the ability of the subject to maintain focus on a variety of target stimulus Frequencies. Although the Secondary task remained constant (i.e., count backwards by ones), the method of response was varied; the subject responded either by writing his answers or counted mentally. The overall design of Phase 1 was three Frequencies (0.1 hz., 0.2 hz., 0.4 hz.) × two Secondary task responses (1X mental count, 1X written count) × three Days × four Time Blocks.

Phase 2 was similar to Phase 1, except that a Square (pulsed) wave was used; the design was three Frequencies (0.1 hz., 0.2 hz., 0.4 hz.) × two Secondary task responses (1X mental count, 1X written count) × three Days × four Time Blocks.

Phase 3 consisted only of a 0.2 hz. Square wave stimulus tracked over a five-day period. The 0.2 hz. Square wave was selected because pilot work had shown it to be the most likely response waveform to show Secondary task effects. The sole purpose of Phase 3 was to determine

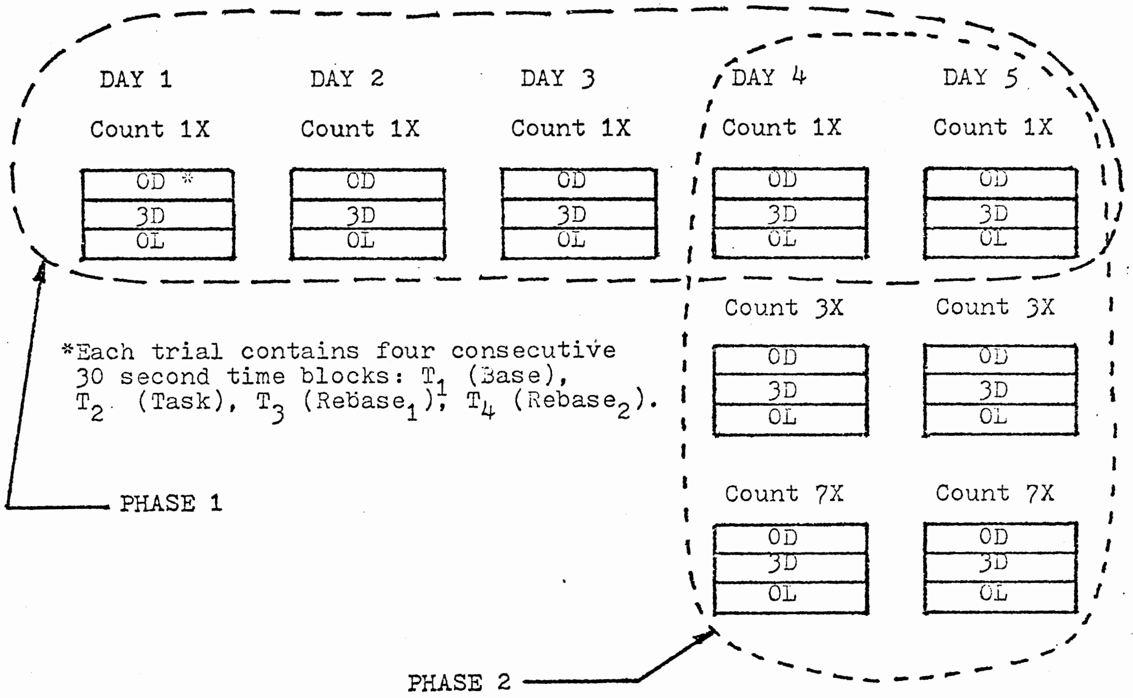


Figure 1. Block Schematic of Phases for Static Accommodation Experiment

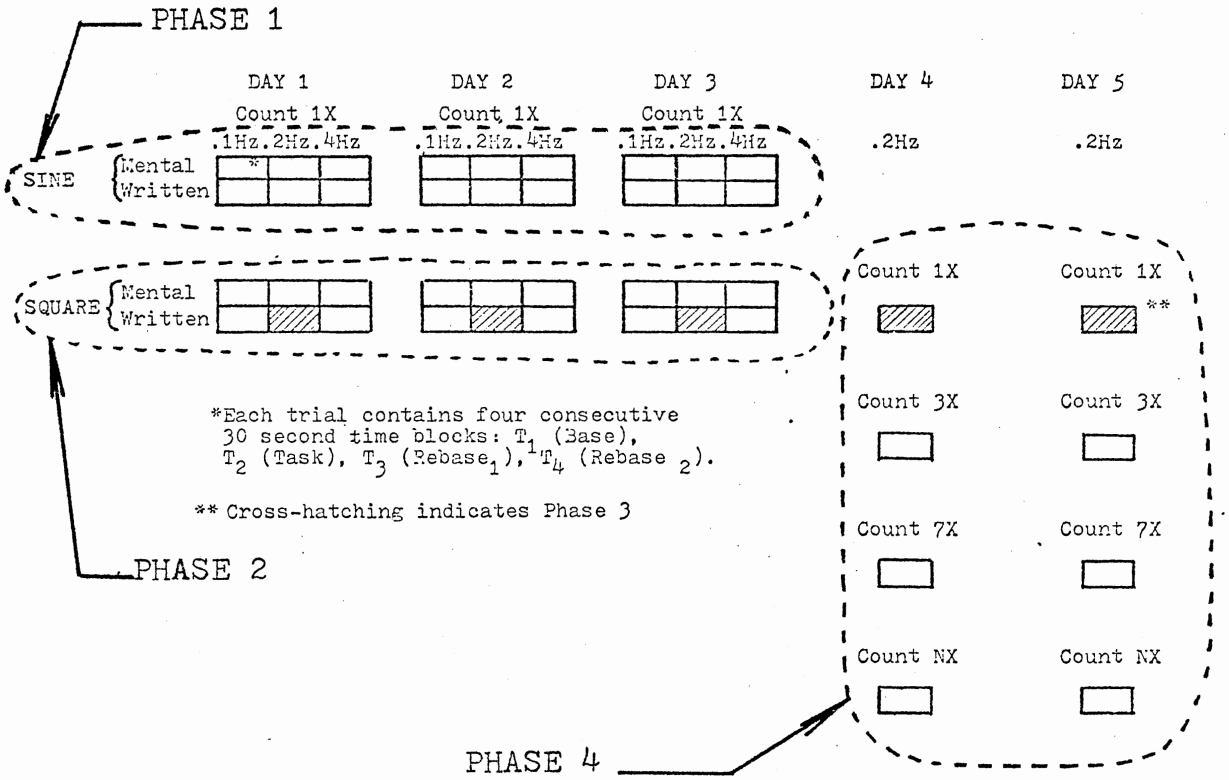
the effects of practice on the tracking response by the Secondary task.

Phase 4 was conducted on Days 4 and 5 only and consisted of a 0.2 hz. Square wave stimulus presented with three Difficulty levels (1X, 3X, 7X). (There was a fourth category of Difficulty, NX. NX refers to a special condition in which the subject did not count and was instructed instead to ignore the target. The NX condition was presented only at the end of the experimental session and was for exploratory purposes only.) The overall purpose of Phase 4 was to determine the effects of varying the Secondary task while holding the Primary task constant. The design of Phase 4 was three Difficulty levels (1X, 3X, 7X) × two Days × four Time Blocks; only one Frequency (0.2 hz.) was used. Difficulty levels were presented in random order. Figure 2 shows a schematic of the presentation of different Phases of the Dynamic experiment.

Instruction and Procedure

Each subject was instructed that this was an experiment designed to measure his ability to perform two concurrent tasks. The first task was that he was to maintain focus on an "X" target which might or might not be continuously changing focus. The second task was a paced counting backwards task, either writing his responses on a tablet placed by his writing arm or to count backwards in his head. The subject was advised that he should treat each task of equal importance and that neither should be considered more important than the other.

Although the experiment was conducted over five consecutive days, the subjects were present for an additional initial day of screening



*Each trial contains four consecutive 30 second time blocks: T_1 (Base), T_2 (Task), T_3 (Rebase$_1$), T_4 (Rebase $_2$).

** Cross-hatching indicates Phase 3

Figure 2. Block Schematic of Phases for Dynamic Accommodation Experiment

and practice of both tracking targets and counting backwards. Thus, each subject began actual trials on a Tuesday and continued through Friday. After a weekend break of two days, the subject completed the experiment on a Monday.

At no time during the course of the experiment was the subject informed of the apparent distance of the "X" target, but only that he should try to hold it in focus. Also, the subjects were given no feedback whether they had done well or poorly on either the Primary or Secondary experiment until after the sixth day. All subjects completed the Static accommodation experiment each day before proceeding to the Dynamic accommodation experiment.

Static Accommodation Experiment

During Phase 1 of the Static accommodation experiment, each subject was informed that he should maintain steady track on either the 0.0D, 3.0D, or the OL target as it was presented. At the end of the first 30 sec., the subject was instructed, "Write backwards by ones, start at . . . (random three-digit number)." At this point, a randomly selected three-digit number was repeated to the subject, and the subject began a paced counting task writing one count (but two digits) every two seconds. The task was paced by the Brush recorder timer which served as a metronome. The timer made an audible tick once every second. For example, if the experimenter said, "One-hundred and seventy-one," the timer was started when the experimenter said "one." At that instant, the subject wrote "7" during the first second and "1" during the second second, "7" during the third second, and "0" during the fourth second, "6" during the fifth second, and "9" during the sixth second, and so on. At the end of the 30 sec. task period, the subject was directed, "Stop counting, continue tracking." At this point, the subject continued tracking the target without counting for the next minute, until the end of the trial. During the OL Static conditions, the subject was first given one minute of viewing the target in OL conditions on the assumption that preaccommodation to an empty field would wash out any residual "biological hysteresis" (Randle, 1975; Roscoe and Benel, 1978). At the end of this first minute of pre-accommodation, the actual OL trial was begun.

During Days 4 and 5, there were additions of three Secondary tasks of counting backwards by threes, one for each of the 0.0D, 3.0D, and OL tasks; there were also additions of three Secondary tasks of counting backwards by sevens, one for each of the 0.0D, 3.0D, and OL tasks.

Dynamic Accommodation Experiment

At this point, the subject was presented the Dynamic accommodation experiment. For the first three days, the subject was presented the "X" target always changing in focus between 0.0D and 3.0D. The twelve possible conditions (written/mental × 0.1 hz./0.2 hz./0.4 hz. × sine wave/square wave) were presented in random order. The subject was then instructed to track the target for 30 sec. until the task portion of the trial. For the written task, the subject was instructed, "Write backwards by ones; start at . . . (random three-digit number)." For the mental task, the subject was instructed, "In your head, count backwards by ones; start at . . . (random three-digit number)." At the completion of the 30 sec. task portion of the trial, the subject was directed, "Stop counting; continue tracking." For the written task, no further Secondary task response was necessary. However, for the mental task, the subject was required to remember the final number he had calculated and to repeat it to the experimenter after the final rebase period. (Verbal responses to the experimenter were impossible during the trials because the subject was affixed to a bite-board.)

During days 4 and 5 (Phase 4), the subject was presented with only the 0.2 hz. square wave target; however, in this Phase the task difficulty was varied to include counting backwards by threes (3X) and sevens (7X). There was also the addition of a special task of ignoring the target and not counting (NX) which was presented at the completion of the 1X, 3X, and 7X tasks. The subjects were not informed of the impending change in the Secondary task Difficulty to preclude the possibility that they would be spending the previous night practicing counting backwards by threes and sevens. All Secondary tasks during Phase 4 were written. All three Difficulties (1X, 3X, and 7X) were presented in random order.

Again, as for the Static experiment, during the first Time Block (T_1) of 30 sec., the subject was instructed to "Track the target." For the second Time Block (T_2), the subject was instructed, "Write backwards by . . . (ones, threes, or sevens); start at . . . (random three-digit number)."

There was a fourth Difficulty condition during which the subject was instructed to "Ignore the target; do not count," (NX) which was included for exploratory purposes. This special NX condition was included only at the completion of the 1X, 3X, and 7X trials.

At the completion of the sixth day, each subject was given a thorough debriefing concerning his performance and compared to others who had performed in the same or similar experiments. Verbatim Instructions to the Subject may be found in Appendix A.

CHAPTER III

RESULTS AND DISCUSSION

The results of this study are divided into numerous and separate analyses of variance, both for the separate experiments, Static and Dynamic, and for the various dependent variables observed during the Dynamic accommodation experiment. The dependent variables observed in the Static experiment were Magnitude and Direction of shift (measured in diopters). For the Dynamic Square wave experiments (Phases 2, 3, and 4), the dependent variables were Magnitude and Direction of shift (measured in diopters), approaching and receding Latency (measured in secs.), and approaching and receding Velocity (measured in diopters per sec.). For the Dynamic Sine wave experiment (Phase 1), the dependent variables measured were Amplitude gain (measured in diopters) and Phase Lag (measured in secs.). It was not considered appropriate to compare the somewhat analogous dependent variables of the Sine and Square wave experiments such as Amplitude with Magnitude or Phase Lag with Latency. The justification for this decision is that the Sinewave accommocation response is considered a smooth or pursuit type of response, unlike a jumpwise adjustment to a pulsed (Square wave) target. For a review of the dependent variables, the reader is again directed to Figures 21 and 22, Appendix C.

Static Accommodation Experiment

Phase 1. (Days 1 Through 5)

Cell means for target Distance as a function of Time Blocks are plotted in Figure 3. An analysis of variance for Phase 1 shows a significant main effect for the target Distance (0.0D, 3.0D, OL), $F(2,6) = 15.557$, $p < 0.01$. There was also a significant interaction effect (towards the far direction) for Time Blocks (1 through 4) × target Distance, $F(6,18) = 3.727$, $p < 0.02$. (The complete analysis of variance summary table is presented as Table II, Appendix B.)

It was also desired to look more closely at any possible dynamic effects on static accommodation over time. Therefore, an analysis of variance was performed for a second-by-second examination of the differences between Time Blocks 1 and 2. For the purposes of this analysis, each original Time Block was subdivided into seven separate Time Intervals to represent each successive five seconds of both the Base and Task Time Blocks. Each interval is actually a mean of five data points to include the time 2.5 sec. before to 2.5 sec. after the Interval. This procedure was used to smooth out any momentary fluctuations such as eye blinks and the 2-3 cycle per second accommodation oscillations.

Cell means of Time Blocks 1 and 2 as a function of target Distance and Time Intervals are plotted in Figure 4. It should be noted that there is an apparent "gap" between the end of the Time Block 1 (Track Only) and the beginning of the Time Block 2 (Track + Count) conditions. This gap is, of course, the five-second interval where the subject was receiving the instructions, "Write backwards by ones, start at . . .

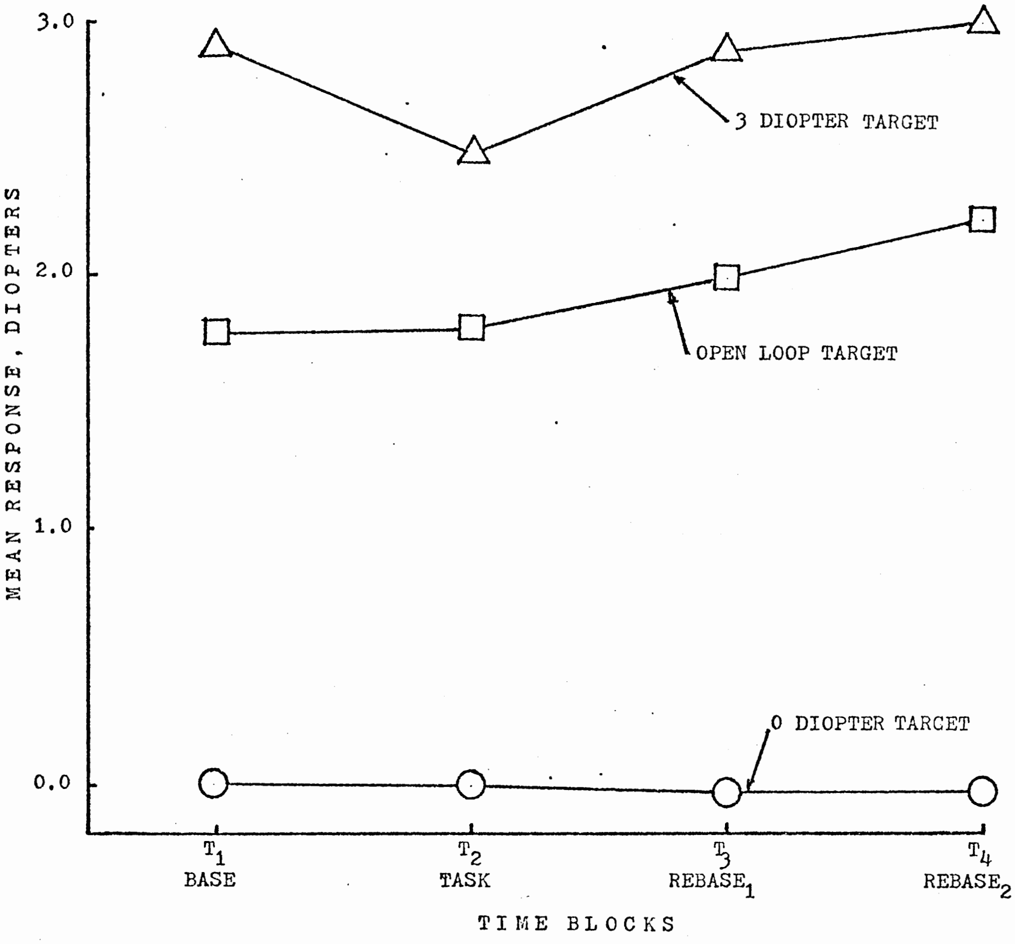


Figure 3. Static Accommodation Experiment. Means of Target Distances Plotted as a Function of Time Blocks

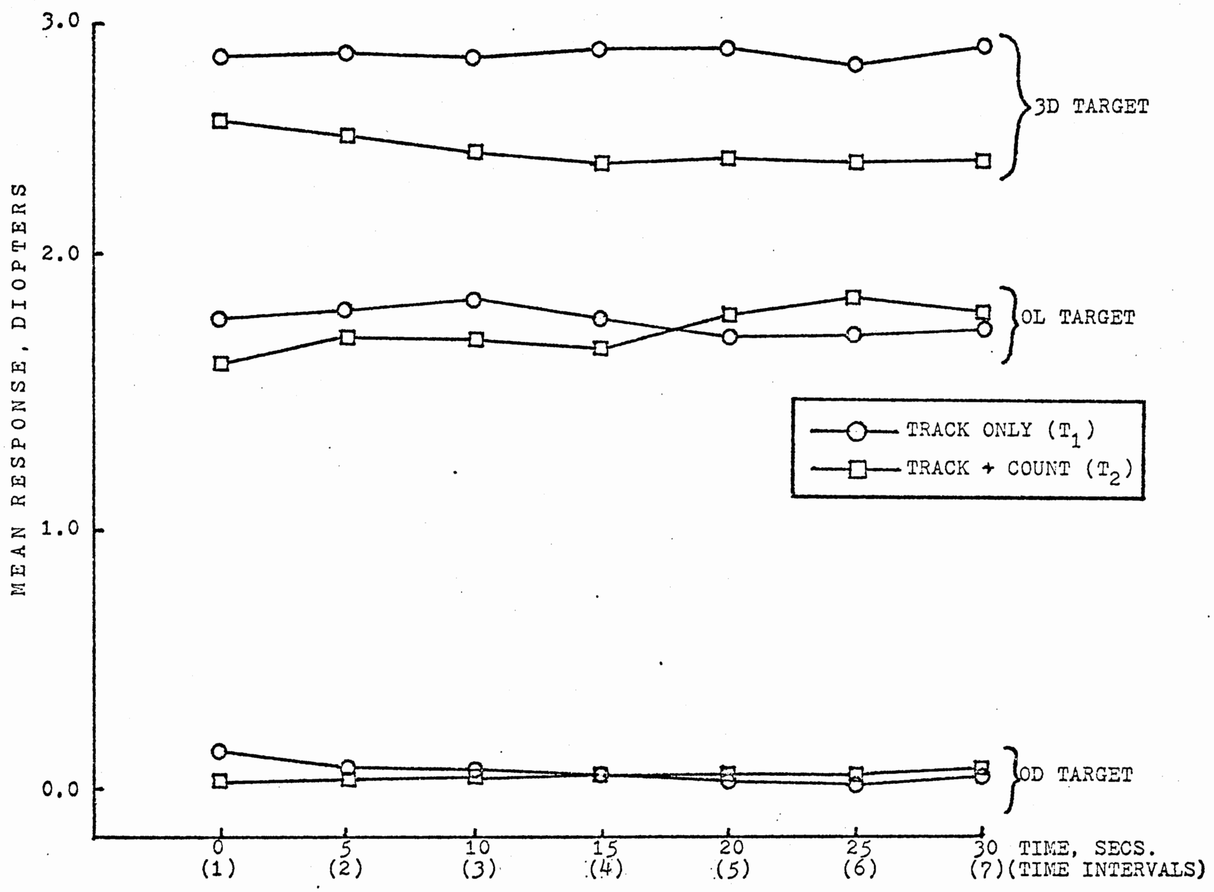


Figure 4. Static Accommodation Experiment. Time Blocks 1 and 2 Plotted as a Function of Time Intervals and Target Distances

(random three-digit number)." Analysis of variance for the two consecutive Time Blocks reveals a significant main effect for Target Distance, $F(2,6) = 12.988$, $p < 0.01$. There is also a single interaction effect for Time Blocks 1 and 2 (Base, Task) × Target Distance, $F(2,6) = 6.798$, $p < 0.05$. (The analysis of variance summary table is presented in Appendix B, Table III.) Again, because the variance of the OL condition was quite large, a separate analysis of variance using only the target Distances of 0.0D and 3.0D was performed. This analysis of variance shows significant main effects for Time Blocks 1 and 2, $F(1,3) = 36.107$, $p < 0.01$, and for target Distance (0.0D, 3.0D), $F(1,3) = 304.116$, $p < 0.001$. There were also two other significant three-way interaction effects, Time Intervals (1 through 7) × Time Blocks (1 and 2) × target Distance, $F(6,18) = 4.531$, $p < 0.01$; the second three-way interaction revealed significant effects for the Time Intervals (1 through 7) × Days (1 through 5) × target Distance, $F(24,72) = 2.312$, $p < 0.01$. (The analysis of variance summary table is presented as Table IV, Appendix B.)

