THE EFFECTS OF TARGET ACUITY, ILLUMINATION LEVEL, DISTANCE AND AGE ON EYE FOCUS TIME

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THE EFFECTS OF TARGET ACUITY, ILLUMINATION LEVEL, DISTANCE AND AGE ON EYE FOCUS TIME

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SUMMARY

The effects of target acuity, illumination level, base distance, target distance and age on eye focus time were studied. The interactions between variables and the affects on eye focus time are discribed.

The experimental task involved fixating on a Landolt Ring, gap up, at a sepcified base distance. A second target was then presented with the base target disappearing at the same instant. The second target was a Landolt Ring with the gap oriented either left or right. The subject responded by throwing a response switch in the appropriate left-right direction. The optometer used allowed the variation of target size (20/20, 20/30, 20/40 and 20/80), illumination level (.145 fc, 1.45 fc, 14.5 fc, and 58 fc), base and target distances at two, three, four, five, six, seven and eight feet. The subjects were grouped into three age groups (18-22, 30-35 and 60-70). There were four subjects in both the 18-22 and 30-35 age groups with each subject performing 1568 trials. The 60-70 age group consisted of two subjects, each performing 219 trials. The response time was recorded from when the targets changed to when the response switch was thrown.

All of the variables studied were found to be statistically significant. As target size increased, eye focus time decreased. The lowest illumination level resulted in increased times while the three brighter illumination levels showed only slight incremental affects. Eye focus time was disproportionately longer for the two feet base distance. Graphs are presented that show the first order and most of the second and third order effects. Mean eye focus time was found to be .283 second.

CHAPTER I

INTRODUCTION

This research was conducted for the purpose of studying the effects of target acuity, illumination, distance changes and age have on focusing time. The range of variables were chosen based on their applicability to the industrial setting.

Four target sizes or acuities were used (20/20, 20/30, 20/40, 20/80). Four illumination levels ranging from very dim (.145 fc) to a level where type written material could be easily read (58 fc). Seven base and target distances between two and eight feet in one foot intervals were used. Ten subjects divided into three age groups (18-22, 30-35, 60-70) were tested.

The method used employed an optometer consisting of two tunnels. A base target with the Landolt Ring, gap up, was viewed then a second target in the other tunnel was illuminated while the base target disappeared. The time interval between when the second target was illuminated and when the subject threw the response switch was recorded.

All the variables studies, with the exception of age where no conclusion could be drawn, had statistically significant affects on eye focus time. Target size was found to have the greatest effect on eye focus time for all conditions.

A review of the literature dealing with accommodation is presented in Chapter II. The methods and procedures used in the study are given in Chapter III. Summaries of the data collected and the results of the ANOVA analysis are given in Chapter IV. A discussion of the results in terms of the first order effects and interactions is presented in Chapter V. A summary of the findings, the conclusions that were drawn and areas for future research are presented in Chapter VI. Calculations that show that the illumination level is the same for all target sizes at every distance used is presented in Appendix A. The instructions that were given to each subject are in Appendix B. Tabulations of the cell means for the variables and interaction terms derived from the ANOVA model are presented in Appendix C.

CHAPTER II

BACKGROUND AND LITERATURE REVIEW

Anatomy of the Eye: The Dioptric System

Vision is a cortical response to stimulation, by electromagnetic radiation, of specialized nerve cells located in the eye. These nerve cells transform the impacting radiation into neural impulses which are then directed to the visual cortex for interpretation.

As shown in Figure 1, the eye is composed of several functional

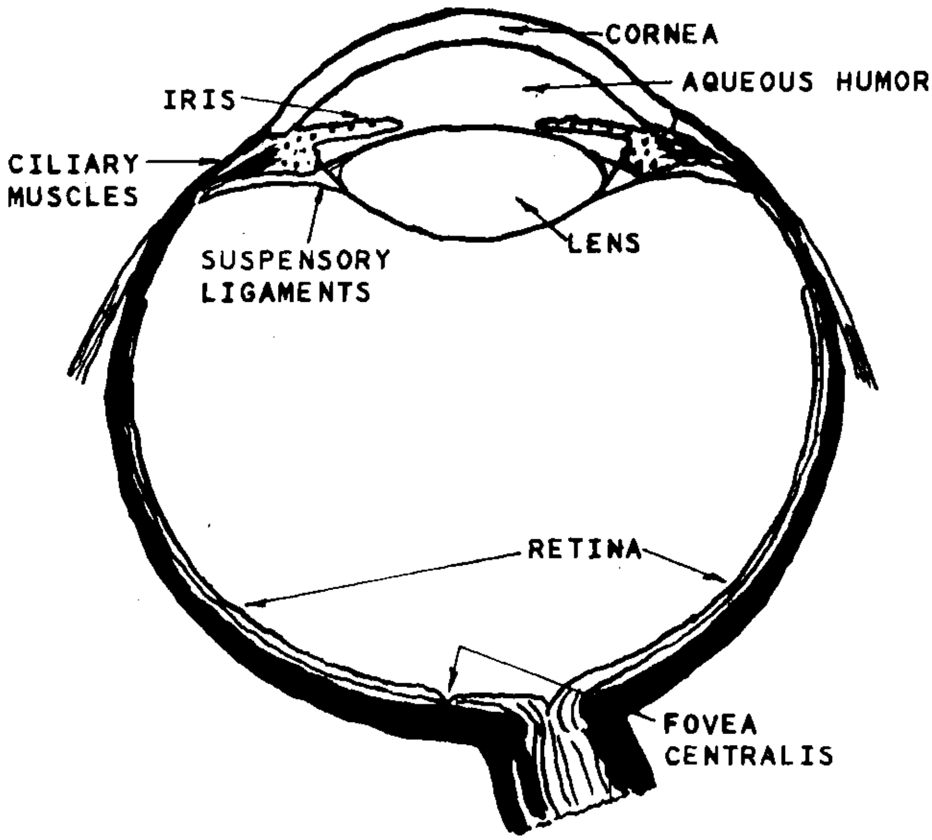

Figure 1. Cross Section of a Left Human Eye

components. The sclera is a protective membrane; the choroidea is a nourishing membrane, and the retina is a layer of interconnected photosensitive cells.

This research is concerned with the operation of the dioptric system (see Figure 1). The dioptric system consists of the following elements:

Cornea

The transparent anterior portion of the eye having a smaller radius of curvature than the remainder of the eye. It provides a portion of the refractive power of the optical system.

Aqueous Humor

The clear fluid contained in the anterior chamber of the eye, providing another refractive medium.

Iris

The pigmented, muscular membrane that encircles the pupil and controls the amount of light that enters the eye.

Lens

A transparent, slightly colored, layered, crystalline, flexible, biconvex body.

Ciliary Muscle

With contraction, it allows the lens to relax, causing an increase in curvature of the lens which changes the refractive power.

Suspensory Ligaments

The non-extensible ligaments which hold the lens in position. When the ciliary muscles are relaxed, the suspensory ligaments apply the stress needed to deform the lens such that it is focused at "infinity". When the ciliary muscles contract, in the plane of the suspensory ligments, the stress exerted by the ligaments is counteracted thus reducing the tension on the lens which allows the convexity of the lens to increase.

Having passed through the lens, the light then passes through the posterior chamber of the eye and falls on the retina. On the retina there is an area called the fovea centralis which contains the highest concentration of cones. The fovea centralis lies on the visual axis of the eye and is the area allowing the greatest visual acuity (see Figure 2).

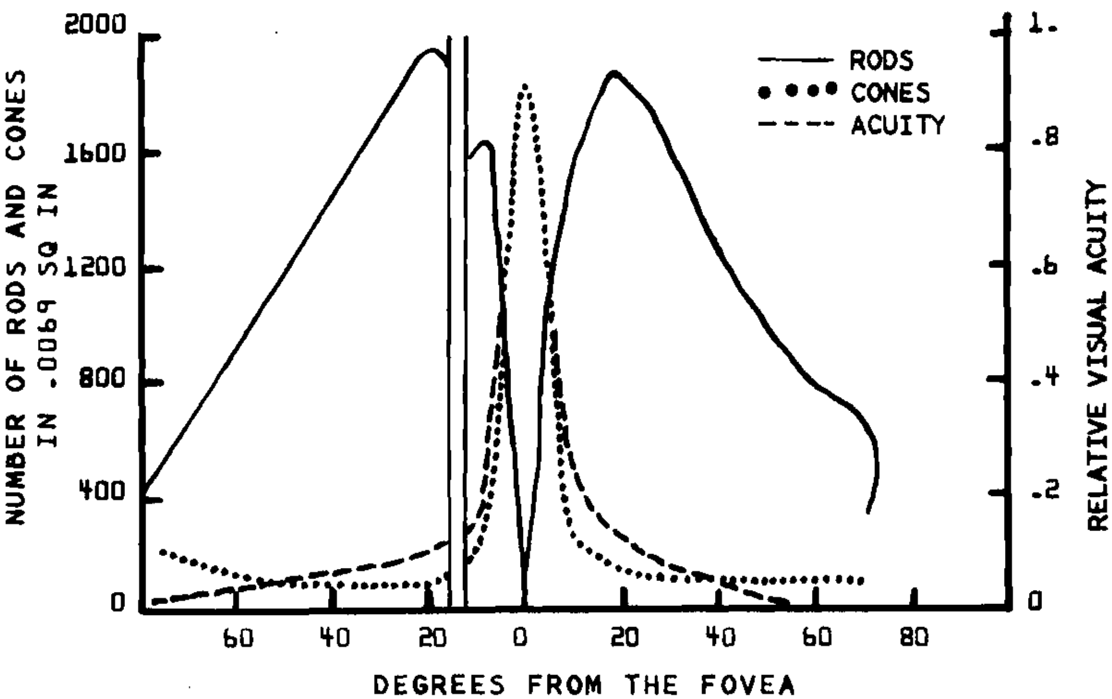

Figure 2. Distribution of Rods and Cones in the Retina (After Osterberg, 1935, in Bioastronautics Data Book)

Accommodation

The process by which an initially blurred retinal image is brought into focus is called accommodation. Light reflected off objects in the visual field passes through the dioptric system and forms an image on the retina. The outer portions of the dioptric system, the cornea and aqueous humor, provide about two-thirds, 43 diopters, of the refractive power of the eye. The term diopter, a measure of the refractive power of a lens is defined as the inverse of the separating distance, in meters, between the eyes and the object in focus. While the refractive power of the cornea-aqueous humor is virtually constant, the eye can alter its total refractive power by changing the curvature of the lens.

The method used by the eye to change the curvature of the lens is by contracting, which increases curvature, or relaxing the ciliary muscles, which decreases the curvature. When the eye is focused at infinity, the ciliary muscles are relaxed leaving the flattened shape of the lens to be determined by the force exerted by the suspensory ligaments on the lens. As the object is moved closer to the eye, the ciliary muscles contract, counteracting the force exerted by the suspensory ligaments resulting in the lens increasing its curvature. The net result being that the refractive power of the lens has been increased.

Drawing together several of the factors that influence the accommodation process, Toates (1970) proposed a model that treates the process as a proportional control system (see Figure 3). The model centers around the observation that the refractive power of the