As might be expected, Static accommodation experiments show strong significant main effects for the target Distance variables. This main effect, however, is a trivial indicator that when a target is set at a particular distance, the eye tends to remain focused on it. In fact, all experiments (either Static or Dynamic) with the concomitant Phases showed this main effect of Distance. Therefore, because this main effect is both trivial and expected, it will not be commented upon further.

The single interaction effect of Time Blocks × Distance is the first indicator that the concurrent mental task is accompanied by a significant shift away from the near point; furthermore, it appears that the recovery may not be instantaneous. In some instances, it took as long as the full minute of the two rebase periods for the subject to bring his accommodation to the original near point after cessation of the Secondary task. The function labeled "3 DIOPTER TARGET" in Figure 3 illustrates that during the rebase period T_3, accommodation has not recovered to the original T_1 value.

Phase 2. (Days 4 and 5)

For Phase 2, days 4 and 5, there was a single significant main effect for target Distance, $F(2,6) = 17.9181$, $p < 0.005$. Since, again, the variance of the OL condition was large, a separate analysis of variance was performed using only the target Distance of 3.0D. For this analysis of variance, there was a significant main effect of Time Blocks, $F(3,9) = 4.195$, $p < 0.05$. The expected significant main effect of levels of Secondary task Difficulty did not occur, although, as before, the accommodation shift in the far direction appeared during the T_2 Time Block. Because of the overall negative nature of the results during Phase 2 of the Static accommodation experiment, no figure is shown. (Complete analysis of variance summary tables for Phase 2, using the three Distance conditions [Table V] and the single 3.0D target Distance [Table VI] are presented in Appendix B.)

As indicated in Table V, Phase 2 results did not immediately indicate any difference between Time Blocks. The most likely reason for this negative finding was the large variance around the OL (Open Loop) conditions. Again, as in Phase 1, a separate analysis of variance for only the Target Distance of 3.0D did indicate a significant shift towards the far point with its subsequent slow recovery time. There was an unexpected negative finding, however; the Difficulty of the Task (1X, 3X, 7X) did not induce any greater significant shift than had been encountered than with the original 1X task.

The separate analysis of variance using only Time Blocks 1 and 2 divided into subsequent Time Intervals 1 through 7 (0 through 30 secs.) reveals a similar two-way interaction of Time Blocks (1 and 2) × Target Distance (see Figure 4). Again dropping the OL condition with its large variance from the analysis of variance yields an Intervals × Time Blocks × Distance significant interaction effect.

Hence, there are several curious and unexpected findings associated with this experiment. First, although it might be expected that the largest accommodation shifts would occur when the eye is at the theorized "resting position" (i.e., an eye not driven by focus requirements) of about 1.0D, this is, in fact, not the case. At this point, about all that can be said of empty field (OL) accommodation shifts is that there are large individual differences and that the "apparent" interaction by any OL conditions (as in Figure 4) should probably be discounted until further extended experimentation can be done. As Roscoe and Benel (1978) have stressed, long-term effects of empty fields (1 minute or longer) on accommodation have not been well studied. The fact that subjects were preaccommodated to OL conditions for at least one minute before the experiment was started may well have induced a "hunting" procedure noted in Roscoe Benel's (1978) paper. Thus far, the only reliable empty-field effects found on accommodation have been short-term (1 minute or less) ones of volitional control (Randle, 1975), visual imagery (Malmstrom and Randle, 1976), and a vestibular-ocular accommodation reflex (Clark, Randle, and Stewart, 1975).

The explanation as to why this rather significant accommodation shift should only be apparent during the presentation of a fixed-focus (near) target is, as yet, unclear. Certainly, it would be understandable that such a far shift would not be expected to occur during presentation of a 0.0D (far) target because of certain boundary effects; that is, the eye is physically incapable of accommodating beyond its far point.

Common sense might suggest that presentation of a fixed-focus target would cause accommodation to "anchor" itself to that target, not unlike a visual capture phenomenon. This is certainly not the case, for if there is a visual capture tending to focus to the near target, there is an equally powerful opposing force tending to push accommodation towards the far point.

It must be stressed that, although large individual differences in the so-called resting position of accommodation have been reported (Leibowitz and Owens, 1975), these differences have not been well examined. Figure 5 shows the large individual variations in the mean accommodation resting position calculated at both the beginning and end of the experimental session and over the five-day period for Phase 1. As can be seen, from this study day-to-day and even task-to-task variations are observed, making this phenomenon even more fertile ground for speculation. Therefore, the apparent trend of extended empty field responses shown in both Figures 3 and 4 should probably be disregarded.

The interaction effect of Target Distance (OD, 3D) × Time Blocks × Time Intervals, using only the OD and 3D Target Distances (see Table VI,

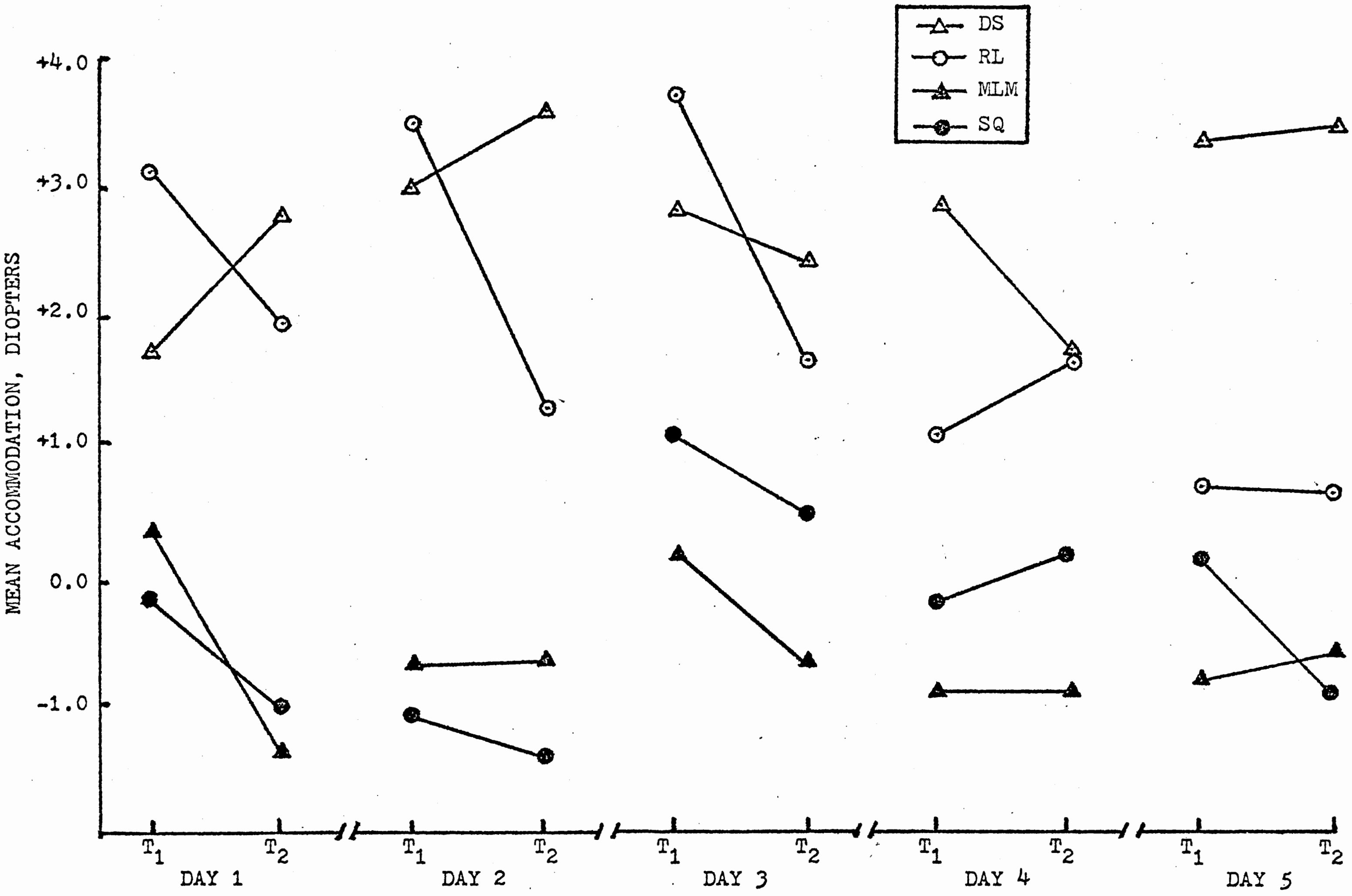


Figure 5. Individual Variations in the Resting Position of Accommodation by Day and by Beginning (T_1) and End (T_2) of Each Experimental Session

Appendix B), indicates, first, that the far accommodation shift effects are only compounded over time. That is, the longer the counting task continues, the more severe the shift. Second, the "gap" of about 0.2D between the 3.0D (near) conditions of the end of Time Block 1 and the beginning of Time Block 2 (see Figure 4) suggests an information "loading" response. That is, the five-second interval where the subject is passively receiving instructions to count backwards is sufficient to initiate a far accommodation shift. Hence, there is a distinct possibility that nearly _any_ information processing, even a passive monitoring of instructions, could be expected to start an accommodation shift in motion.

The original impetus for observing a small number of subjects over a long (five-day) period was to assess the possibility that the accommodation shift during the Secondary Task might be amenable to learning effects. That is, if the subject were to become adapted to both the Primary and Secondary Tasks, one could expect the accommodation shift to disappear. Although there was some significant improvement, for example, on the performance of the Secondary Task from Days 4 to 5 (e.g., see Figure 18), there was no such lessening of the accommodation shift to the far direction by days of practice for Phase 1 or Phase 2. Most of the improvement in performance lies with the Secondary Task and not the Primary Task.

Dynamic Accommodation Experiment

Phase 1. Sine Wave Tracking Response

Amplitude. Figure 6 is a reproduction of actual data obtained on

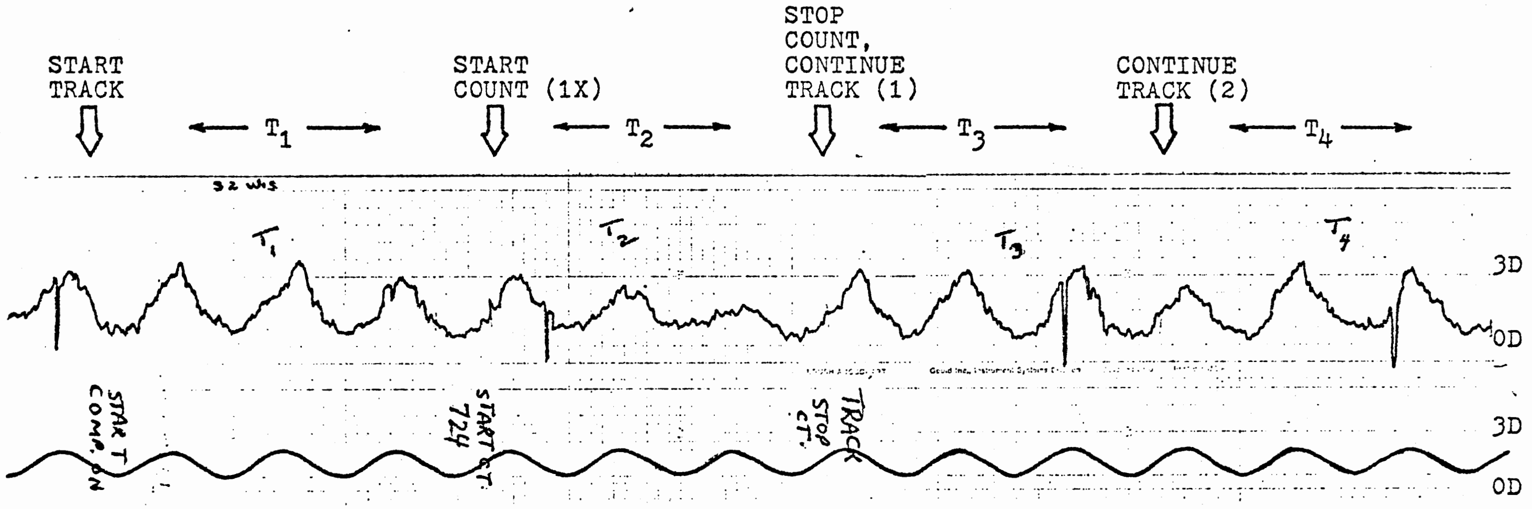


Figure 6. Dynamic Accommodation Experiment. Representative Raw Data From a Subject (MLM) Tracking the 0.1 Hz. Sine Wave, Day 2

Day 2 from subject MLM. The particular task was a Secondary 1X backwards counting task (Mental) and a Primary 0.1 hz. Sine Wave tracking task. The data pictured are typical for this sort of task, showing a suppression of peak responses during the Secondary task (Time Block T_2), with a particular accommodation shift to the far (0.0D) point. Cell means for the Peak-to-Peak Amplitude responses as a function of Time Blocks and Task are plotted on Figure 7. Analysis of variance for Amplitude shows a significant main effect for Time Blocks to the far direction $\underline{F}(3,9) = 5.711$, $\underline{p} < 0.02$. There is also a single two-way interaction effect for Time Blocks × Task (Mental-Written), $\underline{F}(3,9) = 4.817$, $\underline{p} < 0.05$. (The complete analysis of variance summary is shown as Table VII, Appendix B.)

During performance of the Secondary Task, there is a very characteristic decrease in Amplitude, whether the Task is mental or written counting. In this instance, the mental task tended to show the smallest effect relative to the base and rebase periods (see Figure 7). This smaller effect appears to parallel a similar pupillary response experiment by Kahneman, Peavler, and Onuska (1968) in which subjects were required to either respond verbally or only think of answers to a concurrent mental task. In Kahneman, Peavler, and Onuska (1968), greater pupillary dilation was found for the verbal than for the mental response. Accommodation or pupillary response differences would imply that there is a certain amount of output interference by the method of response; however, it should not be overlooked that the main effect of differences between Time Blocks applies for the mental as well as the written task. It also appears that recovery from the accommodation shift is slower after the mental task. This sluggishness in recovery

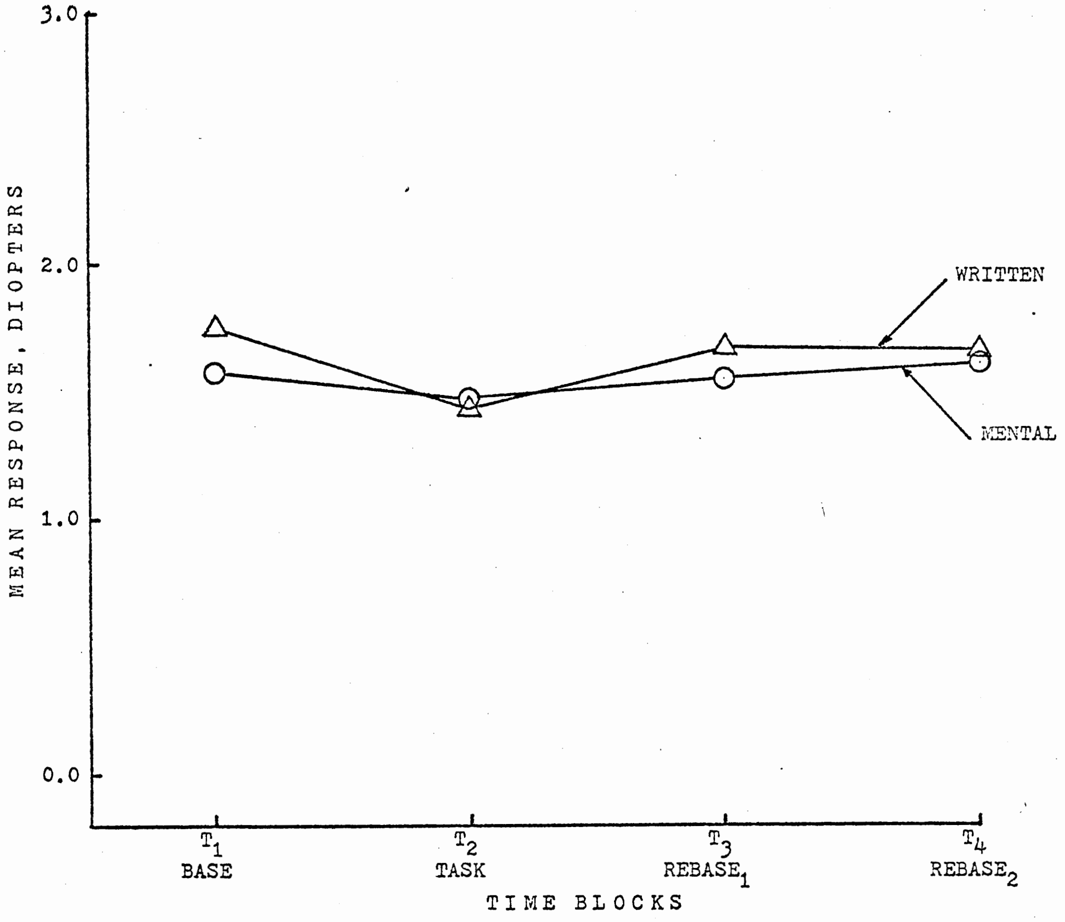


Figure 7. Dynamic Accommodation Experiment, Phase 1. Peak-to-Peak Amplitude Sine Wave Tracking Responses Plotted as a Function of Written and Mental Tasks and Time Blocks

could well be due to the fact that the subject is mentally retaining his answer until the end of the T_4 Time Block, whereas during the written counting Task, the subject has already written his final answer at the end of T_2 Time Block and has no further need to retain the answer. Perhaps a better method of determining whether retaining an answer in short-term memory would induce an accommodation shift to the far direction would have been to have the subject write down his single answer at the conclusion of the T_2 (mental Task) Time Block.

Phase Lag. Figure 8 depicts cell means of Phase Lag, shown in both secs. and degrees, as a function of the stimulus Frequency. An analysis of variance for Phase Lag [measured only in secs. (time units)] shows a single main effect for Frequency (0.1 hz., 0.2 hz., 0.4 hz.) of the moving target stimulus, $F(2,6) = 24.239$, $p < 0.0025$. (Appendix B, Table VIII shows the complete summary table.)

The shift in Phase Lag appears to be solely due to the speed of the moving target and is unaffected by the Secondary task interference. Thus, it would appear that, for this experiment, the time required for the initiation of an accommodation response on a target which changes focus smoothly is primarily reflexive and not volitional. This should not be construed as lack of support for the experiment of Randle and Murphy (1974) who found a definite and steady decrease in Phase Lag over a seven-day period. Their experiment included over five times the number of observations. For the purposes of the present experiment, there was no evidence that Phase Lag improves with practice. It should also be noted that there was a similar negative finding for Latency during Phase 2. (Latency with the Square wave response might be

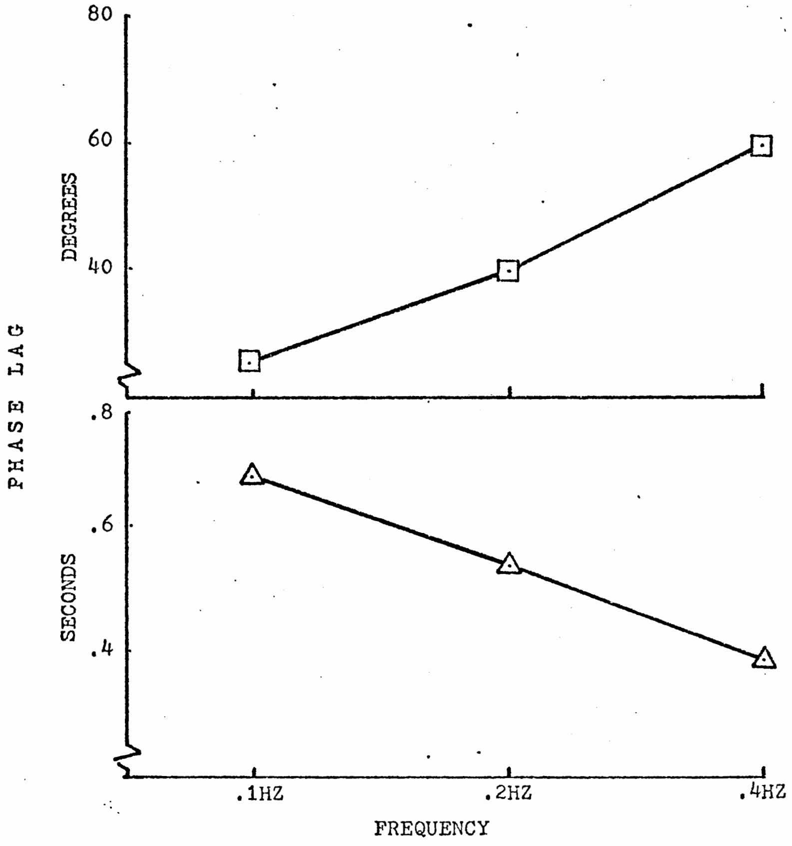


Figure 8. Mean Phase Lag Values Plotted as a Function of Target Stimulus Frequencies

considered analogous to Phase Lag with the Sine wave response.)