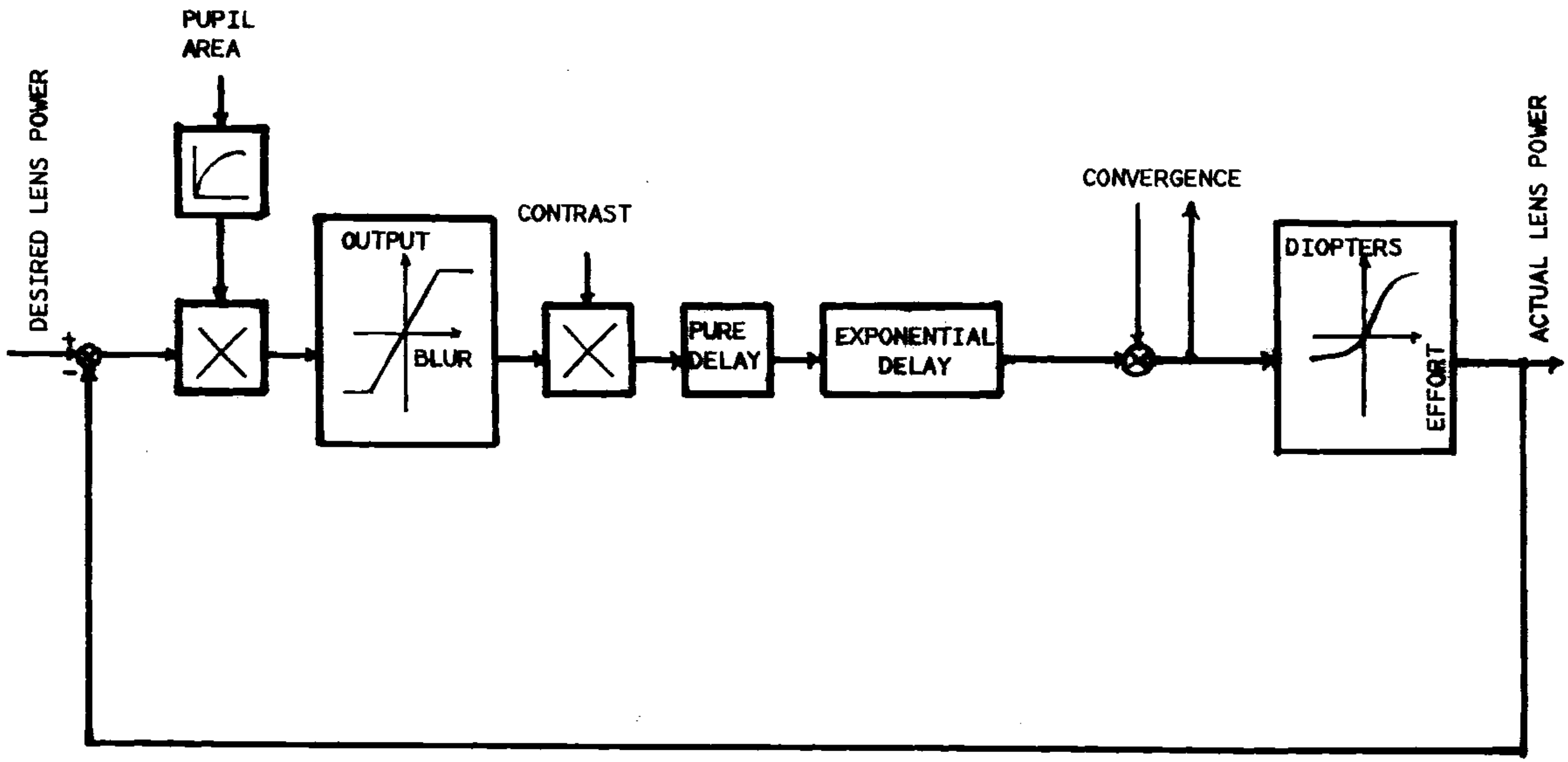

Figure 3. Accommodation - A Proportional Control System Model
(After Toates, 1970)

lens oscillates about the correct point of focus. In 1958, Alpern proposed and confirmed that the cue to the proper change in direction for accommodation was this steady-state oscillation. The visual cortex can interpret whether the eye has over or under focused with the oscillations providing the necessary mechanism to supply this information. Alpern's findings have been confirmed (Cambell, Westheimer and Robson, 1958; Fender 1964). The oscillation has been found to have a frequency of about two cycles per second (Hz) and an amplitude of ± 0.1 diopter (D). (Stark, et al., 1965; Cambell and Robson 1959; Cambell and Westheimer, 1960.) (See Figure 4.) A subsequent study by Brodkey and Stark (1967) indicated the two Hz figure to be a peak value with the average frequency being 1.3 Hz and an amplitude of ± 0.4 D.

The total refractive power of the dioptric system with the ciliary muscles relaxed is on the order of 60 D. An additional 14 D can be achieved by young humans with a maximum contraction of the ciliary muscles but this ability decreases with age (Dartnall, 1962).

Terminology

Positive Accommodation

The changing of eye focus from a near object to one further away.

Negative Accommodation

The changing of eye focus from a far object to one closer to the eye.

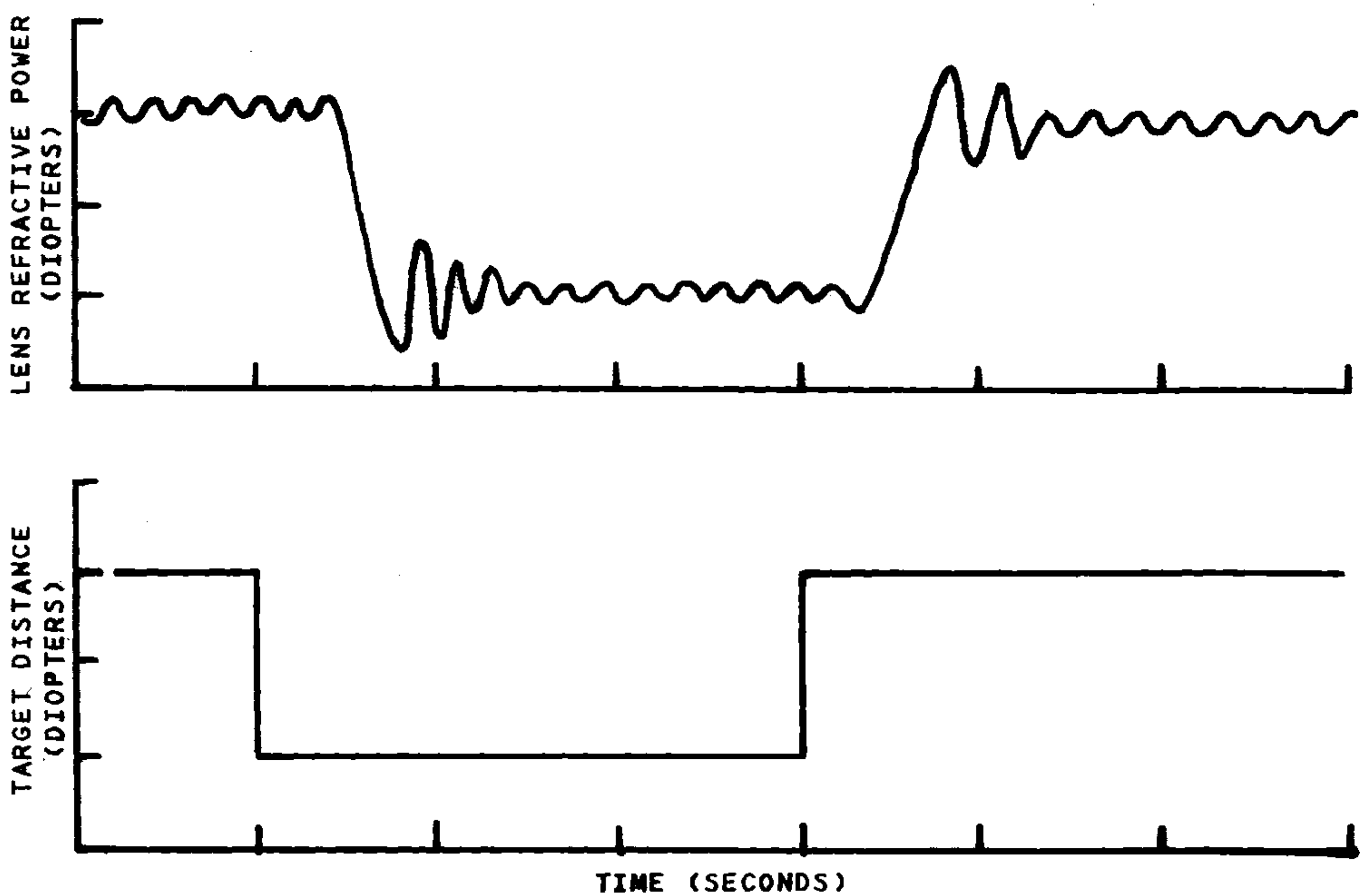

Figure 4. Dioptric System Function Model
(After Risseeuw, 1974)

Accommodative Latency

The time interval between when an out of focus image strikes the retina to when the lens responds by changing shape.