There is an apparent anomaly when Phase Lag is viewed first in time units of seconds and then in physical distance of degrees. The process of converting Phase Lag seconds to degrees reveals that, although the amount of time the subject lags behind a target actually decreases as the Frequency of the moving target is stepped up, the physical distance the subject lags behind the target increases. There is also a possibility the (timewise) decrease in Phase Lag as Frequency is increased may be a compensatory accommodative mechanism to keep tracking from falling too far behind the stimulus movement.

Phase 2. Square Wave Tracking Response

A more parsimonious description of the Magnitude and Direction of the Square wave tracking response will be used from this point on, except when noted. Because both the Near (Pulse Track) and Far (Zero Track) responses could be included in the same analysis of variance, the Magnitude dependent variable will appear as differences between the Zero and Pulse Track. It also follows that differences, or changes in Magnitude, will appear as interaction effects with the Zero-Pulse Track variable. Therefore, these interaction effects are indications of Direction accommodation shifts.

Figure 9 is a reproduction of actual data obtained on Day 5 from subject DS. The particular task was a Secondary 7X backwards counting task (written) and a Primary 0.2 hz. Square wave tracking task. The data pictured are typical for this sort of task, showing a suppression of tracking responses during the Secondary task (Time Block T_2), with a particular accommodation shift to the Zero Track (far point).

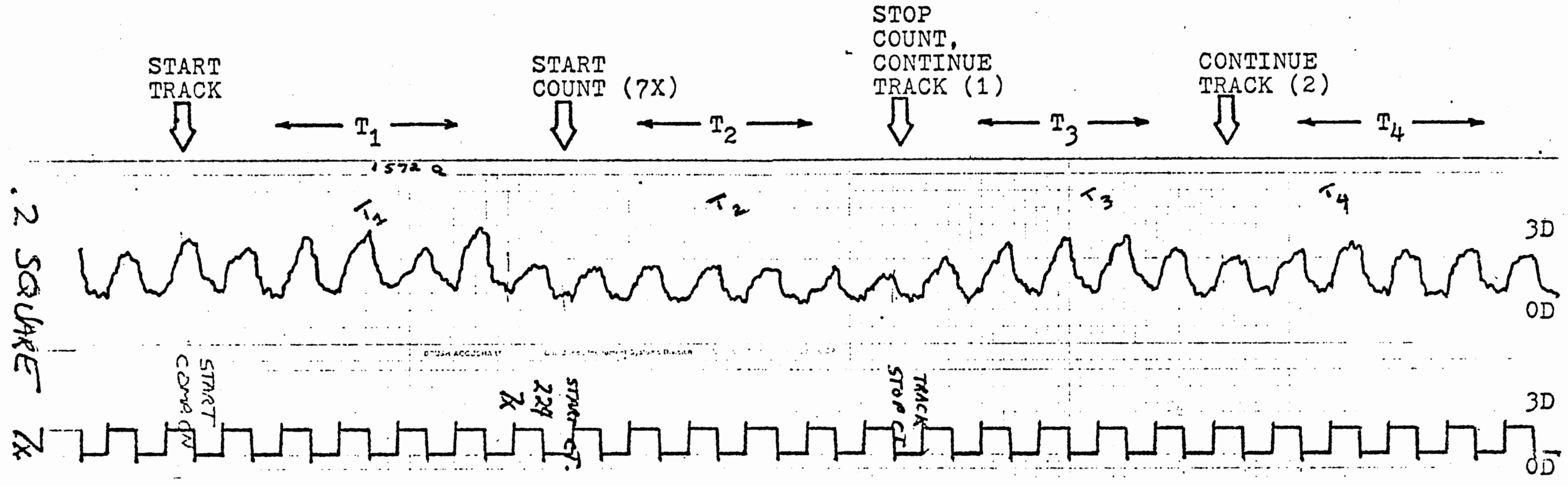


Figure 9. Dynamic Accommodation Experiment. Representative Raw Data From a Subject (DS) Tracking the 0.2 Hz. Square Wave, Day 5

Magnitude and Direction. Cell means of the Zero-Pulse Track values, plotted as a function of Time Blocks, are shown in Figure 10. Also, the cell means of the Zero-Pulse Track values, plotted as a function of the target stimulus Frequencies, are shown in Figure 11. The analysis of variance for the Magnitude and Direction variables shows a significant main effect for differences between Zero and Pulse Track, $F(1,3) = 108.242$, $p < 0.0025$. There are also two related two-way interaction effects; one for Time Blocks × Zero-Pulse Track, $F(3,9) = 7.163$, $p < 0.01$, and the other for stimulus Frequency × Zero-Pulse Track, $F(2,6) = 144.367$, $p < 0.001$. (The analysis of variance summary table is presented in Appendix B as Table IX.) Again, it should be noted in the analysis of variance, that differences between the Zero and Pulse Track functions are, of course, the Magnitudes; and the variations in these magnitudes are the Directions of the shift.

Similar to the findings for a Static target, there also appears to be a relinquishing of focus on the Pulse (3.0D) Track as it moves near. The Zero Track appears relatively unaffected (see Figure 10). Thus, although it appears that the eye is tracking targets well at the far point, it is almost as if a boundary has been established during performance of the Secondary task, beyond which the accommodative system will not venture. One might, perhaps, understand the eye losing focus on a static target as it remains near during a Secondary task on the grounds of a reduced processing capacity; however, during the Dynamic accommodation Phases, the eye is obviously maintaining track as the target moves at the far and intermediate ranges, only to lose it as it moves in close. The eye then appears to wait for the target to emerge from its near extreme before reacquiring it. The raw data recordings

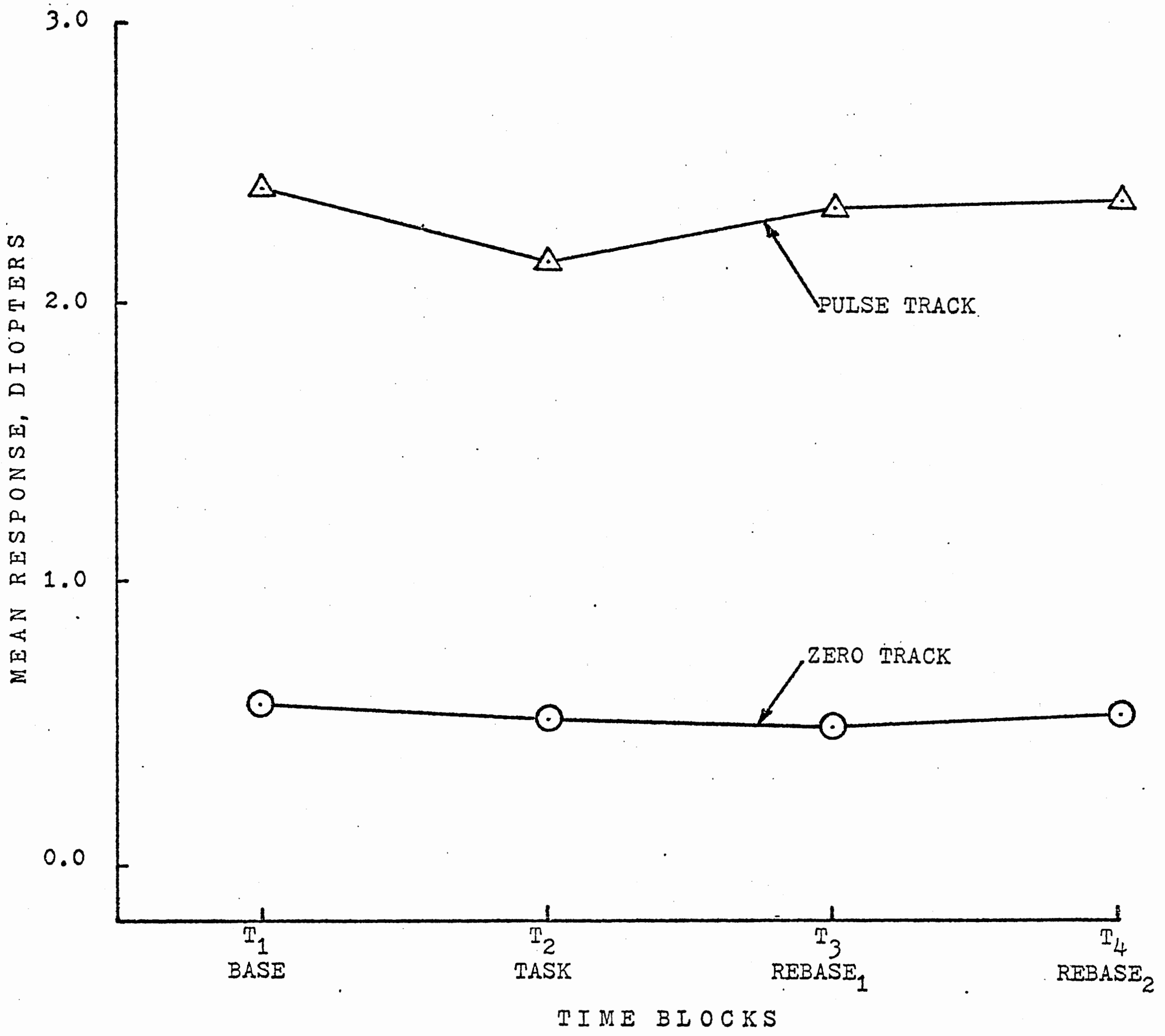


Figure 10. Mean Zero and Pulse Track Values Plotted as a Function of Time Blocks

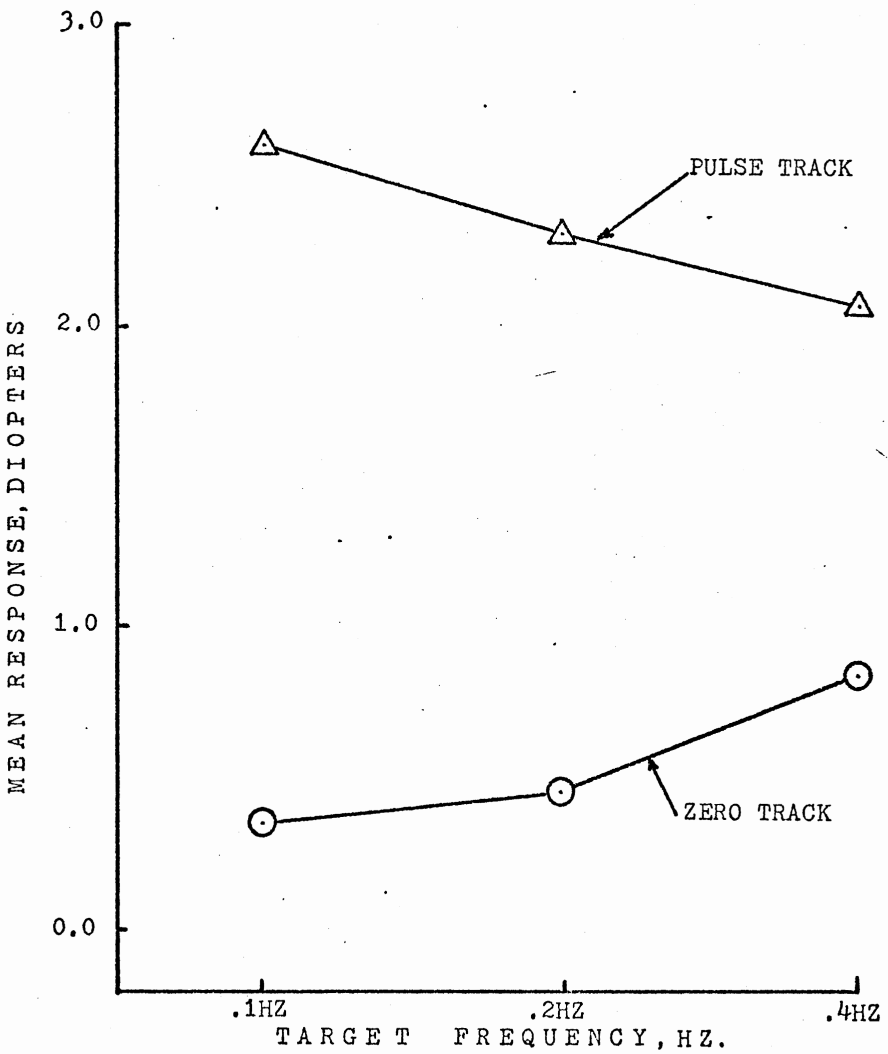


Figure 11. Mean Zero and Pulse Track Values Plotted as a Function of Target Stimulus Frequencies

presented in Figures 6 and 9 bear out this point. Also, as there are no indications that the magnitude of accommodation recovers with trial days, the lack of a learning effect is interpreted as indication that the reduced accommodation magnitude is both an involuntary and inherent effect. It is not overcome by practice.

Although the accommodation shift can be, in part, determined by the nature of the Secondary task, such a shift does not appear to follow an intermediate-resting-state of accommodation model (the shift observed here is only one-sided). The nature of the response to the Primary task may well follow such a model. It will be noted that there was a substantial two-way interaction effect of Target Frequency × Zero-Pulse Track (see Figure 11). It would, thus, appear from the trend of this figure that if the target were cycling fast enough between a near and far point so that the accommodative system could not track the target, the eye might well settle for the intermediate value of these extremes of the target movement.

Latency. Cell means for Latency as a function of stimulus Frequency are plotted in Figure 12. An analysis of variance for Latency shows a significant main effect only for stimulus Frequency, $F(2,6) = 18.886$, $p < 0.005$. There is also a single two-way interaction effect for Time Blocks × Days (1 through 3), $F(6,18) = 4.778$, $p < 0.005$. (The analysis of variance summary table can be seen in Appendix B, Table X.)

Variations in Latency appear mostly due to changes in the Primary Task target stimulus Frequency rather than any addition of or changes in a Secondary Task. There was an observed two-way interaction effect of Time Blocks × Days; however, for this effect it must be stated that

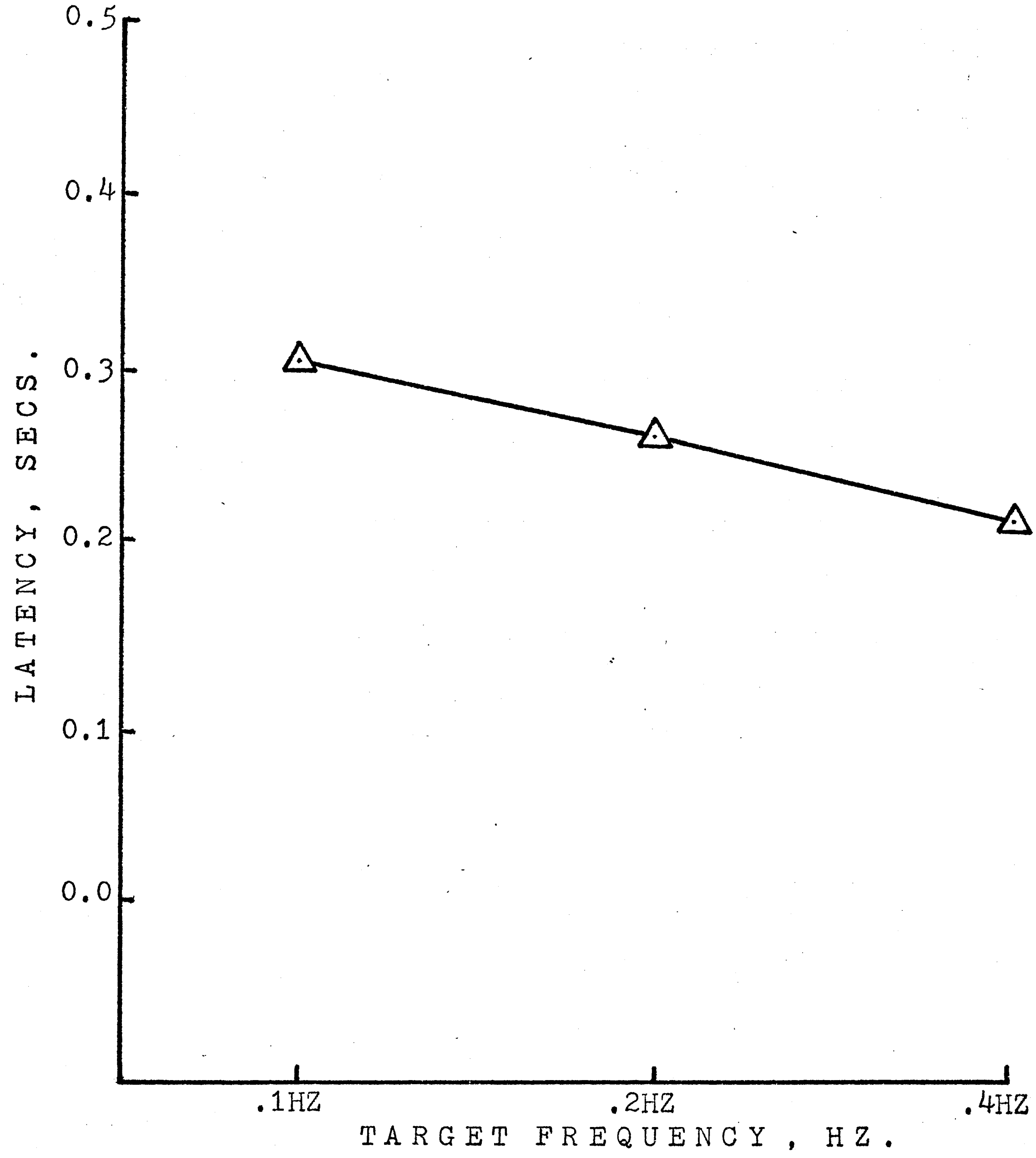


Figure 12. Mean Response Latency Values Plotted as a Function of Target Frequencies

on two of the three days, Latency was shorter during the T_2 (Secondary Task) period, rather than longer as might be expected if the subject were attending to two equally important tasks. Hence, this Time Blocks × Days interaction is not supportive of any particular neurological or attentional model.

Velocity. Cell means for Velocity in diopters/sec. as a function of target Frequency are plotted in Figure 13. An analysis of variance for velocity shows a significant two-way interaction effect for stimulus Frequency × Direction (Approaching-Receding), $F(2,6) = 5.782$, $p < 0.05$. There is also a single three-way interaction for Time Blocks × Days (1 through 3) × Task (Mental-Written), $F(6,18) = 2.470$. In addition, there are two four-way interaction effects of Time Blocks × Days × Task × Frequency, $F(12,36) = 2.100$, $p < 0.05$, and for Time Blocks × Days × Task × Target Direction, $F(6,18) = 2.988$, $p < 0.05$. The complete analysis of variance summary for Phase 2 Velocity is found in Appendix B as Table XI.

The question of whether accommodation on an approaching or receding target is faster still remains unanswered. Contrary to Randle and Murphy (1974), this study appears to show that the velocity of accommodation for these subjects was faster on approaching targets. However, at low speeds (0.1 hz.), the difference in velocity was negligible (see Figure 13). The only conclusion which can be made about the velocity of accommodation is that it is subject to a wide variety of individual differences and may vary from day to day and task to task. Under the conditions of both this study and Randle and Murphy (1974), individual differences may make the velocity of accommodation the least predictable

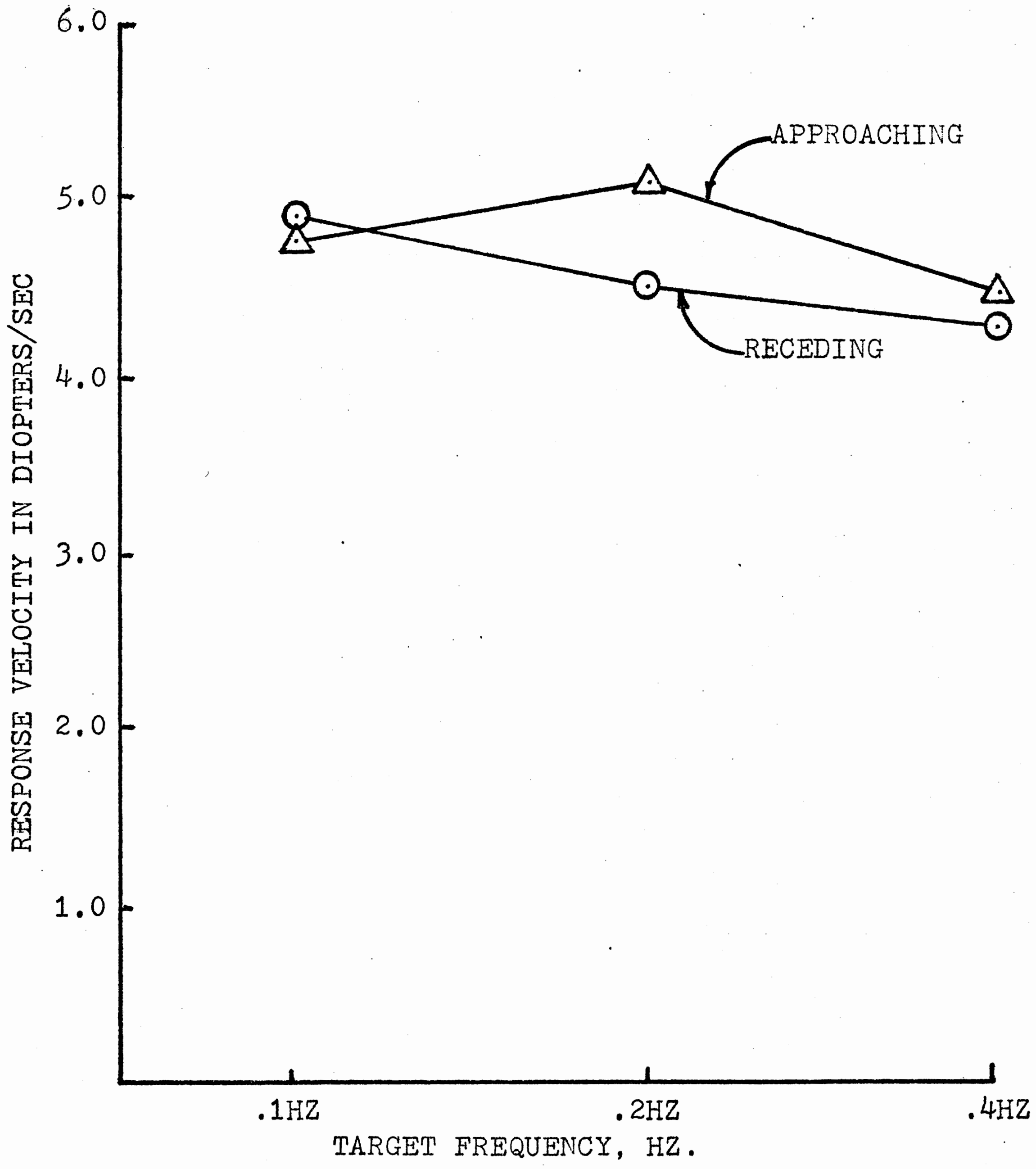


Figure 13. Mean Approaching and Receding Response Velocities Plotted as a Function of Target Frequencies

of all the dependent variables.

Phase 3. 0.2 Hz. Square Wave (Days 1 to 5)

An analysis of variance for the 0.2 hz. target tracked over five consecutive days shows only a single main effect for the Zero-Pulse Track dependent variable, $\underline{F}(1,3) = 85.152$, $\underline{p} < 0.005$. There were no other significant effects noted for either Magnitude, Direction, Latency, nor Velocity. Analysis of variance summary tables for the Zero-Pulse Track, Latency, and Velocity can be found in Appendix B, Tables XII, XIII, and XIV, respectively.

The central purpose of this phase of the experiment was to determine the effects of practice on the suspected accommodation shift, using a single, well-observed target frequency. The 0.2 hz. Square wave was chosen because previous pilot studies had shown it to be one of the more reliable waveforms which would show the accommodation shift. It is noteworthy that the critical main effect of Days (1 through 5) did not reach an acceptable level of significance, nor were there any interaction effects which would implicate changes in Latency or Velocity by Days. It should also be noted that the accommodation far shift, which has been appearing significant with regularity in the previous experiments, also failed to show an acceptable level of significance. However, this lack of significance is not considered particularly disappointing, as it could be mostly attributed to a drastically reduced amount of data and degrees of freedom from other Phases (see Chapter II, Figure 2, for the Block Schematic of Phases). Even with the reduced degrees of freedom, the Time Blocks × Zero-Pulse Track interaction came remarkably close to meeting an acceptable significance level (see also Appendix B, Table XII).

Phase 4. Difficulty of the Secondary Task

Data analysis from Phase 4 was broken into two distinct comparisons using analysis of variance. The first comparison was made with four Difficulty levels of the Secondary Task (1X, 3X, 7X, and NX). Because the NX (do not count, ignore the target) special condition was only administered at the end of the experimental session and because it could not truly be called a counting task, another comparison was made using only the three Difficulty levels (1X, 3X, 7X) of the Secondary task. Analyses used comparing the NX Difficulty level are presented for informational purposes only.

Magnitude and Direction. Cell means of the three collapsed Difficulty levels (1X, 3X, 7X) and the NX level plotted as a function of Zero-Pulse Track and Time Blocks are shown in Figure 14. For the four Difficulty Levels there is a single main effect for the Zero-Pulse Track, $F(1,3) = 53.75$, $p < 0.005$. There is a single two-way interaction for Time Blocks × Zero-Pulse Track, $F(3,9) = 35.80$, $p < 0.0005$; and there is a single three-way interaction effect of Time Blocks × Zero-Pulse Track × Difficulty levels (1X, 3X, 7X, NX), $F(9,27) = 4.804$, $p < 0.001$. (The analysis of variance summary table is presented in Appendix B as Table XV.)

An analysis of variance for the same model using only three Difficulty Levels (1X, 3X, 7X) shows a significant main effect for the Zero-Pulse Track, $F(1,3) = 56.655$, $p < 0.005$, and an additional two-way interaction of Time Blocks × Zero-Pulse Track effect, $F(3,9) = 8.506$,

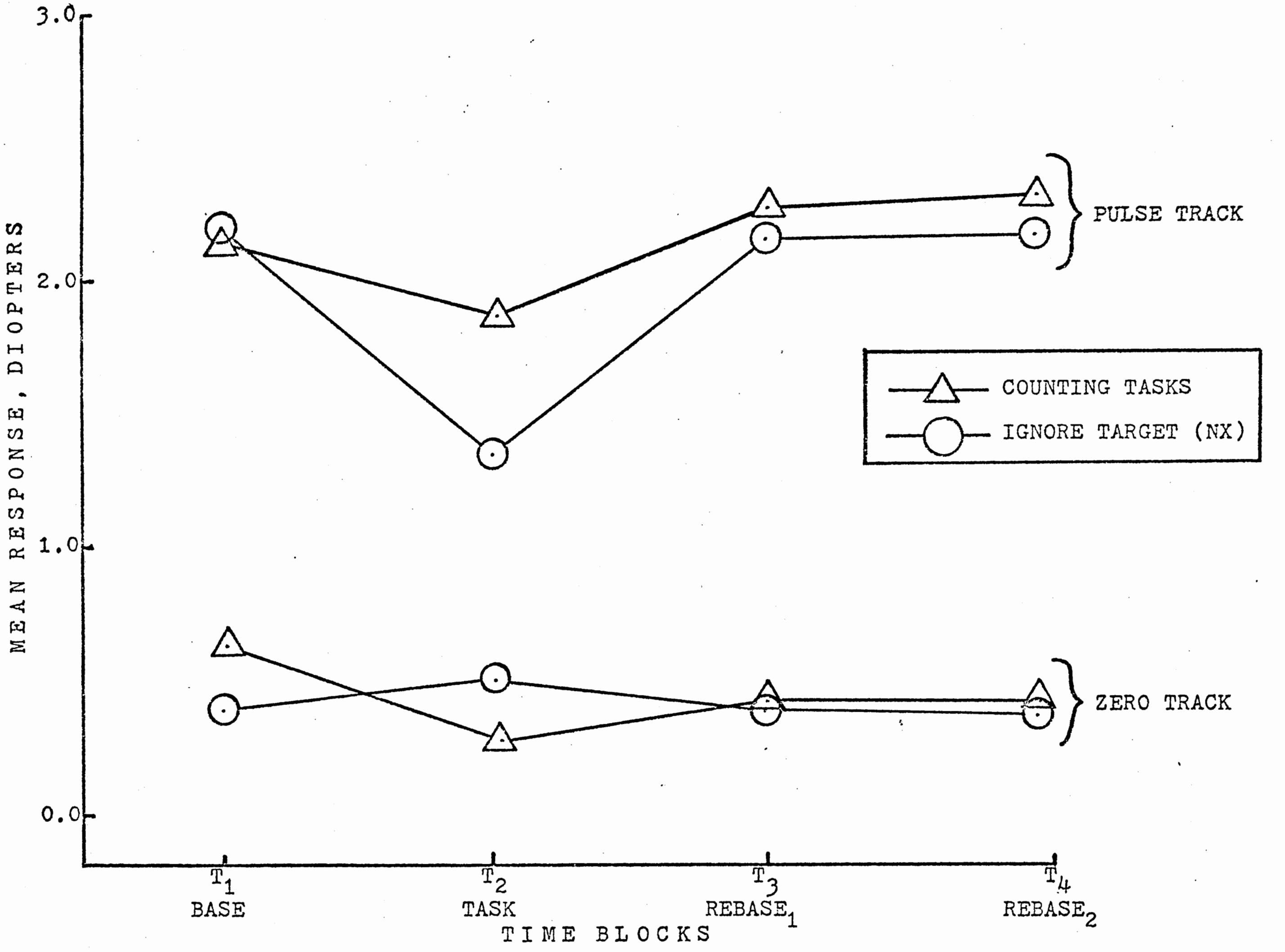


Figure 14. Mean and Zero Track Values Plotted as a Function of Counting and NX Tasks by Time Blocks

$p < 0.01$. (The analysis of variance summary table is shown in Appendix B, Table XVI.)

The central purpose of Phase 4 was to discover whether the degree of Difficulty of the Secondary task would affect the amount of accommodation far shift. To examine this possibility further, Phase 4 must be looked at both with and without the inclusion of the NX (ignore the target; do not count) task. Comparisons of the NX task to the other varying Difficulty Level tasks (1X, 3X, 7X) were to determine whether the two types of tasks showed similar task-related accommodation shifts. If the accommodation shifts were similar, it could be concluded that a concurrent mental task, indeed, caused the eye to "ignore" the moving target. Such a similarity of shift would, therefore, support a Capacity Model of information processing.

The results for the analysis of variance including only the three Difficulty levels (1X, 3X, 7X) showed only effects for the Magnitude and Direction of shift. There was no indication that the varying degree of difficulty made any difference in the amount of shift observed. This was an unexpected finding. Although this negative result could be described as disappointing, there are several possibilities to explain such a lack of significance. Obviously, the lack of observations in Phase 4 could have been a major factor. A more likely explanation, however, lies in the manner of subject selection. The subjects were selected on two major criteria. First, they had exceptionally good vision and accommodative ability; and second, they had well above the average education and intelligence. Therefore, it is quite possible that this experiment might have been limited to subjects less likely to show increased accommodation shifts to a, perhaps, rather boring and uncreative Secondary task. Certainly, previous pilot studies have shown subjects to exhibit larger shifts with increasingly more difficult Secondary tasks. The experiment by Randle, Roscoe, and Petitt (in preparation) showed increasingly greater accommodation shifts by commercial airline pilots when performing critical decisions on a simulated night landing task. Moreover, in Randle, Roscoe, and Petitt's experiment, the decision was intimately related to the visual task; in the present study, conceivably, the subjects could elect to forgo either the Secondary or Primary task without any immediate penalty (e.g., a crash landing). In the simulated landing experiment, the nature of the Secondary task would appear to be somewhat more challenging than a backwards counting task. A larger sample of subjects more representative of the general population or else a task more in line with the abilities of the subjects should tend to show a greater accommodation far shift as the difficulty of the task is increased. Of course, there exists the possibility that the accommodation far shift is an all-or-nothing phenomena, but this possibility does not fit well either with previous pilot studies nor with the nature of the pupillary response.

The analysis of variance for the four Difficulty levels (1X, 3X, 7X, NX) of Secondary task shows effects for Magnitude and Direction of the accommodation shift and for the four Difficulty levels. However, in comparison to the three Difficulty level analysis, there is evidence that the NX task accounts for most of the variance in the effect of the degree of Difficulty. Figure 14 indicates that the magnitude of accommodation during the NX Secondary task is much less. In addition, the indicated direction of the accommodation shift is misleading. The mean between the NX Zero and Pulse track T_2 values appears to be about

1.0 diopter, and this NX condition would appear to be settling towards a resting position of 1.0 diopter. But an examination of the actual raw data reveals this is not the case. Three of the subjects, when instructed to "ignore the target," let their accommodation slip to the far side of the target movement. Figure 15 shows subject DS, day 5, who ignored the target in this typical manner. It can also be seen that there is also some involuntary tracking of the target while the subject is "ignoring" the target. Indeed, there is also a reduced velocity of accommodation to about 3.0D/sec. during this T_2 period, but it does not, as might be expected, fall to zero.

The other subject, curiously, when instructed to "ignore the target," shifted his accommodation to a point <u>inside</u> the target movement. Figure 16 shows subject MLM "ignoring" the target movement on day 4. Again, it can be seen that there is still some residual, involuntary tracking of the target, even though the subject believes he is ignoring the focus stimulator changes. Incidentally, the near accommodation shift during an NX task, while unusual, is by no means unique. It has been observed in other pilot subjects.

The implications of a non-uniform accommodation shift while ignoring a target are several. First, it is suggested that the direction a subject shifts his accommodation from in order to ignore a target is largely arbitrary, so long as the shift occurs in a manner that the eye is focused <u>off</u> the target. Second, it has long been assumed that when a person "lets his mind go blank," accommodation necessarily slips to a resting position, long assumed to be the far point (Singer, 1974). Still others would suggest that this slippage of accommodation might move to a value around 1.0D or the individual resting position of

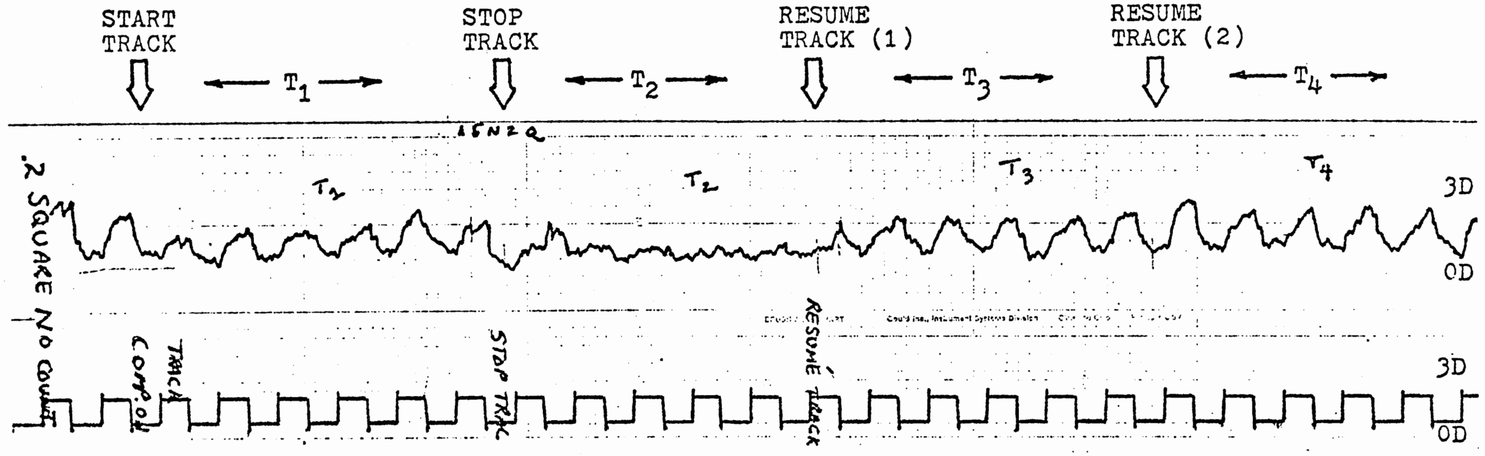


Figure 15. Raw Data From Subject (DS), Instructed to "Ignore the Target," Accommodates to the Far Point

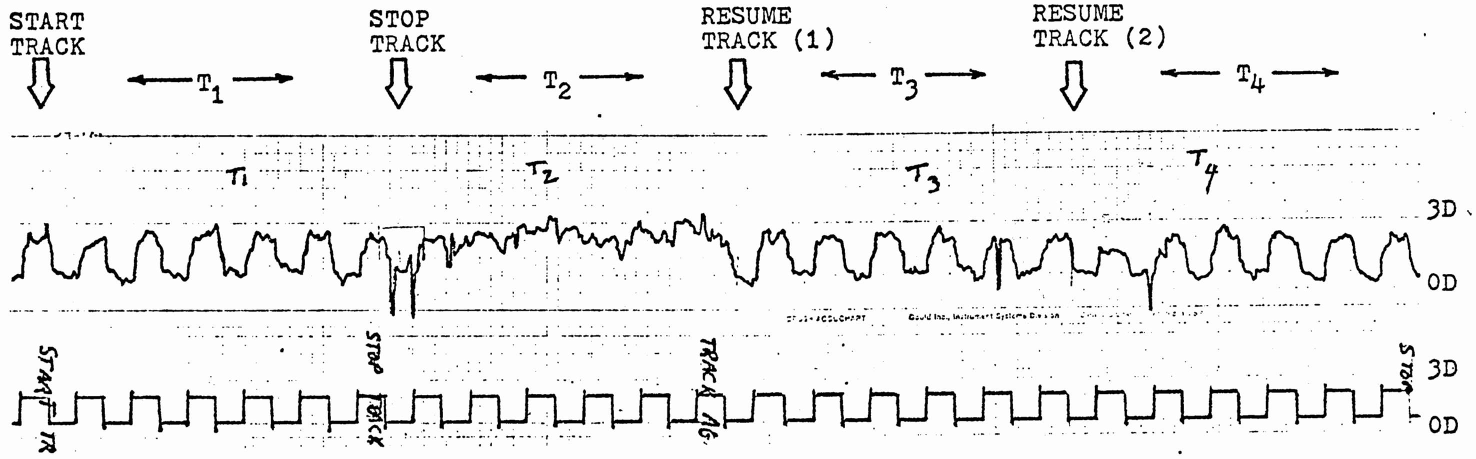


Figure 16. Raw Data From Subject (MLM), Instructed to "Ignore the Target," Accommodates to the Near Point

accommodation. The data presented here supports neither position. In actuality, MLM's empty field resting position was calculated to be around -0.8D (see Figure 5).

Latency. An analysis of variance for the four Difficulty levels (1X, 3X, 7X, NX) shows a single two-way interaction effect of Days (4 and 5) × four Difficulty levels, $F(3,9) = 6.183$, $p < 0.025$. (The summary table for the four Difficulty level analysis of variance can be found in Appendix B, Table XVII.) The analysis of variance for the three Difficulty levels yields a similar two-way interaction effect, $F(2,6) = 9.565$, $p < 0.025$. (This summary table for the analysis of variance is in Appendix B, Table XVIII.)

This interaction would suggest that the Difficulty levels, as measured by any Latency differences, were indistinguishable on day 4; but on day 5 the differences were again significant.

Velocity. Cell means for the three collapsed Difficulty levels (1X, 3X, 7X) and for the single NX task are shown in Figure 17. An analysis of variance for the four Difficulty levels of Secondary task shows only a single two-way interaction effect for the four Difficulty levels × Time Blocks $F(9,27) = 2.407$, $p < 0.05$. (The analysis of variance summary table can be found in Appendix B, Table XIX.) Analysis of variance for the three Difficulty levels of Secondary task reveals no significant effects whatever. (The summary table for this analysis of variance table is presented as Table XX, Appendix B.)