Accommodative Movement Time

The time interval between when the lens begins to change shape and when the oscillations reach a steady-state around the new level of accommodation.

Speed of Accommodation

The time interval between when an out of focus image strikes the retina to when the image is finally brought into focus.

Eye Focus Time

The time it takes the eyes to refocus enough to be able to discern particular characteristics of an object.

Residual Accommodation

The interval between when the characteristic of the object has been discerned and when the oscillations reach steady-state.

Factors That Influence Eye Focus Time

Positive Versus Negative Accommodation

Cambell and Westheimer (1960) found that the accommodative latency (AL), the time between the presentation of a two diopter step simulus and when the eye began to accommodate, was different for positive and negative accommodation. They reported for negative accommodation an AL of .38 ± .08 second and for positive accommodation an AL of .36 ± .09 second. Other researchers have reported similar results (see Table 1).

Table 1. Reported Accommodation Times

			Movement Time	
	(Near-Far)	(Far-Near)	(Near-Far)	(Far-Near)
Campbell & Westheimer (1960)	.38 sec	.36 sec	.64 sec	.56 sec
Stark, Jakakashi, and Zames (1965)	.38	.36		
Methods - Time Measurement (1964)			.26	.26
O'Neill and Stark (1968)	.29	.29		
Cornsweet and Crane (1970)	.40	.40		

Age

The recession of the near-point of clear vision was first noted in 1864 by Donders (see Figure 5). The cause of this moving away of the closest point of clear vision is attributed to the lens loosing its elasticity with age (Heyningen, 1962) while the strength of the ciliary muscles remain constant throughout life (Alpern, 1962, 211). Weston (1949) reported that the refractive power of the lens deminishes from about 12 D at age 16 to four D at 44 to one D at 60. Other researchers have reported similar findings (Breinin and Chin, 1973).

Illumination Level

There is a general lack of agreement as to the effects of illumination level on reaction time. Forbes (1945) reported for an

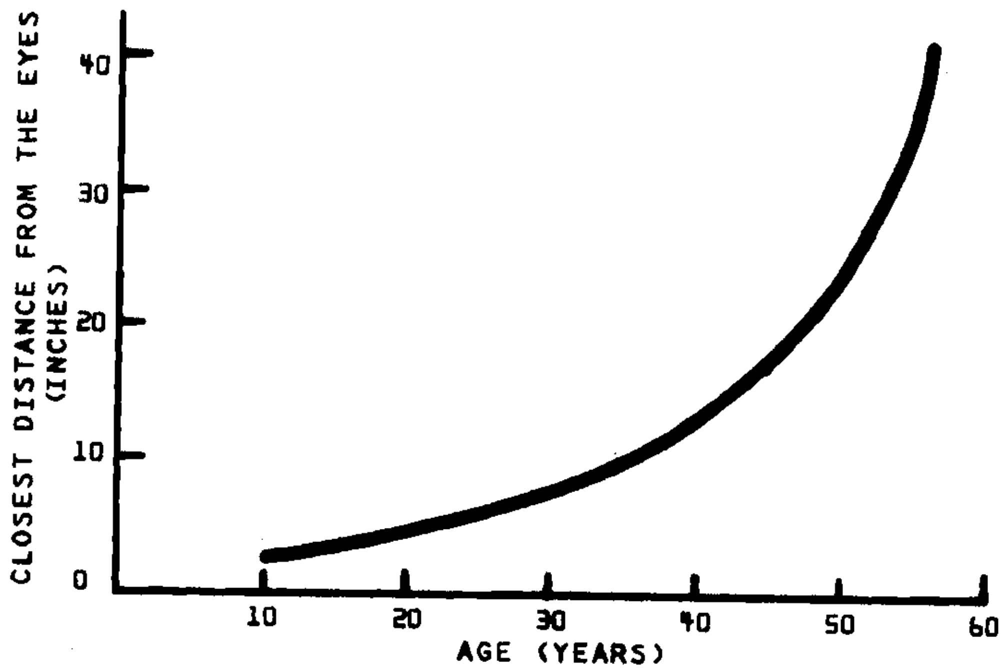

Figure 5. Age and the Closest Point of Clear Vision (After Weston, 1949)

unspecified low illumination level that it took .29 second between stimulus on-set and the time the subject perceived the light. Kaswan and Young (1965) in a study of stimulus intensity and duration found that a duration of .512 second and 11.84 millilamberts (mL) intensity resulted in a RT of .220 second. Raab, et al. (1961) recorded for a light stimulus of .5 second duration the following RT's: .158 at 2787 mL, .171 second at 27.87 mL and .196 second at .2787 mL. Rains (1963) found similar results, while Vaughan, et al. (1966) found RT's about twice as long as Rains in a similar study. These studies are summarized in Figure 6.

Target Acuity

Acuity is defined as the reciprocal of the angle, in minutes

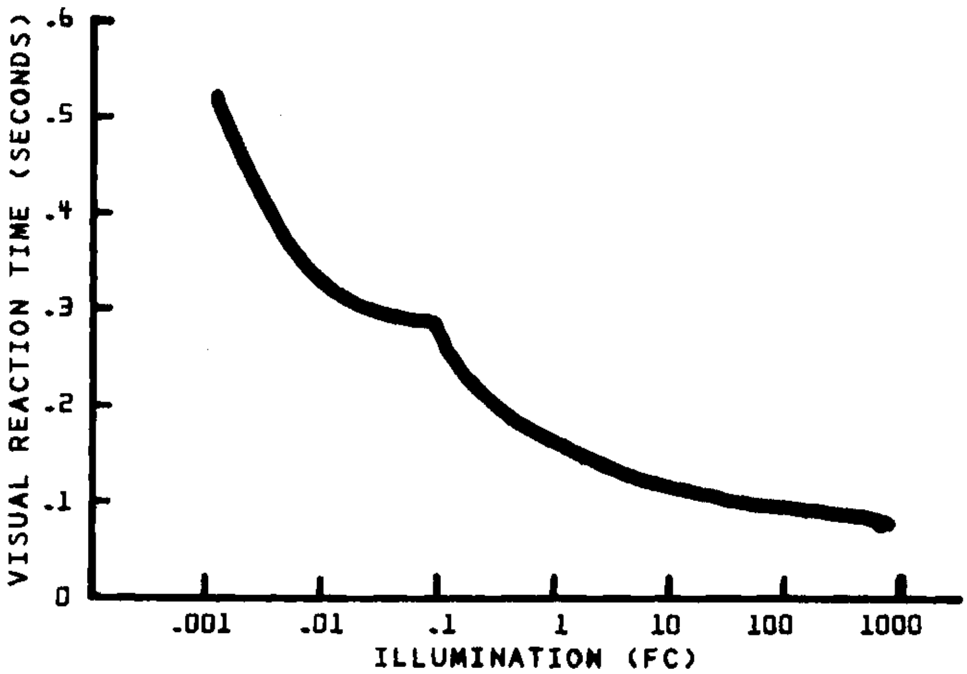

Figure 6. Illumination and Visual Reaction Time
(After Cambell, 1960)

of arc, subtended by the smallest detail which can be seen under given conditions (Pirenne, 1967). For reference, non-technical measures of acuity such as 20/20, 20/30, 20/40 and 20/80 correspond to 1.0, 1.5, 2.0 and 4.0 minutes of arc, respectively.

For a single straight line, the minimum visual angle for perception was found to be .5 second of arc (Hecht and Mintz, 1939). For recognition of gap position on a Landolt Ring, the minimum angle was found to be less than 30 seconds of arc (Schlaer, 1937). The effects of illumination level on acuity is shown in Figure 7. The eyes' sensitivity to detail corresponds closely with the distribution of cones in the retina. The size, shape and sensitivity of cones are what enable the eye to detect greater detail than with rods.

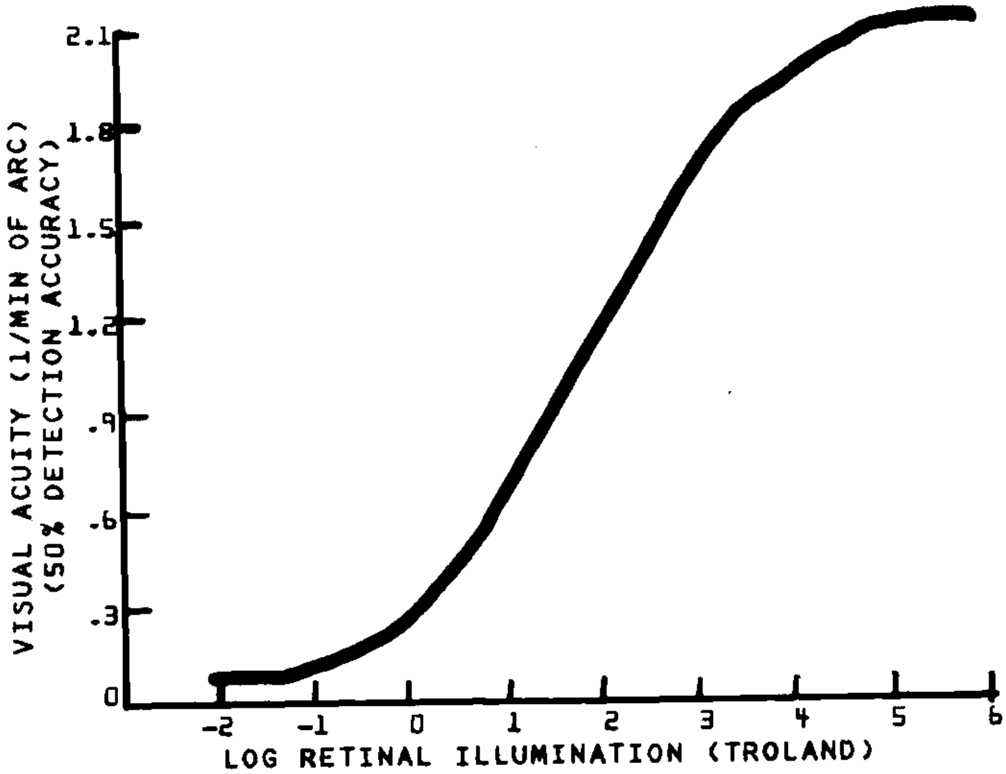

Figure 7. Illumination and Acuity
(After Schlaer, 1937)

Illumination Wavelength

The eye's sensitivity to light differs with the wavelength (see Figure 8). Under photopic conditions, the eye's maximum sensitivity occurs at a wavelength of about 555 nanometers (nm) while for scotopic vision the maximum occurs at about 510 nm. (Hopkinson and Collins, 1970.) Under scotopic conditions, RT is positively correlated to wavelength while for photopic conditions there is no significant differences in RT for various wavelengths (Pollack, 1968). It has been noted that the curves for RT at different wavelengths and illumination levels follow the same form as RT at different illumination levels with white light (Lit, et al., 1971).