Comparisons of the four- and three-Difficulty levels of Secondary task reveals a substantial difference between the velocity of accommodation when a subject is both intentionally tracking and ignoring a

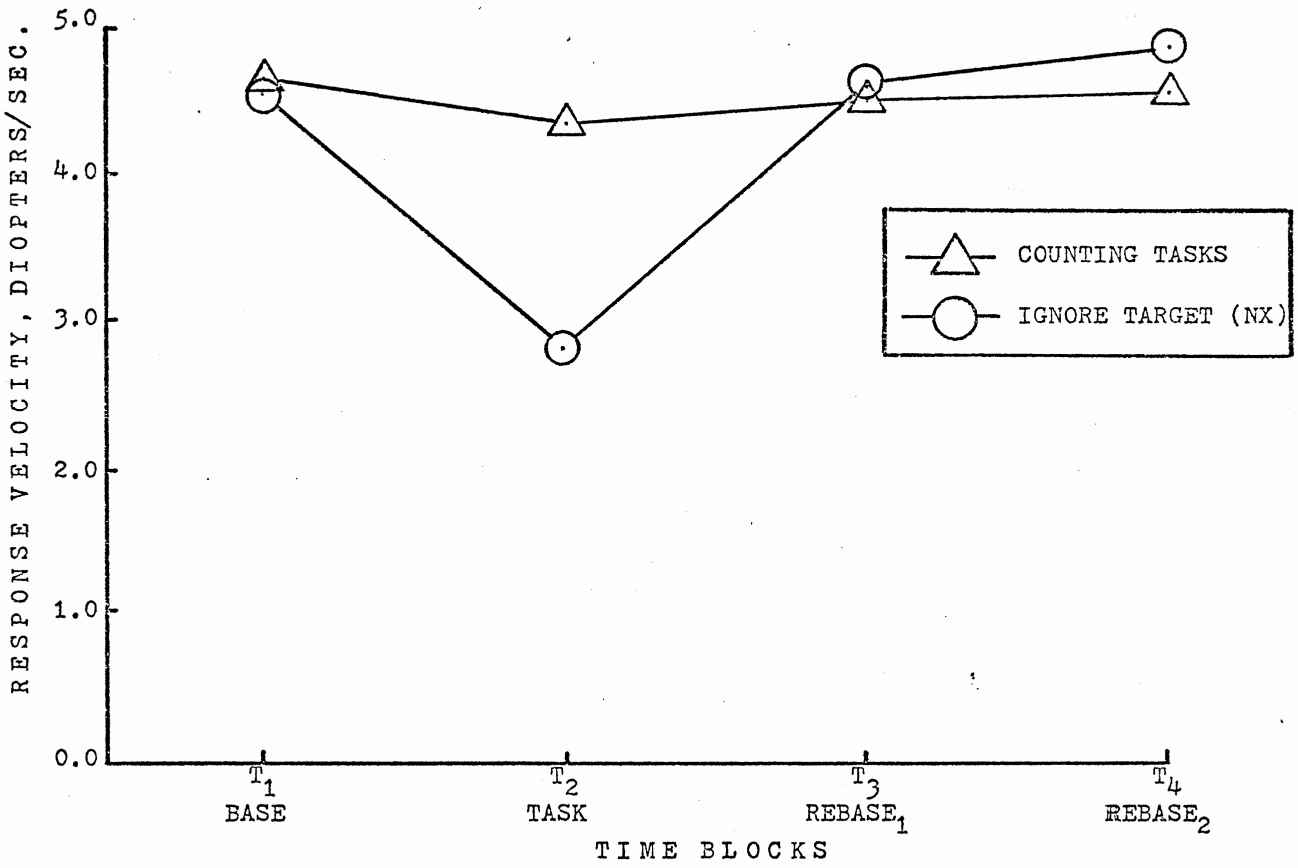


Figure 17. Mean Response Velocities Plotted as a Function of Counting and NX Tasks by Time Blocks

target changing in focus. However, the velocity of accommodation does not drop off to zero while the target is being ignored but merely slows to around 3.0D/sec. Inspection of the raw data shown in Figures 15 and 16 should reveal that there is a definite cyclical pattern of target tracking during the T_2 Time Block. The Fourier transform used in data reduction (see Appendix C) confirms this statement.

Secondary Task

A separate descriptive analysis of errors on the Secondary Task (backwards counting) was also tabulated. Different methods of scoring errors between the written and mental tasks were, of course, necessary. Whereas it was possible to recheck every counting step in the written task, only a final number, or solution, to the mental task was available to the experimenter at the end of each trial. The error on the mental counting task was merely the arithmetic difference between the number the subject arrived at and the number he should have arrived at. Base rates for mental backwards 1X counting task were zero; all base rates were arrived at by having the subject count backwards with his eyes closed. A table of the base error rates by subject for the written tasks, days 4 and 5, are listed in Table I.

Although it appeared initially that during Phase 1 and Phase 2 that the error rates for the written task were about half that of the mental task, when both tasks are scored on the same criterion, arithmetic deviation from the final "correct" number, the error deviations became more nearly equal. That is, the error deviation for the written task was 1.71 per trial and for the mental task was 2.03 per trial.

TABLE I

MEAN BASE ERROR RATES PER TRIAL ON SECONDARY TASK, DAYS 4 AND 5, BY SUBJECT

SUBJECT	1X	3X	7X
DS	0.0	0.0	0.0
SQ	0.0	4.5	5.5
MLM	0.0	0.0	3.5
RL	0.0	0.0	0.0

It was previously concluded that practice effects were not observed on the Primary tracking task. However, a descriptive analysis of the written task data indicates that there were rather striking practice effects on the Secondary counting task from days 4 to 5. Furthermore, these practice effects seem to become less pronounced the more difficult the nature of the Primary task becomes. Hence, there is a rather curious indication that, although the performance on the Primary task remains at a relatively constant level over days, performance on the Secondary task improves. Figure 18 shows the effects of practice on the Secondary task over days 4 and 5. The baseline rate is the Eyes Closed condition.

Because the Magnitude of accommodation shift appeared to be the most reliable dependent variable which indicated the addition of a Secondary task, it was decided to present an abbreviated scatterplot showing the subjects' Secondary task performance relative to his

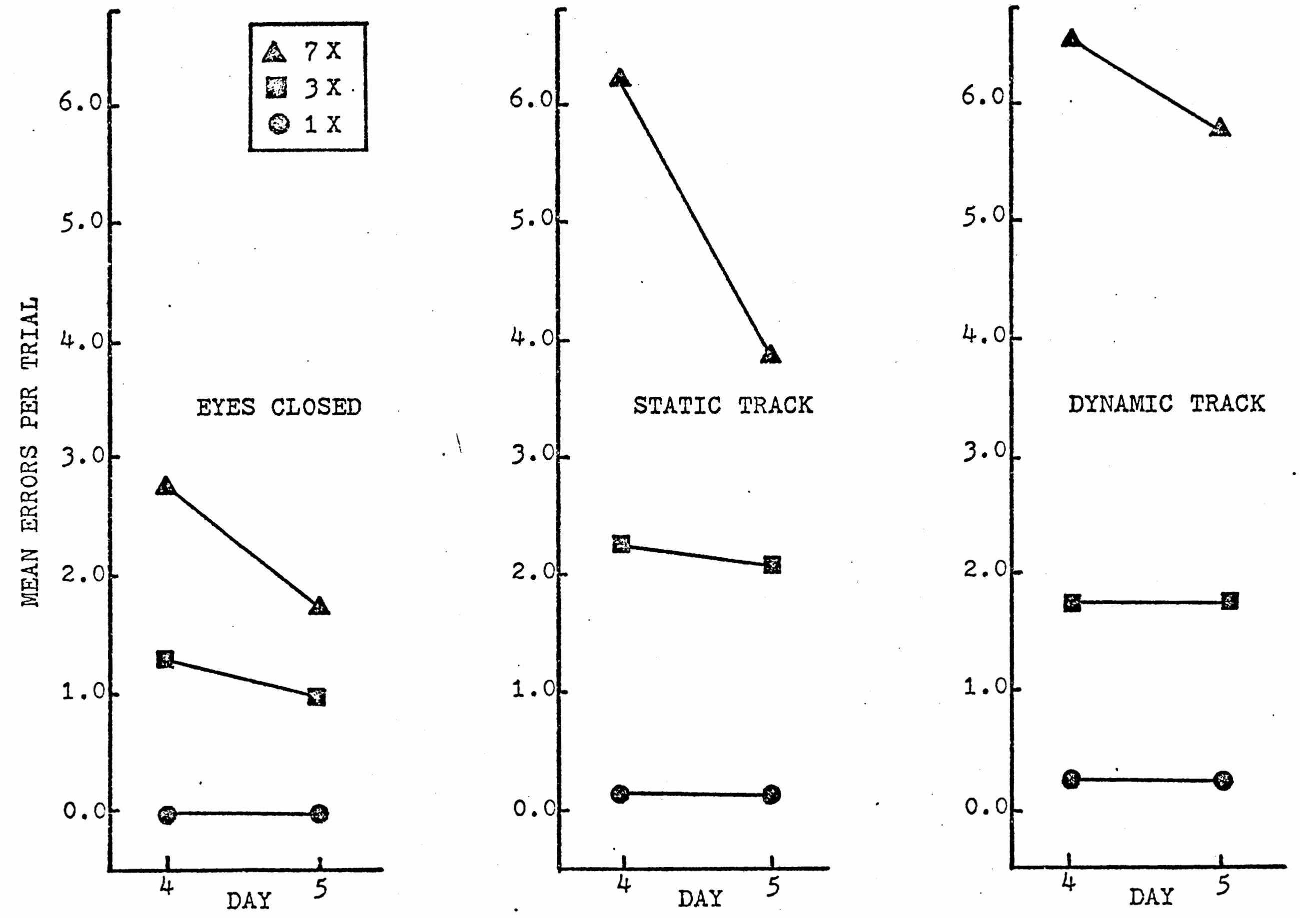


Figure 18. Effects of Practice on Written Secondary Task From Day 4 to 5. Mean Values of Errors per Trial on Eyes Closed (Baseline), Static Target, and Dynamic Target Conditions

Primary task performance. Figure 19 shows the individuals' average errors per trial as a function of average diopters shift from the 3D Static target. Similarly, Figure 20 shows a scatterplot of the individuals' average magnitude of accommodation shift during the 0.2 hz. Square wave tracking task on days 4 and 5, relative to their average error rates per trial.

Although it may be difficult to draw many firm conclusions about data trends from a scattergram containing only four points, the following statements appear justifiable. For three of the four subjects, it appears that the ones who showed the largest accommodation shift also performed more poorly on the Secondary task. The exception was subject SQ who appeared to have initially done so poorly on the 3X and 7X tasks that he gave up all attempts at further counting and appeared to concentrate only on the Primary tracking task. Examination of his 3X and 7X calculations revealed that he typically performed only three or four subtractions during the time the other subjects performed the usual fifteen. In addition, subject SQ showed a smaller accommodation shift during the 3X and 7X Secondary tasks, a further indication that he had given up attempts to perform the Secondary task.

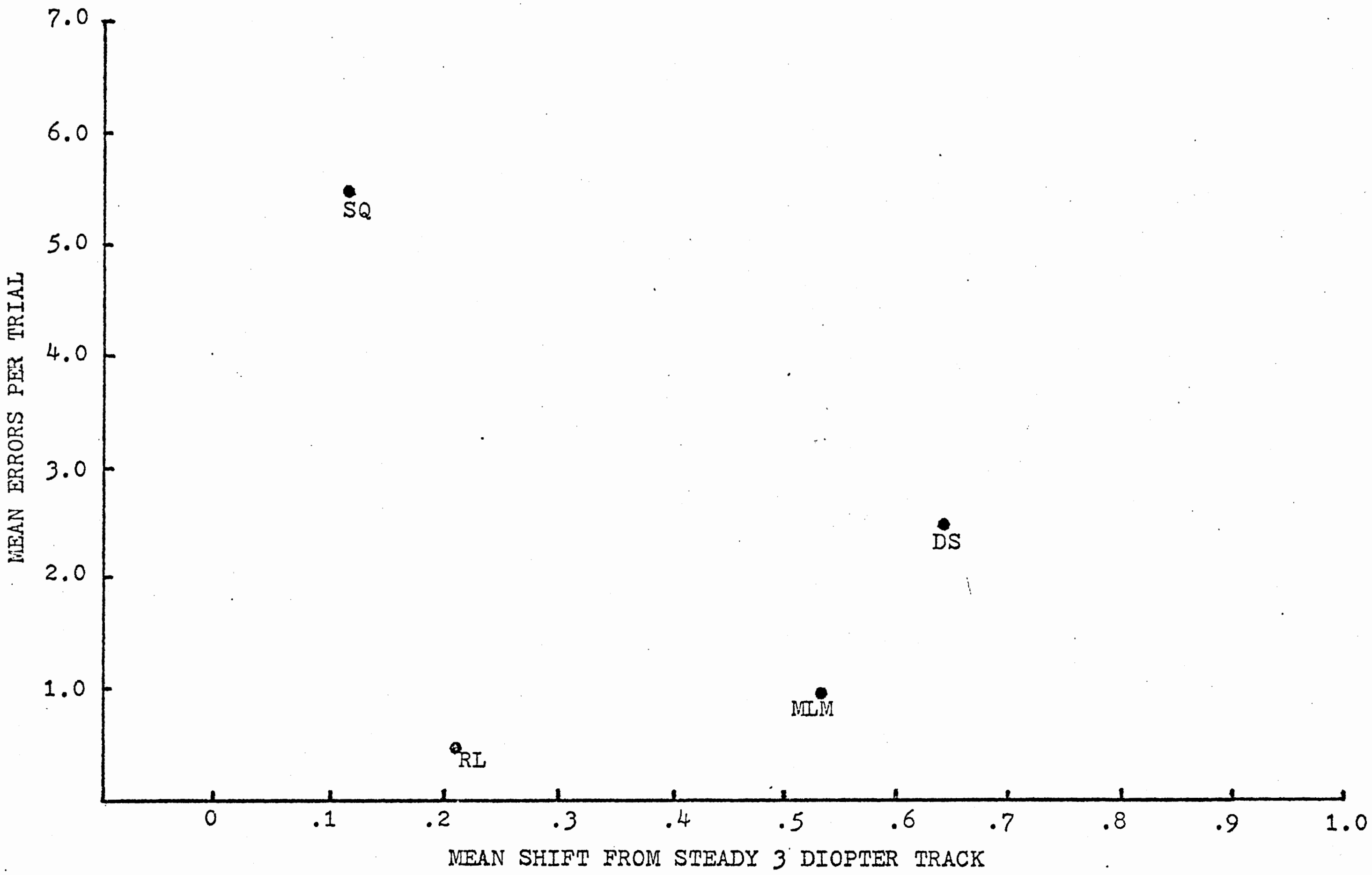


Figure 19. Static Accommodation Experiment. Subjects' Mean Number of Counting Errors per Trial as a Function of Their Mean Accommodation Shift From the 3 Diopter Steady Track

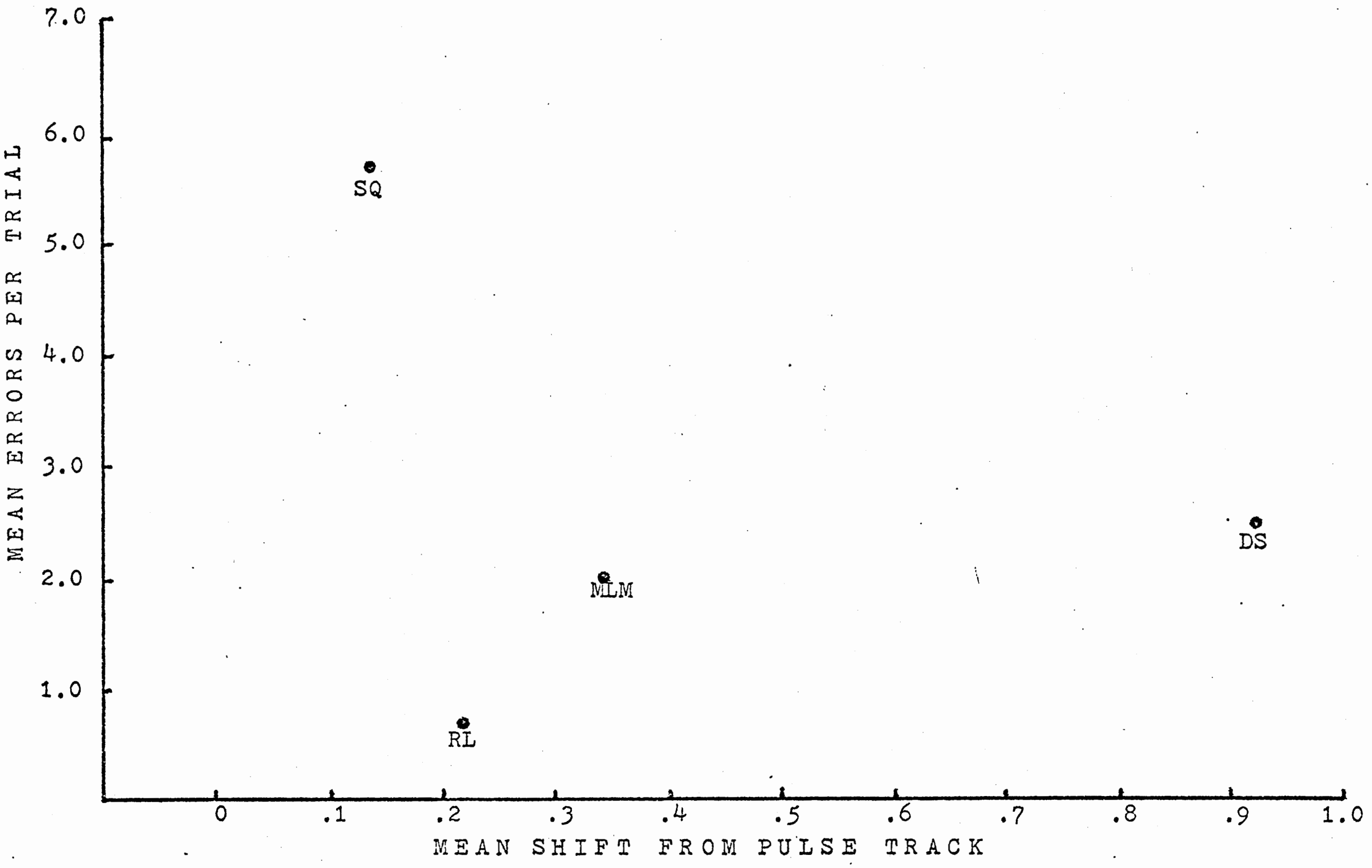


Figure 20. Dynamic Accommodation Experiment. Subjects' Mean Number of Counting Errors per Trial as a Function of Their Mean Accommodation Shift From the 3 Diopter Pulse Track

CHAPTER IV

GENERAL DISCUSSION

Overall, the findings of this study support neither a Capacity nor a Parasympathetic Arousal Model. The data do, however, strongly support a Sympathetic Arousal Model. It is of peculiar interest that the accommodation shift was most clearly seen when the eye was attempting to focus on a near target; the far accommodation shift was not observed under empty field (OL) conditions. The Sympathetic Arousal Model is quite in agreement with well-known pupillary dilation responses to mental loading (cf. Kahneman, Peavler, and Onuska, 1968). Furthermore, since accommodation and pupillary responses have long been known to operate quasi-dependently, this finding should not be unexpected.

An absence of the accommodation shift in the far direction during empty-field conditions should not be construed as evidence that no changes occurred but only that there may, as yet, be unaccounted-for effects during extended empty-field conditions. Certainly, as Roscoe and Benel (1978) have stressed, very little is known about the long-term effects of empty-field myopia. Westheimer (1957) observed a long-term rise in empty-field accommodation with the two subjects he intentionally insulted. (If, indeed, pupillary contraction and positive accommodation are indicators of parasympathetic arousal, Westheimer's subjects must have found the experience of being insulted a truly distasteful ordeal.) Quite possibly, such factors as subjects' attitudes or the involuntary "hunting" behavior of the accommodation system are topics for further research. For example, previous pilot work in the optometer laboratory using over ten subjects attempted to investigate accommodation responses to diverse concepts as "joy," "anger," and "death" in empty-field conditions. The subject responses usually produced some magnitude of accommodation change, although the direction of the shift was by no means predictable. Likewise, the (intentional) utterance of "accidental" obscenities or the intrusion of a sudden, loud noise nearly always produced an accommodation shift of unpredictable direction.

It appears that the addition of a Secondary task establishes an accommodation boundary beyond which the eye's near accommodation does not venture. This boundary establishes itself whether the target is moving or static. Furthermore, extended practice appears to make no difference in overcoming the shift. Hence, this finding is interpreted as evidence that the accommodation shift in the far direction is a neurological indicator of some degree of mental activity and not a tradeoff in processing capacity.

Residual effects from the accommodation shift in the far direction seem to last as long as one minute, although most subjects appeared to regain their normal range of accommodation within the first 30 seconds.

Within any particular static accommodation trial, continuation of a Secondary task only served to exaggerate the accommodation shift. The exact human adaptive value of such a response is unclear. From an evolutionary standpoint, it may well be that intense periods of mental activity coupled with the necessity to maintain an extended near focus (such as in reading or mathematical problem solving) are only very recent human endeavors. If it could be shown that, say, extended periods of reading and concentration were to involve a constant battle of an ongoing accommodation far shift and a recurring attempt to eliminate the retinal blur from the shift, such an opponent process would go a long way towards explaining subjective reports of long-term reading eye fatigue. In the past, reports of eye fatigue have been popularly ascribed to eye-muscle fatigue or even "psychological phenomena." Historically, the explanations for eye fatigue have been both unsatisfactory and insufficient.

Overall, Latency, Velocity, and Phase Lag show negative effects as functions of the Secondary task. The negative results of Latency and Velocity are possible indications that these dependent variables are more sensitive to variations in the target stimulus motion and distance than variations in the nature of the Secondary task.

It has not been established whether velocity of accommodation for an approaching target is faster than velocity for a receding target. There are large individual differences in abilities of velocity of accommodation, and it is quite possible that rapidity in approaching accommodation velocity could make substantial differences to persons requiring highly skilled hand-eye coordination, such as professional tennis or baseball players.

Subjects instructed to "ignore" a target changing in focus did not all show the same type of response as when they performed the Secondary counting tasks. Thus, it may be concluded that the observed Secondary task-related accommodation far shift is not identical to an allocation of processing capacity. Again, the Capacity Model is not supported insofar as it may be applied to visual accommodation and a Secondary task.