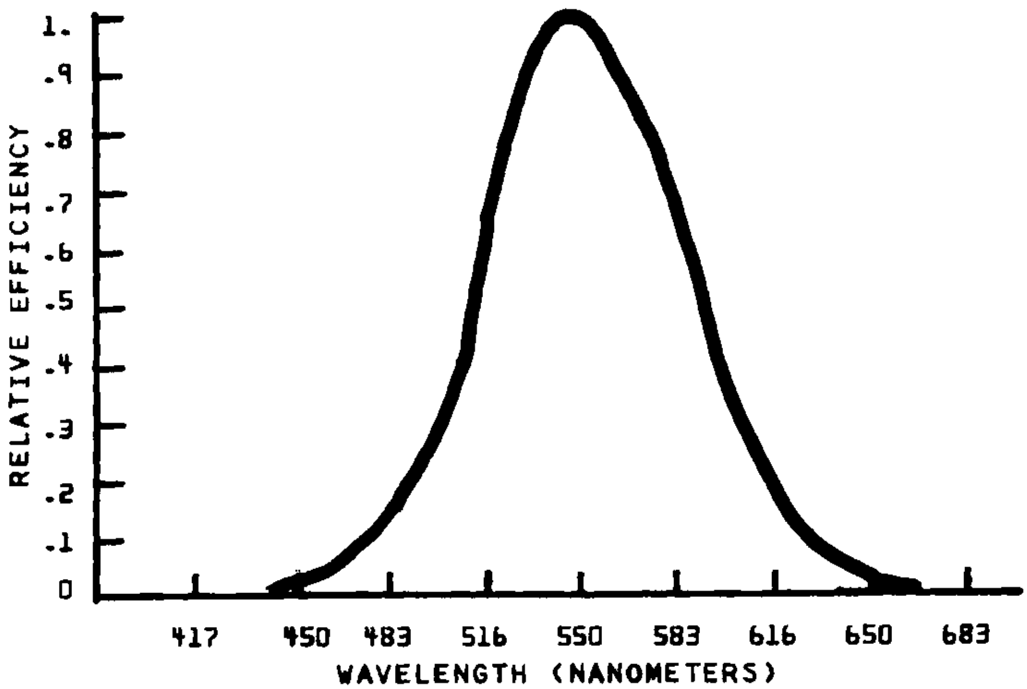

Figure 8. The Eye's Sensitivity to Wavelength of Light (After Bioastronautics Data Book, 1973)

Illumination Contrast

Contrast defined as the difference between target and background brightness, has been found to affect accuracy of detection; that is, as contrast is increased, errors in detection decrease (Weston, 1949; Blackwell, 1959). When using black opague targets with a white light field surrounding it, the contrast is simply the brightness of the light field with some level arbitrarily set at 100 percent contrast.

In studying the effects of contrast on acuity, bars (Bryam, 1944), discs (Blackwell, 1959) and rectangles (Lamar, et al., 1947) have been used as test objects. These studies indicate that as the target size decreases the contrast must increase to achieve the same rate of detection.

Convergence

One type of vergence movement is fusion, the orienting of the eyes such that the visual field in view is the same for each eye. The fusional movement occurs when a disparity exists between the visual fields of the eyes and usually occurs during the accommodation process. The RT associated with fusional movements is between .15 and .20 seconds (Alpern, 1962). The maximum velocity for a lateral fusion of 5.5 degrees was found to be about 21 degrees per second (Westheimer and Mitchell, 1956).

Stimulus Uncertainty

In a study of stimulus and response uncertainty for choice reaction time, it was found that RT was lineal and positively correlated to uncertainty (Bernstein, et al., 1967). These researchers reported RT's, the time between when the light came on and when the corresponding button was pushed, of .332 second for a one bit decision, .348 second for two bits and .357 second for three bits. In a study of combined manual and decision tasks, an average value of .125 second per bit for pure decision time has been reported (Sadosky, 1969).

Fitts (1954) reported movement times in a one bit choice reaction time experiment. The subjects moved a stylus either right or left of center to a target stripe that was either two, four, eight or sixteen inches from center. Movement time was found to be linearly related to the distance moved; a two inch move took .1 second, a four inch move took .2 second and a 16 inch move took .38 second.

Mental Set

The occurrence of errors as well as the reaction time may both be reduced by giving explicit instructions as to the nature of the task and stimulus. The magnitude of improvement depends on the nature of the task with complex tasks receiving greater gains than simple tasks (Dember, 1963). The improvement in RT will gradually deminish with learning. In a study of the stimulation of both the visual and auditory sensory channels, RT was shorter than for simple visual RT, about 80 percent of the simple visual RT value (Bernstein, et al., 1969).

Summary

The accommodation process is affected by many variables. Those presented in the above review represent those variables studied in this research. Under low illumination and small targets, eye focus time would be expected to increase. Age is known to affect the near-point of clear vision but the affect on eye focus time is unknown. Wavelength, stimulus uncertainty and mental set were controlled in this research.

CHAPTER III

METHODS AND PROCEEDURES

Method Used to Measure Eye Focus Time

This study utilized an optometer designed and constructed by D. P. Risseeuw (1974). The optometer consists of two eight foot long tunnels which were attached together to form a 90° angle (see Figure 9). A half silvered mirror was positioned diagonally at the junction of the two tunnels. Rectangular light fields in each tunnel trans-illuminate the Landolt Rings which serve as the targets. With a target positioned gap up in the reflected tunnel at one of the one foot increments between two and eight feet and a target with its gap either left or right placed at some distance in the transmitted tunnel, the experimenter is ready to begin.

With the subject once in place with a response switch (RS) in hand, the master control switch (MCS) is positioned such that the gap up target is illuminated. The subject focuses on this base display. The experimenter then gives command "Ready" and one second later flips the MCS to illuminate the other target. The base target light field decayes in 25 m second while the other light field reaches 95 percent of full illumination in 14 m seconds. The flipping of the MSC starts a clock that counts in units of .0001 second. Once the subject has accommodated enough to identify the gap position on the second target, he throws the RS in the appropriate direction. This action stops the

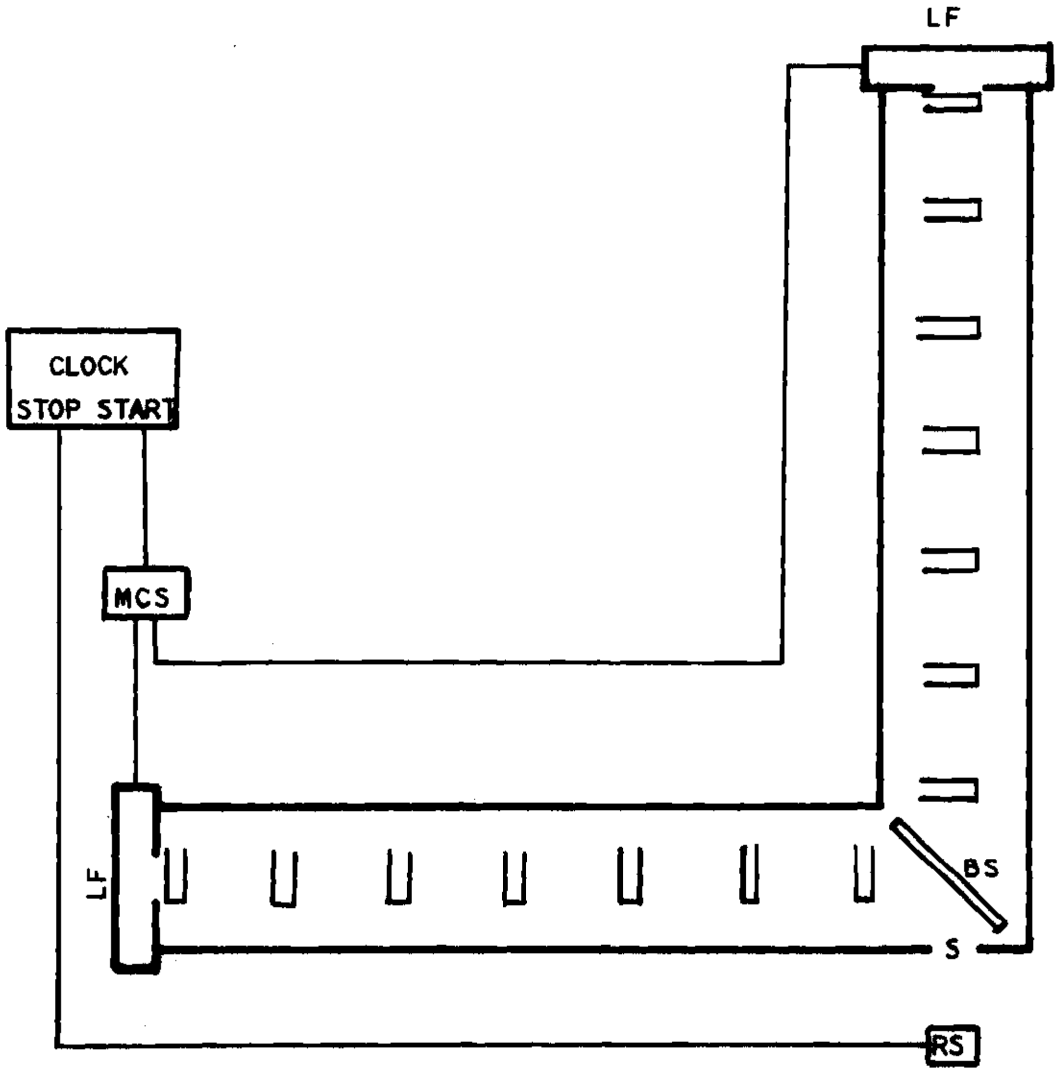

Figure 9. Optometer; LF - Light Field; BS - Beam Splitter; S - Subject; RS - Response Switch; MCS - Master Control Switch (After Risseeuw, 1974)

clock. The experimenter records the elapsed time shown and sets the system back to the initial point.

Each set of trails consisted of seven trials with the base distance and illumination level held constant and target distance and gap position randomly changed. Base distance, illumination level and target distance sequence were changed after each set of trials.

Description of the Apparatus

Figure 9 is a diagram of the major components of the optometer used in this study. For a more detailed discussion of the electrical components, Landolt Ring calculations and basic optometer design, the reader is referred to Risseeuw (1974).

Beam Splitter (BS)

The BS is eight inches square and one-eight inch thick glass with Beam Splitter Coating No. 405, produced by the Liberty Mirror Division of Libbey-Owens-Ford Company. The BS is coated on the front surface to both reflect and transmit 42 ± 3 percent of the total incident light.

Light Field (LF)

A LF consists of four F24T12/CW Sylvania Flourescent Lamps (20 watts, 24 inches long, 1.5 inches wide, cool white), powered by a pair of 300-1321 Jefferson ballists. The LF is limited to a 12 x 2 inch slit by the mounting frame. The light passes through a translucent prismatic styrene sheet to produce an even field of white light.

Displays

The targets are Landolt Rings photographically printed on

Kodak Lantern Slides, 4 x 3.25 inches (Figure 10). The displays may be placed at any one foot increment between two and eight feet and require 20/20, 20/30, 20/40 or 20/80 visual acuity.

Master Control Switch (MCS)

The MCS is a standard double pole, single throw toggle switch. When the MCS is thrown, the corresponding LF is illuminated while concurrently providing an 18 volt pulse to the counter to start the clock. The pulse is provided by an 18 volt output from a Lambda Power Supply, model LT-1095 M.

Response Switch (RS)

The RS is a standard center-off, single pole, double throw switch. When the switch is thrown either left or right of center, a pulse from the power supply is routed to the counter to stop the clock.

Clock

The clock consists of a Hewlett-Packard Model 2724A Electronic counter into which the output of a 10 kHz oscillator is fed. The clock is accurate to ± .1 millisecond each second.

Subject Alignment

The subjects' head position and distance from targets are regulated by a head support which insures uniform level of sight and target distance.

Light Control

The light level inside the tunnels is controlled by the use of a flat black interior, permanent and movable baffles. The result is that the targets appear as an illuminated square with a Landolt Ring in the center with the remaining area around the target being completely

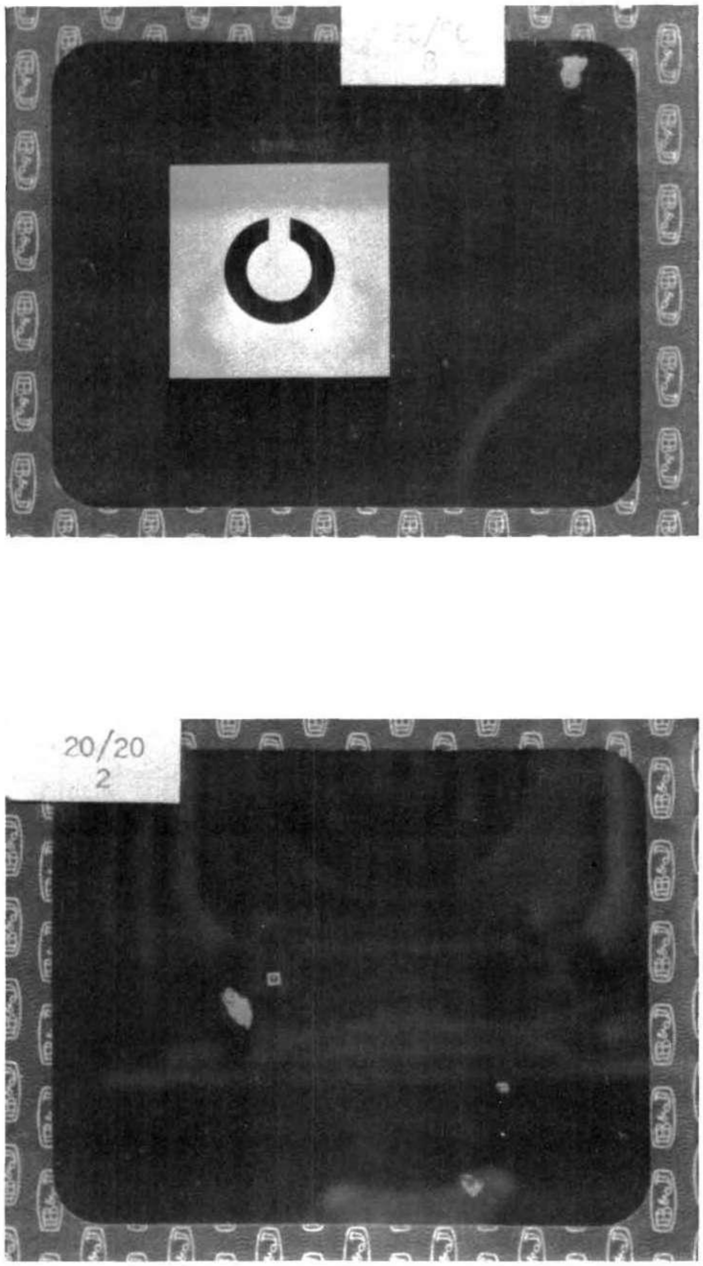

Figure 10. Landolt Ring Targets

black.