The observation that incremental accommodation shifts were not noted with increasing difficulty of the Secondary task may, in part, be attributable to the limited number and type of subject examined for this study. The high intelligence and exceptional accommodation control of these subjects may have led to a very conservative estimate of the eye's sensitivity to mental loading. In the long run, we are optimistic that the accommodation response may prove to be every bit as reliable an indicator of sympathetic and parasympathetic arousal as the pupillary response.

CHAPTER V

SUMMARY AND CONCLUSIONS

The original impetus of this study was to investigate the nature of an accommodation range restriction during a concurrent mental backwards counting task. Of particular interest were the magnitude and direction of the shift and the long-term effects of practice on this accommodation range restriction. The preponderance of evidence in this study pointed to the conclusion that the addition of a Secondary, concurrent mental task resulted in an overall shift of accommodation of about 0.3 diopter from a 3.0 diopter (near) target towards the far point. Furthermore, this accommodation shift in the far direction was strongly in agreement with a general Sympathetic Arousal Model, much like the well-established pupillary dilation response.

The nature of the accommodation shift which was attributable to the Secondary task appears to have several curious and important ramifications:

(1) The shift to the far direction occurs whether or not the target observed is moving or stationary. A concurrent mental task appears to establish a boundary within which accommodation does not occur.

(2) The accommodation shift was only observed away from the near (3 diopter) target and not at all in empty-field conditions. Furthermore, the far accommodation shift became more intense

the longer the Secondary task continued.

(3) Recovery of the normal range of accommodation, while sometimes instantaneous, often took as long as 20 to 40 seconds. Thus, it is believed that this long recovery time could be used as a measure of the subject's arousal by the Secondary task.

(4) Subjects were unable to overcome the accommodation shift in the far direction, even by five days of practice on both the Primary and Secondary task. Hence, it was also concluded that this shift in the far direction could be used as an indicator of sympathetic arousal.

(5) The subject responses of accommodative Phase Lag, Latency, and Velocity were also observed to vary, but only as a function of changes in the Primary task. The addition of the Secondary task had little or no effect on Phase Lag, Latency, and Velocity.

(6) Varying the degree of difficulty of the Secondary task did not appear to affect the degree of accommodation shift observed. This unexpected negative effect may have, in part, been attributable to the limited number of observations and the high degree of motor coordination of the subjects observed in this study.

The fact that this accommodation shift in the far direction consistently showed significant results with such a limited number of subjects and observations implies that it is a very reliable and robust phenomenon. The shift has occurred, of course, not only for this study, but also during numerous pilot studies and experiments whenever some measure of a Secondary task was involved. The results of this study, therefore, may have permitted some measure of understanding about the origin and nature of the shift. There is a very real possibility that objective measures of accommodation may be as reliable an indicator of interest and attitude changes as the well-documented pupillary response.

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APPENDIX A

INSTRUCTIONS

INSTRUCTIONS TO SUBJECTS

This is an experiment designed to see how well you can do two things at one time. We do many things concurrently every day, and we do many of them quite well, such as carrying on a conversation and driving a car or listening to the radio and typing a letter. Many of these things seem quite easy to do at once; however, maybe the first time you tried to perform some of these concurrent tasks, it wasn't so easy, and maybe it took you just a little more practice than you now remember.

This large piece of machinery with the wires and prisms is called an optometer, and what it does is measure the point in space you're looking at for any instant. Your entire task with the optometer, for today and for the next five days, will be to hold the target in focus as best you can; your eye need do nothing else. Sometime the target will be changing in focus, and sometimes it will remain steady and not change focus. Whatever it does, I'll let you know before any experimental trial whether it will be changing focus or not.

As for the second part of the task, I want to see how well you can count backwards by ones. This may not seem to be a very exciting job, but we have good reason to believe that even something as simple as this may have effects on your ability to focus on a target. Imagine that instead of sitting here in a laboratory looking at an "X" target and counting backwards, you're a pilot searching for the end of a runway in fog and the ground controller is on the aircraft's radio telling you to change headings and climb to another altitude. Now, perhaps you can see that the problem becomes more interesting. Do you miss seeing the end of the runway because you had something else on your mind? With this in mind, let's see how well you do at tracking some steady and some moving targets.

[At this point, the subject was given several trials at tracking both static and dynamic targets. If he could not perform the task satisfactorily, he was discarded.]

Now, moving to the second part of the experiment, I'd like to see how well you can perform a backwards counting task. By your right arm [all subjects were right-handed], there's a pencil and a pad of paper. What I'd like you to do is listen to the timer behind you; it ticks once every second. I'm going to give you instructions, for example, "Write backwards by ones, start at three-hundred and seventy-six." When I say "six," I'd like you to start counting backwards at that number, seventy-six; do not write the number "three," as it's only there to remind you that you won't ever have to do any negative counting. Only think about two-digit numbers. On the first tick, write "7," and on the second tick, write the numeral "6." On the third tick, write the numeral "7" again, and on the fourth tick, write the numeral "5," and so on. The pacing is really quite easy if you remember to write only one digit each second. If you counted backwards for 30 seconds, starting at "76," you'd have eventually ended up at the number "61."

During all of these counting tasks, what I'll be doing is giving you the first thirty seconds of normal target tracking, just as you did earlier in the day; however, at the end of the first thirty-second period, I'll say to count backwards for the next thirty seconds. At the end of that thirty-second counting period, I'll say, "Stop counting; continue tracking." At that time, just put your pencil down and continue tracking the target. Let's try just a few practice trials of your counting backwards on paper with your eyes closed.

[After the subject had accomplished the written counting task, he was given a backwards mental counting task.]

Now that you've accomplished that kind of task, I'd like you to try the same kind of counting task, only this time, it'll be in your head instead of on paper. If I say to you, "In your head, count backwards by ones, start at three-hundred and seventy-six," I want you to think "7-6, 7-5, 7-4," and so on, one digit each second until I say, "Stop counting; continue tracking." Since you won't be able to answer what number you arrived at when I say "Stop counting," just hold the number in the back of your mind until you come off the optometer at the end of the tracking period. One other thing, it won't do you any good to subtract fifteen from each number I give you at the beginning of the counting task to get the correct number; because sometimes I'll let you go for thirty-two or maybe even for as long as forty seconds before I say "Stop counting." This is just something extra to keep you honest.

[After the subject had demonstrated proficiency on both the written and mental backwards counting tasks, he was given practice on a concurrent 0.1 hz. Sine wave tracking task and the backwards writing task. At the end of the practice trials, he departed and was instructed to return the next day for the first of five experimental sessions.]

For all Static target tracking tasks, the subject was instructed,

> "Write backwards by . . . (ones, threes, sevens), start at . . . (randomly selected three-digit number)."

For all Dynamic target tracking tasks, the subject was instructed either,

> "Write backwards by . . . (ones, threes, sevens), start at . . . (randomly selected three-digit number)."

or

> "In your head, count backwards by ones, start at . . . (randomly selected three-digit number)."

For the Ignore the Target (NX) task, the subject was instructed,

> "Stop tracking,"

and to resume tracking on the target on the NX task, the subject was instructed,

"Resume tracking."

At the end of the fifth experimental session, the subject was informed about his performance.

That concludes the experiment, and I thank you for your patience. Thus far, I haven't been able to tell you how well you've done on all these tasks, mostly because if you'd been flying a plane, you wouldn't have known how well you could be focusing on targets and performing concurrent mental tasks, also. What you probably don't know is that you actually did quite well in holding focus on the target we gave you. For every person we selected to participate in this experiment, we had to tell three other persons to go home at the end of the first day; you were among a select few who had an exceptionally good accommodation response in addition to good eyesight. Now, if you'd like, let's take some of this data upstairs and go over it; and I'll be glad to answer any questions you have.

APPENDIX B

ANALYSIS OF VARIANCE TABLES

TABLE II

ANALYSIS OF VARIANCE SUMMARY FOR PHASE 1--STATIC TARGET--THREE DISTANCES

Source	df	MS	*F*	*p*
Subjects (SS)	3	41.9030		
Time Blocks (TI)	3	1.0392	3.5675	0.05986
SS TI	9	0.2913		
Days (DA)	4	2.2286	0.5689	0.69242
SS DA	12	3.9173		
Distance (DI)	2	169.9724	15.5566	0.00496
SS DI	6	10.9261		
TI DA	12	0.0648	1.0970	0.39182
SS TI DA	36	0.0591		
TI DI	6	0.4598	3.7272	0.01382
SS TI DI	18	0.1234		
DA DI	8	0.4358	0.3611	0.93061
SS DA DI	24	1.2067		
TI DA DI	24	0.0790	1.1175	0.34792
SS TI DA DI	72	0.0707		
TOTAL	239			

TABLE III

ANALYSIS OF VARIANCE SUMMARY FOR PHASE 1--STATIC TARGET--THREE DISTANCES--SEVEN TIME INTERVALS

Source	df	MS	*F*	*p*
Subjects (SS)	3	61.3866		
Time Intervals (TV)	6	0.0130	0.4191	0.85696
SS TV	18			
Time Blocks (TI)	1	4.5585	7.5571	0.06959
SS TI	3	0.6032		
Days (DA)	4	1.3688	0.2190	0.92130
SS DA	12	6.2513		
Distance (DI)	2	508.2229	12.9878	0.00731
SS DI	6	39.1309		
TV TI	6	0.0572	1.3902	0.27122
SS TV TI	18	0.0411		
TV DA	24	0.0240	0.5140	0.96529
SS TV DA	72	0.0467		
TV DI	12	0.0420	1.9651	0.05830
SS TV DI	36	0.0214		
TI DA	4	0.1849	0.5028	0.73659
SS TI DA	12	0.3677		
TI DI	2	2.8104	6.7976	0.02893
SS TI DI	6	0.4134		
DA DI	8	1.6996	0.4396	0.88526
SS DA DI	24	3.8668		
TV TI DA	24	0.0475	1.3723	0.15310
SS TV TI DA	72	0.0346		
TV TI DI	12	0.0843	1.5306	0.15829
SS TV TI DI	36	0.0551		
TV DA DI	48	0.0293	0.9551	0.56123
SS TV DA DI	144	0.0306		
TI DA DI	8	0.0696	0.2627	0.97153
SS TI DA DI	24	0.2650		
TV TI DA DI	48	0.0253	0.6936	0.92790
SS TV TI DA DI	144	0.0365		
TOTAL	839			

TABLE IV

ANALYSIS OF VARIANCE SUMMARY FOR PHASE 1--STATIC TARGET--ZERO AND THREE DIOPTER--SEVEN TIME INTERVALS

Source	df	MS	*F*	*p*
Subjects (SS)	3	2.6105		
Time Intervals (TV)	6	0.0422	2.2016	0.09063
SS TV	18			
Time Blocks (TI)	1	5.4214	36.1065	0.00790
SS TI	3	0.1502		
Days (DA)	4	0.9731	1.6671	0.22130
SS DA	12	0.5837		
Distance (DI)	1	980.1841	304.1157	0.00040
SS DI	3	3.2231		
TV TI	6	0.0041	0.3785	0.88309
SS TV TI	18	0.0108		
TV DA	24	0.0192	0.6645	0.86863
SS TV DA	72	0.0289		
TV DI	6	0.0085	0.4452	0.83937
SS TV DI	18	0.0191		
TI DA	4	0.0769	0.3273	0.85433
SS TI DA	12	0.2349		
TI DI	1	4.5935	8.8224	0.05765
SS TI DI	3	0.5207		
DA DI	4	0.4025	0.9848	0.54670
SS DA DI	12	0.4087		
TV TI DA	24	0.0155	0.8565	0.65590
SS TV TI DA	72	0.0181		
TV TI DI	6	0.0656	4.5307	0.00597
SS TV TI DA	18	0.0145		
TV DA DI	24	0.0308	2.3117	0.00363
SS TV DA DI	72	0.0133		
TI DA DI	4	0.1098	0.5039	0.73583
SS TI DA DI	12	0.2180		
TV TI DA DI	24	0.0174	0.7609	0.77070
SS TV TI DA DI	72	0.0229		
TOTAL	559			

TABLE V

ANALYSIS OF VARIANCE SUMMARY FOR PHASE 2--STATIC TARGET--THREE DISTANCES

Source	df	MS	*F*	*p*
Subjects (SS)	3	73.4240		
Time Blocks (TI)	3	1.8843	1.6783	0.23995
SS TI	9	0.3742		
Days (DA)	1	4.3564	1.5593	0.30069
SS DA	3	2.7938		
Distance (DI)	2	157.7266	17.9181	0.00367
SS DI	6	8.8027		
Counts (CT)	2	1.1991	0.8040	0.50680
SS CT	6	1.4914		
TI DA	3	0.2760	1.4652	0.28798
SS TI DA	9	0.1883		
TI DI	6	0.5094	2.1469	0.09748
SS TI DI	18	0.2372		
TI CT	6	0.0591	0.8240	0.56700
SS TI CT	18	0.0717		
DA DI	2	0.2427	0.1915	0.83076
SS DA DI	6	1.2672		
DA CT	2	0.4672	3.2523	0.11025
SS DA CT	6	0.1437		
DI CT	4	0.5069	2.0350	0.15294
SS DI CT	12	0.2491		
TI DA DI	6	0.0658	0.5531	0.76268
SS TI DA DI	18	0.1190		
TI DA CT	6	0.0846	1.9425	0.12827
SS TI DA CT	18	0.0435		
TI DI CT	12	0.0433	0.5587	0.8600
SS TI DI CT	36	0.0775		
DA DI CT	4	0.3703	0.5820	0.6831
SS DA DI CT	12	0.6362		
TI DA DI CT	12	0.0447	0.4967	0.90296
SS TI DA DI CT	36	0.0899		
TOTAL	287			

TABLE VI

ANALYSIS OF VARIANCE SUMMARY FOR PHASE 1--
STATIC TARGET--THREE DIOPTER ONLY

Source	df	MS	*F*	*p*
Subjects (SS)	3	14.1605		
Time Blocks (TI)	3	0.6130	4.1953	0.04071
SS TI	9	0.1461		
Days (DA)	1	0.4913	2.4507	0.21521
SS DA	3	0.2005		
Counts (CT)	2	0.4408	0.8475	0.52330
SS CT	6	0.5202		
TI DA	3	0.0860	0.8425	0.50609
SS TI DA	9	0.1021		
TI CT	6	0.0398	1.0259	0.44107
SS TI CT	18	0.0388		
DA CT	2	0.2871	0.9615	0.56353
SS DA CT	6	0.2986		
TI DA CT	6	0.0461	1.6247	0.19657
SS TI DA CT	18	0.0283		
TOTAL	95			

TABLE VII

ANALYSIS OF VARIANCE SUMMARY FOR PHASE 1--DYNAMIC TARGET--SINE WAVE AMPLITUDE

Source	df	MS	*F*	*p*
Subjects (SS)	3	3.5428		
Time Blocks (TI)	3	0.1523	5.7111	0.01817
SS TI	9	0.0267		
Days (DA)	2	0.4444	2.0163	0.21360
SS DA	6	0.2204		
Mental-Written (MW)	1	0.1251	1.1368	0.36581
SS MW	3	0.1100		
Frequency (HZ)	2	7.3401	4.2144	0.07177
SS HZ	6	1.7417		
TI DA	6	0.0197	1.0437	0.43099
SS TI DA	18	0.0189		
TI MW	3	0.0419	4.8174	0.02866
SS TI MW	9	0.0087		
TI HZ	6	0.0102	0.9401	0.50817
SS TI HZ	18	0.0109		
DA MW	2	0.0688	0.7186	0.52780
SS DA MW	6	0.0958		
DA HZ	4	0.0076	0.1126	0.97297
SS DA HZ	12	0.0676		
MW HZ	2	1.0976	1.0774	0.39985
SS MW HZ	6	1.0187		
TI DA MW	6	0.0100	1.3999	0.26770
SS TI DA MW	18	0.0072		
TI DA HZ	12	0.0107	1.2135	0.31126
SS TI DA HZ	36	0.0088		
TI MW HZ	6	0.0095	0.7636	0.60902
SS TI MW HZ	18	0.1024		
DA MW HZ	4	0.0225	0.2026	0.93042
SS DA MW HZ	12	0.1109		
TI DA MW HZ	12	0.0098	1.1675	0.34137
SS TI DA MW HZ	36	0.0084		
TOTAL	287			

TABLE VIII

ANALYSIS OF VARIANCE SUMMARY FOR PHASE 1-- DYNAMIC TARGET--SINE WAVE PHASE LAG

Source	df	MS	F	p
Subjects (SS)	3	0.9056		
Time Blocks (TI)	3	0.0188	0.8941	0.51732
SS TI	9	0.0210		
Days (DA)	2	0.0073	0.1800	0.83962
SS DA	6	0.0404		
Mental-Written (MW)	1	0.0093	0.4568	0.54964
SS MW	3	0.0203		
Frequency (HZ)	2	1.8564	24.2388	0.00196
SS HZ	6	0.0766		
TI DA	6	0.0417	1.3217	0.29758
SS TI DA	18	0.0316		
TI MW	3	0.0145	0.2288	0.87408
SS TI MW	9	0.0632		
TI HZ	6	0.0143	0.4822	0.81368
SS TI HZ	18	0.0296		
DA MW	2	0.0022	0.0312	0.97037
SS DA MW	6	0.0718		
DA HZ	4	0.0573	0.9743	0.54164
SS DA HZ	12	0.0588		
MW HZ	2	0.0057	0.1447	0.86771
SS MW HZ	6	0.0396		
TI DA MW	6	0.0138	0.6572	0.68609
SS TI DA MW	18	0.0210		
TI DA HZ	12	0.0176	0.8141	0.63547
SS TI DA HZ	36	0.0216		
TI MW HZ	6	0.0130	0.3413	0.90551
SS TI MW HZ	18	0.0380		
DA MW HZ	4	0.0450	0.8298	0.53269
SS DA MW HZ	12	0.0543		
TI DA MW HZ	12	0.0165	0.7212	0.72222
SS TI DA MW HZ	36	0.0229		
TOTAL	287			

TABLE IX

ANALYSIS OF VARIANCE SUMMARY FOR PHASE 2--DYNAMIC TARGET--SQUARE WAVE--ZERO-PULSE TRACK

Source	df	MS	*F*	*p*
Subjects (S)	3	3.1384		
Time Blocks (TI)	3	0.5776	1.6172	0.25267
SS TI	9	0.3571		
Days (DA)	2	4.8842	0.3489	0.72158
SS DA	6	13.9981		
Mental-Written (MW)	1	0.9234	0.8231	0.56649
SS MW	3	1.1217		
Frequency (HZ)	2	0.5735	0.5401	0.61188
SS HZ	6	1.0617		
Zero-Pulse (ZP)	1	458.1348	108.2420	0.00154
SS ZP	3	4.2325		
TI DA	6	0.0832	1.0081	0.45128
SS TI DA	18	0.0825		
TI MW	3	0.1226	0.8595	0.50176
SS TI MW	9	0.1426		
TI HZ	6	0.1180	1.2059	0.34774
SS TI HZ	18	0.0978		
TI ZP	3	0.3492	7.1629	0.00960
SS TI ZP	9	0.0488		
DA MW	2	0.8999	0.5279	0.61825
SS DA MW	6	1.7047		
DA HZ	4	0.3068	0.2168	0.92154
SS DA HZ	12	1.4039		
DA ZP	2	0.7622	1.5993	0.27745
SS DA ZP	6	0.4766		
MW HZ	2	0.1368	0.1914	0.83081
SS MW HZ	6	0.7148		
HZ ZP	2	12.5729	144.3757	0.00011
SS HZ ZP	6	0.0871		

TABLE IX (Continued)

Source	df	MS	F	p
TI DA MW	6	0.1365	1.4101	0.26400
SS TI DA MW	18	0.0968		
TI DA HZ	12	0.0594	0.8962	0.55924
SS TI DA HZ	36	0.0663		
TI DA ZP	6	0.0046	0.1657	0.98151
SS TI DA ZP	18	0.0278		
TI MW HZ	6	0.0627	0.7850	0.59393
SS TI MW HZ	18	0.0799		
TI MW ZP	3	0.0910	2.7711	0.10271
SS TI MW ZP	9	0.0328		
TI HZ ZP	6	0.0235	0.6474	0.69329
SS TI HZ ZP	18	0.0363		
DA MW HZ	4	0.5515	2.1650	0.13468
SS DA MW HZ	12	0.2548		
DA MW ZP	2	0.0468	0.5944	0.58458
SS DA MW ZP	6	0.0788		
DA HZ ZP	4	0.1329	0.5762	0.68759
SS DA HZ ZP	12	0.2306		
MW HZ ZP	2	0.0605	2.6607	0.14857
SS MW HZ ZP	6	0.0228		
TI DA MW HZ	12	0.0937	1.8698	0.07288
SS TI DA MW HZ	36	0.0501		
TI DA MW ZP	6	0.0093	0.3819	0.88097
SS TI DA MW ZP	18	0.0242		
TI DA HZ ZP	12	0.0090	0.5413	0.87274
SS TI DA HZ ZP	36	0.0166		
TI MW HZ ZP	6	0.0527	1.8394	0.14744
SS TI MW HZ ZP	18	0.0287		
DA MW HZ ZP	4	0.1703	2.7799	0.07566
SS DA MW HZ ZP	12	0.0612		
TI DA MW HZ ZP	12	0.0224	0.8647	0.58826
SS TI DA MW HZ ZP	36	0.0259		
TOTAL	575			

TABLE X

ANALYSIS OF VARIANCE SUMMARY FOR PHASE 2--DYNAMIC TARGET--SQUARE WAVE--LATENCY

Source	df	MS	F	p
Subjects (SS)	3	0.3097		
Time Blocks (TI)	3	0.0124	0.5514	0.66261
SS TI	9	0.0225		
Days (DA)	2	0.0318	0.3200	0.33543
SS DA	6	0.0241		
Mental-Written (MW)	1	0.0236	1.2442	0.34694
SS MW	3	0.0190		
Frequency (HZ)	2	0.3513	18.8855	0.00328
SS HZ	6	0.0186		
Direction (DR)	1	0.0429	5.1094	0.10816
SS DR	3	0.0084		
TI DA	6	0.0256	4.7782	0.00471
SS TI DA	18	0.0054		
TI MW	3	0.0097	1.7698	0.22245
SS TI MW	9	0.0055		
TI HZ	6	0.0157	1.0996	0.40057
SS TI HZ	18	0.0143		
TI DR	3	0.0044	1.7542	0.22518
SS TI DR	9	0.0025		
DA MW	2	0.0179	1.8337	0.23882
SS DA MW	6	0.0098		
DA HZ	4	0.0150	2.1542	0.13610
SS DA HZ	12	0.0070		
DA DR	2	0.0049	0.2758	0.76079
SS DA DR	6	0.0179		
MW HZ	2	0.0082	1.2014	0.36505
SS MW HZ	6	0.0068		
MW DR	1	0.0087	0.4130	0.56808
SS MW DR	3	0.0211		
HZ DR	2	0.0142	0.7569	0.51184
SS HZ DR	6	0.0188		

TABLE X (Continued)

Source	df	MS	*F*	*p*
TI DA MW	6	0.0054	0.6842	0.66628
SS TI DA MW	18	0.0080		
TI DA HZ	12	0.0150	1.5425	0.15415
SS TI DA HZ	36	0.0097		
TI DA DR	6	0.0047	0.3715	0.8875
SS TI DA DR	18	0.0126		
TI MW HZ	6	0.0051	0.5071	0.79600
SS TI MW HZ	18	0.0100		
TI MW DR	3	0.0018	0.2653	0.84929
SS TI MW DR	9	0.0069		
TI HZ DR	6	0.0060	1.8628	0.14285
SS TI HZ DR	18	0.0032		
DA MW HZ	4	0.0070	0.9958	0.55190
SS DA MW HZ	12	0.0070		
DA MW DR	2	0.0171	2.4273	0.16859
SS DA MW DR	6	0.0070		
DA HZ DR	4	0.0028	0.2093	0.92672
SS DA HZ DR	12	0.0135		
MW HZ DR	2	0.0077	2.0520	0.20910
SS MW HZ DR	6	0.0037		
TI DA MW HZ	13	0.0131	1.4329	0.19621
SS TI DA MW HZ	36	0.0091		
TI DA MW DR	6	0.0053	0.7670	0.60661
SS TI DA MW DR	18	0.0069		
TI DA HZ DR	12	0.0065	0.6173	0.81366
SS TI DA HZ DR	36	0.0105		
TI MW HZ DR	6	0.0028	0.5365	0.77479
SS TI MW HZ DR	18	0.0052		
DA MW HZ DR	4	0.0032	0.5203	0.72479
SS DA MW HZ DR	12	0.0062		
TI DA MW HZ DR	13	0.0061	0.5199	0.88769
SS TI DA MW HZ DR	36	0.0118		
TOTAL	575			

TABLE XI

ANALYSIS OF VARIANCE SUMMARY FOR PHASE 2--DYNAMIC TARGET--SQUARE WAVE--VELOCITY

Source	df	MS	*F*	*p*
Subjects (SS)	3	107.6763		
Time Blocks (TI)	3	3.9040	2.7489	0.10436
SS TI	9	1.4202		
Days (DA)	2	5.2612	3.1211	0.11750
SS DA	6	1.6857		
Mental-Written (MW)	1	1.5083	0.9607	0.59886
SS MW	3	1.5700		
Frequency (HZ)	2	9.8434	2.2156	0.18999
SS HZ	6	4.4427		
Direction (DR)	1	7.1425	2.2607	0.22955
SS DR	3	3.1595		
TI DA	6	2.2417	1.5157	0.22877
SS TI DA	18	1.4790		
TI MW	3	0.2505	0.1393	0.93334
SS TI MW	9	1.7984		
TI HZ	6	2.8399	2.1636	0.09534
SS TI HZ	18	1.3126		
TI DR	3	1.9550	1.3884	0.30804
SS TI DR	9	1.4081		
DA MW	2	2.0860	2.2883	0.18225
SS DA MW	6	0.9116		
DA HZ	4	7.9719	1.6910	0.21595
SS DA HZ	12	4.7142		
DA DR	2	0.4107	0.4992	0.63355
SS DA DR	6	0.8227		
MW HZ	2	0.3417	0.1213	0.88723
SS MW HZ	6	2.8177		
MW DR	1	0.2146	0.8248	0.56690
SS MW DR	3	0.2602		
HZ DR	2	5.8054	5.7817	0.03994
SS HZ DR	6	1.0041		
TI DA MW	6	2.4695	3.6257	0.01549
SS TI DA MW	18	0.6811		

TABLE XI (Continued)

Source	df	MS	*F*	*p*
TI DA HZ	12	1.5559	1.5548	0.14999
SS TI DA HZ	36	1.0007		
TI DA DR	6	0.4713	0.4925	0.80641
SS TI DA DR	18	0.9570		
TI MW HZ	6	1.1456	1.1632	0.36817
SS TI MW HZ	18	0.9848		
TI MW DR	3	0.3391	0.2130	0.88480
SS TI MW DR	9	1.5921		
TI HZ DR	6	0.4404	0.4957	0.80417
SS TI HZ DR	18	0.8885		
DA MW HZ	4	1.1270	1.1061	0.39857
SS DA MW HZ	12	1.0189		
DA MW DR	2	0.5634	0.3066	0.74899
SS DA MW DR	6	1.8375		
DA HZ DR	4	0.5731	0.4522	0.77076
SS DA HZ DR	12	1.2673		
MW HZ DR	2	0.1442	0.0462	0.95564
SS MW HZ DR	6	3.1214		
TI DA MW HZ	12	2.0948	2.0989	0.04256
SS TI DA MW HZ	36	0.9981		
TI DA MW DR	6	1.0295	2.9982	0.03293
SS TI DA MW DR	18	0.3345		
TI DA HZ DR	12	0.7185	0.7222	0.72133
SS TI DA HZ DR	36	0.9949		
TI MW HZ DR	4	0.6683	1.2971	0.30762
SS TI MW HZ DR	18	0.5152		
DA MW HZ DR	4	0.5350	0.6513	0.63901
SS DA MW HZ DR	12	0.8214		
TI DA MW HZ DR	12	1.3293	1.2892	0.26640
SS TI DA MW HZ DR	36	1.0311		
TOTAL	575			

TABLE XII

ANALYSIS OF VARIANCE SUMMARY FOR PHASE 3--DYNAMIC TARGET--FIVE DAYS--ZERO-PULSE TRACK

Source	df	MS	*F*	*p*
Subjects (SS)	3	3.3813		
Time Blocks (TI)	3	0.2336	0.8849	0.51322
SS TI	9	0.2640		
Days (DA)	4	0.7538	0.5573	0.70013
SS DA	12	1.3526		
Zero-Pulse (ZP)	1	137.9212	85.1518	0.00217
SS ZP	3	1.6197		
TI DA	12	0.0761	1.7375	0.09907
SS TI DA	36	0.0438		
TI ZP	3	0.1659	3.3018	0.07120
SS TI ZP	9	0.0502		
DA ZP	4	0.0500	0.3391	0.84667
SS DA ZP	12	0.1474		
TI DA ZP	12	0.0136	0.7626	0.68380
SS TI DA ZP	36	0.0178		
TOTAL	159			

TABLE XIII

ANALYSIS OF VARIANCE SUMMARY FOR PHASE 3--DYNAMIC TARGET--FIVE DAYS--LATENCY

Source	df	MS	*F*	*p*
Subjects (SS)	3	0.0719		
Time Blocks (TI)	3	0.0018	0.2860	0.83513
SS TI	9			
Days (DA)	4	0.0179	1.1898	0.36458
SS DA	12	0.0150		
Distance (DI)	1	0.0004	0.0393	0.84838
SS DI	3	0.0114		
TI DA	12	0.0084	1.0389	0.43702
SS TI DA	36	0.0080		
TI DI	3	0.0030	0.9614	0.54636
SS TI DI	9	0.0031		
DA DI	4	0.0087	0.7087	0.60325
SS DA DI	12	0.0123		
TI DA DI	12	0.0034	0.8230	0.62716
SS TI DA DI	36	0.0041		
TOTAL	159			

TABLE XIV

ANALYSIS OF VARIANCE SUMMARY FOR PHASE 3--
DYNAMIC TARGET--FIVE DAYS--
VELOCITY

Source	df	MS	F	p
Subjects (SS)	3	46.3845		
Time Blocks (TI)	3	0.8764	0.4950	0.69735
SS TI	9	1.7705		
Days (DA)	4	1.3798	0.4552	0.76872
SS DA	12	3.0314		
Direction (DR)	1	6.9356	7.5359	0.06982
SS DR	3	0.9203		
TI DA	12	0.7692	0.7431	0.70198
SS TI DA	36	1.0351		
TI DR	3	0.0094	0.0069	0.99892
SS TI DR	9	1.3662		
DA DR	4	0.8577	0.9918	0.55002
SS TI DR	12	0.8648		
TI DA DR	12	0.5923	0.8115	0.63789
SS TI DA DR	36	0.7299		
TOTAL	159			

TABLE XV

ANALYSIS OF VARIANCE SUMMARY FOR PHASE 4--DYNAMIC TARGET--FOUR DIFFICULTIES--ZERO-PULSE TRACK

Source	df	MS	*F*	*p*
Subjects (SS)	3	6.8184		
Time Blocks (TI)	3	1.1654	2.3699	0.13807
SS TI	9	0.4917		
Days (DA)	1	6.8484	8.3920	0.06132
SS DA	3	0.8161		
Counts (CT)	3	0.5719	0.2756	0.84224
SS CT	9	2.0749		
Zero-Pulse (ZP)	1	185.9524	53.7509	0.00432
SS ZP	3	3.4595		
TI DA	3	0.1416	2.8286	0.09858
SS TI DA	9	0.0501		
TI CT	9	0.0536	0.1196	0.99832
SS TI CT	27	0.4481		
TI ZP	3	0.7024	35.8196	0.00011
SS TI ZP	9	0.0196		
DA CT	3	0.1152	0.2371	0.86847
SS DA CT	9	0.4859		
DA ZP	1	0.0346	0.2183	0.67120
SS DA ZP	3	0.1585		
CT ZP	3	0.2703	2.0137	0.18222
SS CT ZP	9	0.1342		
TI DA CT	9	0.2151	1.6599	0.14815
SS TI DA CT	27	0.1296		
TI DA ZP	3	0.0053	0.4268	0.74079
SS TI DA ZP	9	0.0124		
TI CT ZP	9	0.1459	4.8039	0.00094
SS TI CT ZP	27	0.0304		
DA CT ZP	3	0.0387	0.5470	0.66527
SS CA CT ZP	9	0.0708		
TI DA CT ZP	9	0.0121	0.8325	0.59348
SS TI DA CT ZP	27	0.0146		
TOTAL	255			

TABLE XVI

ANALYSIS OF VARIANCE SUMMARY FOR PHASE 4--DYNAMIC TARGET--THREE DIFFICULTIES--ZERO-PULSE TRACK

Source	df	MS	*F*	*p*
Subjects (SS)	3	1.7615		
Time Blocks (TI)	3	0.6801	3.5618	0.06008
SS TI	9	0.1909		
Days (DA)	1	6.2114	9.3490	0.05362
SS DA	3	0.6644		
Counts (CT)	2	0.7553	1.0575	0.40586
SS CT	6	0.7142		
Zero-Pulse (ZP)	1	147.2556	56.6548	0.00399
SS ZP	3	2.5992		
TI DA	3	0.0131	0.1636	0.91769
SS TI DA	9	0.0798		
TI CT	6	0.0507	0.7547	0.61534
SS TI CT	18	0.0672		
TI ZP	3	0.1758	8.5062	0.00582
SS TI ZP	9	0.0207		
DA CT	2	0.0707	0.1518	0.86197
SS DA CT	6	0.4657		
DA ZP	1	0.0562	0.3560	0.59428
SS DA ZP	3	0.1578		
CT ZP	2	0.1937	2.1776	0.19421
SS CT ZP	6	0.0889		
TI DA CT	6	0.0609	0.6485	0.69252
SS TI DA CT	18	0.0930		
TI DA ZP	3	0.0059	0.5485	0.66434
SS TI DA ZP	9	0.0108		
TI CT ZP	6	0.0107	0.6708	0.67616
SS TI CT ZP	18	0.0160		
DA CT ZP	2	0.0466	0.4767	0.64590
SS DA CT ZP	6	0.0978		
TI DA CT ZP	6	0.0177	1.5819	0.20908
SS TI DA CT ZP	18	0.0112		
TOTAL	191			

TABLE XVII

ANALYSIS OF VARIANCE SUMMARY FOR PHASE 4-- DYNAMIC TARGET--FOUR DIFFICULTIES-- LATENCY

Source	df	MS	*F*	*p*
Subjects (SS)	3	0.1159		
Time Blocks (TI)	3	0.0160	3.1503	0.07883
SS TI	9	0.0051		
Days (DA)	1	0.0036	0.1795	0.69807
SS DA	3	0.0201		
Counts (CT)	3	0.0085	0.2958	0.82848
SS CT	9	0.0287		
Direction (DR)	1	0.0172	1.5615	0.30040
SS DR	3	0.0110		
TI DA	3	0.0201	1.2168	0.35901
SS TI DA	9	0.0165		
TI CT	9	0.0131	1.5124	0.19358
SS TI CT	27	0.0087		
TI DR	3	0.0033	0.7001	0.57750
SS TI CT	9	0.0047		
DA CT	3	0.0313	6.1833	0.01458
SS DA CT	9	0.0051		
DA DR	1	0.0094	3.3362	0.16485
SS DA DR	3	0.0028		
CT DR	3	0.0030	0.8173	0.51795
SS CT DR	9	0.0037		
TI DA CT	9	0.0056	0.7031	0.70181
SS TI DA CT	27	0.0080		
TI DA DR	3	0.0067	1.2931	0.33523
SS TI DA DR	9	0.0052		
TI CT DR	9	0.0049	0.9366	0.51082
SS TI CT DR	27	0.0052		
DA CT DR	3	0.0022	0.6150	0.64297
SS DA CT DR	9	0.0036		
TI DA CT DR	9	0.0024	0.3548	0.94638
SS TI DA CT DR	27	0.0068		
TOTAL	255			

TABLE XVIII

ANALYSIS OF VARIANCE SUMMARY FOR PHASE 4--DYNAMIC TARGET--THREE DIFFICULTIES--LATENCY

Source	df	MS	F	p
Subjects (SS)	3	0.1064		
Time Blocks (TI)	3	0.0048	2.5971	0.11653
SS TI	9	0.0044		
Days (DA)	1	0.0048	0.1961	0.68619
SS DA	3	0.0243		
Counts (CT)	2	0.0127	0.9470	0.55866
SS CT	6	0.0134		
Direction (DR)	1	0.0126	1.0736	0.37780
SS DR	3	0.0117		
TI DA	3	0.0166	1.3973	0.30562
SS TI DA	9	0.0119		
TI CT	6	0.0034	0.4203	0.85613
SS TI CT	18	0.0081		
TI DR	3	0.0092	1.3382	0.32202
SS TI DR	9	0.0069		
DA CT	2	0.0464	9.5645	0.01416
SS DA CT	6	0.0048		
DA DR	1	0.0072	1.3012	0.33764
SS DA DR	3	0.0055		
CT DR	2	0.0045	1.2430	0.35428
SS CT DR	6	0.0036		
TI DA CT	6	0.0056	0.6483	0.69268
SS TI DA CT	18	0.0087		
TI DA DR	3	0.0018	0.2760	0.84199
SS TI DA DR	9	0.0064		
TI CT DR	6	0.0020	0.4617	0.82802
SS TI CT DR	18	0.0043		
DA CT DR	2	0.0033	1.0230	0.41652
SS DA CT DR	6	0.0032		
TI DA CT DR	6	0.0018	0.2201	0.96422
SS TI DA CT DR	18	0.0082		
TOTAL	191			

TABLE XIX

ANALYSIS OF VARIANCE SUMMARY FOR PHASE 4--DYNAMIC TARGET--FOUR DIFFICULTIES--VELOCITY

Source	df	MS	*F*	*p*
Subjects (SS)	3	78.5084		
Time Blocks (TI)	3	6.3714	3.8117	0.05132
SS TI	9	1.6715		
Days (DA)	1	2.9057	1.4065	0.32163
SS DA	3	2.0660		
Counts (CT)	3	4.0376	1.5084	0.27739
SS CT	9	2.6767		
Direction (DR)	1	0.0094	0.0058	0.94260
SS DR	3	1.6211		
TI DA	3	1.3374	1.0586	0.41478
SS TI DA	9	1.2534		
TI CT	9	2.7145	2.4067	0.03726
SS TI CT	27	1.1279		
TI DR	3	2.3798	3.6566	0.05659
SS TI DR	9	0.6510		
DA CT	3	0.7366	0.3770	0.77380
SS DA DT	9	1.9540		
DA DR	1	0.0171	0.0584	0.81725
SS DA DR	3	0.2923		
CT DR	3	0.3614	0.3912	0.76437
SS CT DR	9	0.9238		
TI DA CT	9	2.0416	2.0767	0.06858
SS TI DA CT	27	0.9831		
TI DA DR	3	0.0831	0.1032	0.95555
SS TI DA DR	9	0.8052		
TI CT DR	9	0.3027	0.2587	0.98033
SS TI CT DR	27	1.1703		
DA CT DR	3	0.6115	0.6203	0.62190
SS DA CT DR	9	0.9858		
TI DA CT DR	9	0.1661	0.1498	0.99663
SS TI DA CT DR	27	1.1094		
TOTAL	255			

TABLE XX

ANALYSIS OF VARIANCE SUMMARY FOR PHASE 4-- DYNAMIC TARGET--THREE DIFFICULTIES-- VELOCITY

Source	df	MS	*F*	*p*
Subjects (SS)	3	65.5253		
Time Blocks (TI)	3	0.6908	0.3799	0.77185
SS TI	9	1.8184		
Days (DA)	1	4.3612	1.8226	0.26989
SS DA	3	2.3929		
Counts (CT)	2	3.1356	2.1803	0.19391
SS CT	6	1.4382		
Direction (DR)	1	0.2990	0.3338	0.60523
SS DR	3	0.8958		
TI DA	3	2.3071	1.7281	0.23014
SS TI DA	9	1.3351		
TI CT	6	0.0904	0.0781	0.99660
SS TI CT	18	1.1570		
TI DR	3	1.5376	2.2238	0.15444
SS TI DR	9	0.6914		
DA CT	2	0.3556	0.1810	0.83885
SS DA CT	6	1.9646		
DA DR	1	0.2044	3.3842	0.16270
SS DA DR	3	0.0604		
CT DR	2	0.1137	0.1022	0.90374
SS CT DR	6	1.1129		
TI DA CT	6	2.4935	2.2579	0.08410
SS TI DA CT	18	1.1043		
TI DA DR	3	0.0338	0.0332	0.99105
SS TI DA DR	9	1.0200		
TI CT DR	6	0.3955	0.3401	0.90624
SS TI CT DR	18	1.1630		
DA CT DR	2	0.2782	0.2925	0.75841
SS DA CT DR	6	0.9511		
TI DA CT DR	6	0.2120	0.1937	0.97339
SS TI DA CT DR	18	1.0945		
TOTAL	191			

APPENDIX C

DATA TRANSFORMATION PROCEDURES

DATA TRANSFORMATION PROCEDURES

All optometer data was in analog form and needed both digital conversion and averaging. Therefore, the Ames Research Center's STATS (Statistical Analysis of Time Series) computer program was used. Analog-to-digital conversion was accomplished at a sampling of twenty points per second; therefore, any individual thirty-second time block consisted of a total of 600 data points.

Sine wave components of Amplitude and Phase Lag were taken for each individual waveform. Therefore, for example, a 0.2 hz. Sine wave which generated six complete cycles every thirty seconds, there were computed six separate Amplitudes and six corresponding Phase Lags. These six separate values were averaged into a single Amplitude and Phase Lag for each Time Block. Figure 21 shows the individual measurement of Amplitude and Phase Lag values from the raw data. The attachment "Analysis of Optometer Sinewave Data" is reproduced in its entirety from Randle (1973) and is the procedure used by the STATS program in data transformation. For this study, paragraph two, beginning, "In the Circadian Rhythm studies . . . " should be disregarded, as, obviously, the input frequencies here are 0.1, 0.2, and 0.4 Hertz.

Square wave components of Zero Track, Pulse Track, Magnitude, Receding Latency, Approaching Latency, Receding Velocity, and Approaching Latency were taken for each individual waveform. Likewise, for example, a 0.2 hz. Square wave which generated six complete cycles every thirty-second time block, there would be computed six separate values of Pulse Track, Zero Track, Magnitudes, Receding Latency, Approaching Latency, Receding Velocity, and Approaching Latency. Each

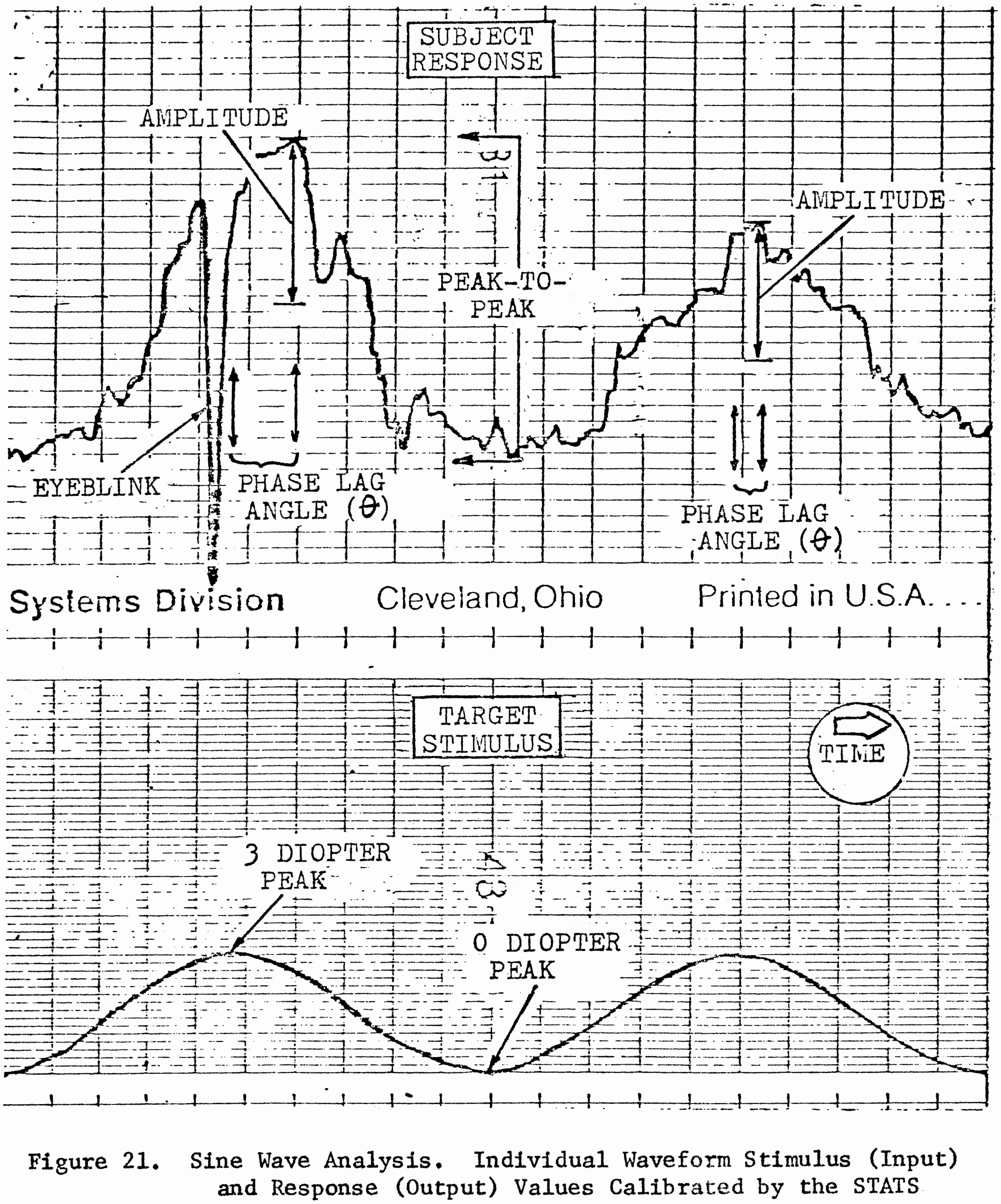

Figure 21. Sine Wave Analysis. Individual Waveform Stimulus (Input) and Response (Output) Values Calibrated by the STATS Program for Obtaining Amplitude and Phase Lag

one of these dependent variables was averaged for a single value within any Time Block. Figure 22 shows the individual waveform measurements of the components of these dependent variables from raw data. The nomenclature is identical to that listed in the attached "Analyais of Optometer Square Wave Data," reproduced in its entirety from Randle (1973) and is the same procedure used by the STATS program.

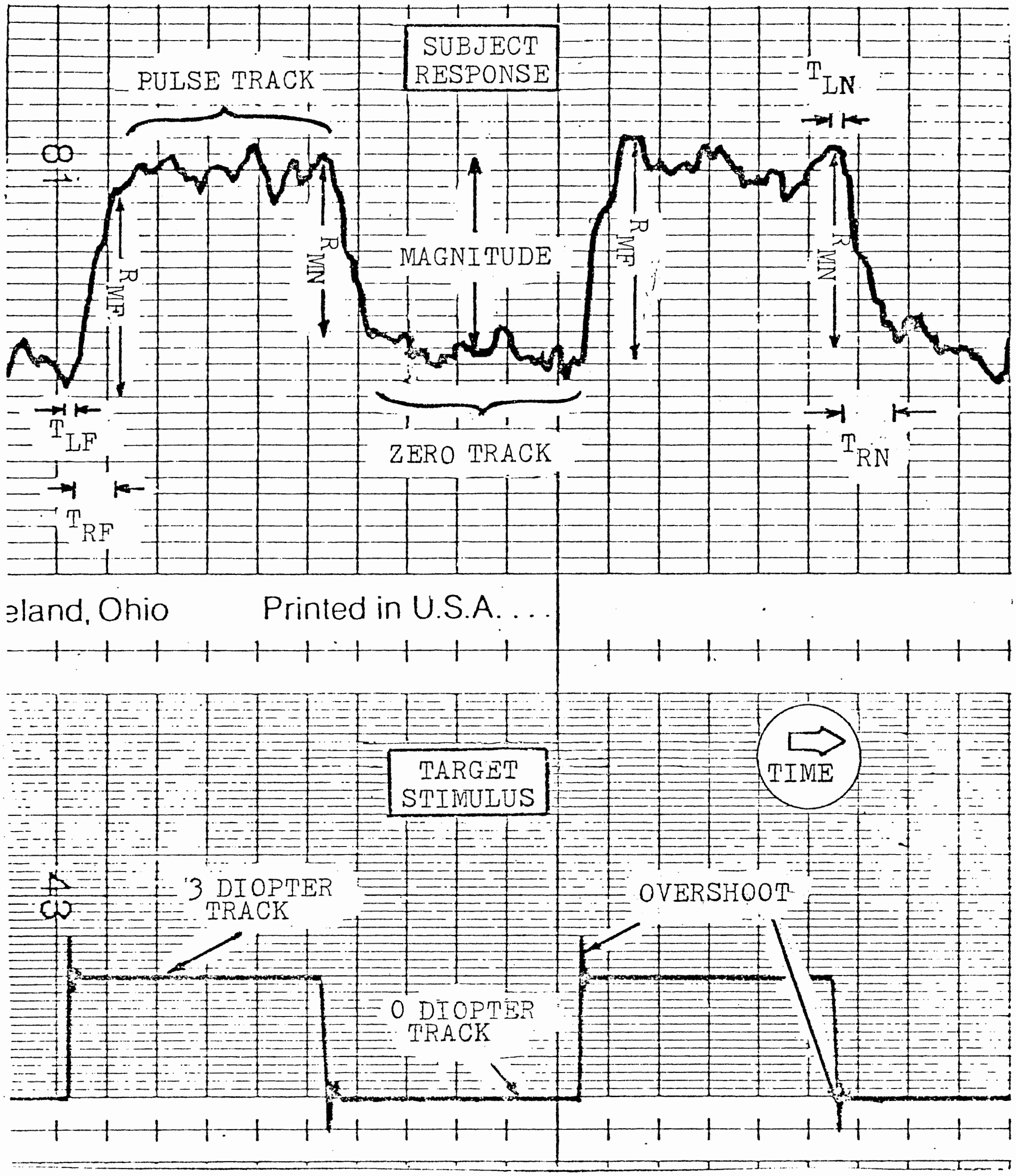

Figure 22. Square Wave Analysis. Individual Waveform Stimulus (Input) and Response (Output) Values Calculated by the STATS Program for Obtaining Magnitude, Direction, Latency, and Velocity

ANALYSIS OF OPTOMETER SINEWAVE DATA

For each stimulus (input) and response (output) pair of sinewave time series, the Frequency Response Function is computed to obtain the amplitude gain and phase lag of the response with respect to the stimulus. The range of data points used for the analysis is chosen so that the input frequency of the sinewave is equal to one of the harmonics for which the coefficients are computed.

In the Circadian Rhythm studies the input frequencies were .3 and .5 Hertz. The data ranges used were 200, 400, or 800 points so that the fundamental frequencies (Δf) were .1, .05, and .025 respectively.

The analysis includes the following steps:

1. The mean value is removed for each time series.
2. The Fourier coefficients are computed for the new series.
3. The Frequency Response Function is computed by dividing the response coefficients by the stimulus coefficients
4. The amplitude and phase representation is computed and printed for the stimulus, response, and Frequency Response.

Note:

The time series data is scaled so that the units are diopters. After removing the mean value from the time series, the range of the stimulus is +2. to -2. diopters and the amplitude of the input frequency is 2.

THE FOURIER TRANSFORM

The Fourier Transform is used to obtain the Amplitude and Phase spectra of the time series.

For a time series f(n) with 2N functional values and a sampling interval of Δt, the Fourier transform has the form,

$$F(u_n) = a_n - ib_n$$

where n is harmonic number and $0 \leq n \leq N$

$$u_n = \frac{n}{2N\Delta t} \qquad \text{frequency}$$

$$a_o = \frac{1}{N} \sum_{i=1}^{2N-1} f(i) \qquad b_o = 0$$

$$a_n = \frac{1}{N} \sum_{i=1}^{2N-1} f(i) \cos \frac{\pi ni}{N}$$

$$b_n = \frac{1}{N} \sum_{i=1}^{2N-1} f(i) \sin \frac{\pi ni}{N}$$

$$a_N = \frac{1}{N} \sum_{i=1}^{2N-1} f(i) \cos \pi i \qquad b_N = 0$$

The a_n's and b_n's correspond to the coefficients for the Finite Fourier series representation of the original time series. The Finite Fourier series is composed of the sums of sine and cosine functions whose frequencies are multiples or harmonics of a fundamental. The fundamental frequency has a period of $2N\Delta t$ (the range of the time domain) and equals $\frac{1}{2N\Delta t}$. The units are in Hertz if the Δt is in seconds. The highest frequency present is $\frac{1}{2\Delta t}$ which corresponds to a period of $2\Delta t$ (two sampling intervals). The original time series is represented as

$$f(k) = \frac{a_o}{2} + \sum_{n=1}^{N-1} \left(a_n \cos \frac{\pi nk}{N} + b_n \sin \frac{\pi nk}{N}\right) + \frac{a_N}{2} \cos \pi k$$

If polar coordinates are introduced, such that

$$a_n = r_n \cos \theta_n$$

$$b_n = r_n \sin \theta_n$$

Then the Finite Fourier Series has the form

$$f(k) = \frac{r_o}{2} + \sum_{n=1}^{N-1} r_n \cos \left(\frac{\pi nk}{N} - \theta_n\right) + \frac{r_N}{2} \cos \pi k$$

where $r_n = (a_n^2 + b_n^2)^{1/2}$

and $\theta_n = \arctan \left(\frac{b_n}{a_n}\right)$

r_n is the amplitude of the nth harmonic.

θ_n is the phase of the nth harmonic relative to the fundamental.

The units of the amplitude are the same as the units of the original time series. The phase angles are in degrees.

The Fourier Transform in polar coordinates becomes

$$F(u_n) = r_n e^{-i\theta_n}$$

STATS uses the Fast Fourier transform computational Method as implemented by R. C. Singleton.

FREQUENCY RESPONSE FUNCTION

For a linear system the Frequency Response Function shows the amplitude gain and the phase lag of output with respect to the input at each frequency.

The output function, $r(t)$ can be represented as the convolution of an impulse response function, $h(t)$, with the input function, $s(t)$.

$$r(t) = \int h(t)S(t-u)du$$

Taking the Fourier transform of each function, the relation of convolution becomes multiplication in the frequency domain.

$$R(f) = H(f)S(f)$$

where $H(f)$ is the frequency response function. The equation may be solved for $H(f)$. Using amplitude and phase representation of the transforms

$$A_R(f)e^{-iF_R(f)} = A_H(f)e^{-iF_H(f)} \cdot A_S(f)e^{-iF_S(f)}$$

$$A_H(f)e^{-iF_H(f)} = \frac{A_R(f)}{A_S(f)} e^{-i(F_R(f) - F_S(f))}$$

Thus,

The Amplitude gain is

$$A_H(f) = \frac{A_R(f)}{A_S(F)}$$

and the phase lag is

$$F_H(f) = F_R(f) - F_S(f)$$

STATS computes the Frequency Response Function by complex division of the Fourier coefficients of the output function by the Fourier coefficients of the input function. The resulting coefficients are used to compute the amplitude gain function and the phase lag.

ANALYSIS OF OPTOMETER SQUARE WAVE DATA

The stimulus and response for a single square wave trial are processed together. Calculations are made for individual pulses relating the stimulus and response times at corresponding positions of the square wave. The individual pulses are detected by examining stimulus and response data point by point. The onset of the pulse will be referred to as s_1 and r_1 in the stimulus and response respectively. Similarly, s_2 and r_2 are the attainment of maximum value of the pulse; s_3 and r_3 are the start of step-down of the pulse; and s_4 and r_4 are the attainment of the minimum value.

The following quantities are computed for each pulse and then the average (mean), the maximum, the minimum, and the standard deviation for these quantities are calculated.

T_{LN} Response latency for an approaching stimulus

The time from the onset of the pulse in the stimulus to the onset of the pulse in the response. s_1 is subracted from r_1.

T_{LF} Response latency for a receding stimulus

The time difference between the step-down of pulse in the stimulus and in the response. s_3 is subtracted from r_3.

T_{RN} Response time for an approaching stimulus

The time to make the same change as the stimulus when the stimulus moves toward the observer, i.e. the time difference between the attainment of the maximum value of the pulse in the stimulus and response. r_1 is subtracted from r_2.

T_{RF} Response time to a receding stimulus

The time for the subject to make the same change as the stimulus when the stimulus moves away from the observer. r_3 is subtracted from r_4.

R_A Absolute response level

The steady state value of eye focus, i.e. the magnitude for r_2.

S_A Absolute stimulus level

The magnitude for s_2.

R_{MN} Response magnitude for approaching stimulus

The difference between the two successive response levels for an approaching stimulus, i.e. the magnitude for r_1 is subtracted from the magnitude at r_2.

R_{MF} Response magnitude for receding stimulus

The difference between the two successive response levels for a receding stimulus, i.e. the magnitude for r_4 is subtracted from the magnitude at r_3.

S_M Stimulus Magnitude

The difference between the levels of the stimulus, i.e. the magnitude at s_1 is subtracted from the magnitude at s_2.

V_{RF} Response velocity to a receding stimulus

The response magnitude for a receding stimulus is divided by the response time, i.e.

$$V_{RF} = \frac{R_{MF}}{T_{RF}}$$

V_{RN} Response velocity to an approaching stimulus

The response magnitude for an approaching stimulus is divided by the response time, i. e.

$$V_{RN} = \frac{R_{MN}}{T_{RN}}$$

D_{SR} Difference between absolute stimulus and response levels.

$$D_{SR} = S_A - R_A$$

In addition, the subject's average tracking levels for zero diopters and pulse magnitude are calculated and printed.

MATHEMATICAL METHODS USED IN SQUARE WAVE ANALYSIS

1. Wild points are removed from the stimulus and response.
   - a. The mean and standard deviation are calculated for the raw data
   - b. Secondary means and standard deviations are calculated for all points above the mean and for all points below the mean. The secondary means are printed as the average tracking levels for zero diopters and the pulse magnitude
   - c. Points which are greater than the upper secondary mean plus one corresponding standard deviation or less than the lower secondary mean minus one corresponding standard deviation are considered wild points. They are set equal to the appropriate secondary mean.

2. The Response time series is smoothed by taking a moving average over 5 points.

3. The first and second order differences are computed for stimulus and response.

$$\Delta f(n) = f(n) - f(n-1)$$

$$\Delta^2 f(n) = \Delta f(n) - \Delta f(n-1)$$

4. The mean and standard deviation is computed for the first order differences of stimulus and response.

5. A table is constructed from the first and second differences
   - a. Pairs of time values bounding an interval where the first order differences are all positive or all negative.
   - b. The number of zeroes in the second order differences, and points at which zeroes occur for each interval.

6. The square wave pulses in the stimulus are detected.

For each pulse,

a. S1 and S2 are detected by locating a set of continguous values in the first order differences which are greater than 1.5 times the standard deviation. (The mean is zero.) S1 is set to the first such data point, S2 is set to the last data point.

b. S3 and S4 are detected by locating a set of continguous values in the first order differences which are less than -1.5 times the the standard deviation. S3 is set to first and S4 is set to the last such data point.

c. Checking is done to insure that the approach and retreat of the pulse occur in the proper sequence.

7. The square wave pulses are detected in the response, using the same criteria as described for the stimulus with the following additional restrictions.

a. Only one standard deviation in the first order differences is used.

b. For an individual pulse, $r_1 > s_1$, $r_2 > s_2$, $r_3 > s_3$, $r_4 > s_4$, and $r_1 < s_4$ must be true.

c. If the response time, $(r_2 - r_1)$, is greater than one half the length of the pulse, $(s_4 - s_1) / 2$, then r_2 is taken as the time value where the second order difference is zero (an inflection point in the time series)

d. If the onset of pulse in the response, r_1, occurs before the onset of the pulse in the stimulus, s_1, then r_1 is taken as the first time value in response which has a second order zero occuring after s_1.

e. Similarly the retreat of the pulse in the response must follow the retreat of pulse in the stimulus. r_3 is taken as the first time value in the response which has a second order zero occuring after s_3.

f. If the length of the pulse in the response exceeds 1.5 times the length of the pulse in the stimulus the entire pulse is ignored.

g. If any of the preceeding restrictions can not be satisfied the entire pulse is ignored.

8. The quantities, Response Latency, Response time, Response magnitude Response velocity, described earlier are calculated for each pulse and stored on disk. Means and standard deviations are computed and printed along with individual pulse values.

ANALYSIS OF OPTOMETER VOLITIONAL DATA

Standard statistical computations (mean, standard deviation, maximum, and minimum,) were performed on the response time series.

The mean and standard deviation computed from the raw data are used to remove wild points. The wild points are presumed to be introduced by blinks. Hence, points one standard deviation below the mean or two standard deviations above the mean are discarded.

The mean, standard deviation, maximum and minimum re-calculated for the smoothed data.

The values for both the smoothed and raw data are printed.

VITA 2

Frederick Vincent Malmstrom

Candidate for the Degree of

Doctor of Philosophy

Thesis: EFFECTS OF CONCURRENT MENTAL ACTIVITY ON STATIC AND DYNAMIC ACCOMMODATION RESPONSES

Major Field: Psychology

Biographical:

Personal Data: Born in Kalamazoo, Michigan, September 8, 1939, the son of Mr. and Mrs. Vincent F. Malmstrom; married to Susan G. Gates, June 1, 1974, in Reno, Nevada; one son, Carl Vincent, born December 28, 1977, in Tulsa, Oklahoma.

Education: Graduated from The Leelanau School, Glen Arbor, Michigan, in June, 1957; received the Bachelor of Science degree from the United States Air Force Academy, Colorado, in June, 1964; received the degree of Master of Aerospace and Operations Management from the University of Southern California in January, 1970; received the Master of Science degree in Psychology from Oklahoma State University in December, 1972; completed the requirements for the Doctor of Philosophy degree in December, 1978.

Professional Experience: Air Force Electronic Warfare Officer, 1965-1970 and 1974-1975; Academic Adviser, Course Director, and Assistant Professor of Behavioral Sciences, U. S. Air Force Academy, Colorado, 1971-1974; Guest Worker, NASA/Ames Research Center, Sunnyvale, California, 1973-present; U. S. Air Force Reserve Major and Human Performance Engineer at the USAF/Rome Air Development Center, Rome, New York, 1976-present; Assistant Professor of Human Factors, University of Southern California, 1978-present.

Professional Affiliations: American Psychological Association; American Association for the Advancement of Science; History of Science Society; Sigma Xi.