The variation of light level is achieved by placing a three inch square Kodak No. 96 Wratten Neutral Density Filter (40, 10, 1, and 0.1 percent transmission with a ± 10 percent of transmission factor tolerance were used) at the two foot display position. Appendix A presents the calculations for determining the illumination received by the subjects through the targets.

Experimental Procedure

The Task

The subject seated himself, grasped the response switch (toggle switch) in one hand while holding the switch box in the other hand, and positioned his head against the forehead rest. The subject then fixated on the illuminated gap up display in the reflected tunnel. Having inserted a display with the gap left or right in the transmitted tunnel, the experimenter then gave the preparatory command "Ready"; then threw the master control switch approximately one second later; recorded the response time; returned the master control switch so that the base display was illuminated; recycled the clock; changed the transmitted tunnel display and then repeated the above sequence.

Prior to testing, each subject stated whether he preferred to use his left hand or his right hand in operating the response switch. Each subject was allowed to use his preferred hand but was required to be consistent, that is the hand configuration could not be altered between tests.

The Experimental Design

There were four target acuities (20/20, 20/30, 20/40, 20/80), seven base and seven target distances (2,3,4,5,6,7,8 ft.), and four illumination levels (58, 14.5, 1.45, .145 Fc) used. The task proceeded in sets of seven trials. Each set consisted of one base distance, one illumination level, and one acuity level with the seven target distances presented in random order. The gap position (left or right) was randomized. The acuity levels were given in blocks of four sets of seven trials with the base distance and illumination level randomized within blocks. The blocks were randomized with respect to other blocks. The result was that all base distances were tested at all levels of acuity and illumination. Eact test condition was replicated. Thus, 1568 tests were required of each subject (49 base target combinations, 4 acuity levels, 4 illumination levels, and a replicate).

Movement Plus Reaction Time

This sub-study was performed during the course of the experiment. The experimentor instructed the subject that the next set of trials would consist of going from a gap up target to a blank light field. The subject was to respond by throwing the response switch as soon as the gap up target disappeared. These trials were used to get a measure of the subject's movement and simple reaction times using the response switch.

Decision Plus Response Time

In this sub-study, the experimentor instructed the subject that the base distance would equal the target distance and that only the target gap position would change (left or right). The subject was to respond by throwing the response switch in the appropriate direction. These trials were used to get a measure of the subject's decision plus response times.

The two sub-studies were given in sets of six trials and tested each acuity and illumination level. The instructions given to the subjects for each type of trial set can be found in Appendix B.

Subjects

Ten male caucasians were used as subjects. Their ages ranged from 19 to 68 years. Each subject's vision was tested with a Bausch and Lomb Ortho-Rater. The eight subjects in the 19-22 and 30-35 age groups showed to have 20/20 vision while the two subjects in the 60-70 age group showed to have 20/30 corrected vision. Demographic information is provided in Table 2.

Table 2. Demographic Information

Subject	Vision	Age	Height	Weight	Education	Occupation
RC	20/20	22	6' 0"	180 lbs.	3rd. yr. college	Student
TW	20/20	20	6' 2"	190 lbs.	3rd. yr. college	Student
GM	$20/20_c$	19	6' 1"	175 lbs.	2nd yr. college	Student
TR	20/20	21	6' 4"	190 lbs.	3rd. yr. college	Student
THS	20/20	31	5' 6"	155 lbs.	BME, Grad.	Air Force Pilot
RKS	20/20	30	5' 10"	180 lbs.	Ph.D.	College Professor
TLS	$20/20_c$	33	5' 6"	150 lbs.	BSEE, Grad.	Army Capt.
JD	$20/30_c$	67	5' 9"	190 lbs.	BSEE MSEE	Retired Power Engr.
HG	$20/30_c$	68	5' 7"	200 lbs.	High School	Retired Businessman

c = corrected

CHAPTER IV

RESULTS

The data were statistically tested using an Analysis of Variance (ANOVA) Model. Table 3 presents the general ANOVA results. For a more detailed presentation the reader is referred to Appendix C. The ANOVA model is a factorial design.

ANOVA Model

$$RT = \mu + S_i + A_j + L_k + B_\ell + T_m + (\text{interactions}) + e_{ijK\ell m}$$

μ = Residual

S_i = Subjects; i = 1,2,3,4,5,6,7,8.

A_j = Target Acuity; j = 1, 20/20; 2, 20/30; 3, 20/40; 4, 20/80.

L_k = Illumination; k = 1, 58 Fc; 2, 14.5 Fc; 3, 1.45 Fc; 4, .145 Fc.

B_ℓ = Base Distance; ℓ = 1, 2 ft.; 2, 3 ft.; 3, 4 ft; . . . 7, 8 ft.

T_m = Target Distance; m = 1, 2ft.; 2, 3 ft.; 3, 4 ft.; . . . 7, 8 ft.

$e_{ijk\ell m}$ = Residual

Table 3. ANOVA Table

Source	d.f.	MS	F test	Level of Significance
S	7	12.827	131.02	.1 %
A	3	207.367	2118.15	.1 %
L	3	58.753	600.13	.1 %
B	6	12.406	126.59	.1 %
T	6	22.567	203.28	.1 %
SA	21	2.196	22.41	.1 %
SL	21	2.262	23.08	.1 %
SB	42	.116	1.18	NS
ST	42	.627	6.40	.1 %
AL	9	8.206	83.73	.1 %
AB	18	.516	5.27	.1 %
AT	18	.586	5.98	.1 %
LB	18	.228	2.33	5.0 %
LT	18	.109	1.11	NS
BT	36	5.331	57.38	.1 %
SAL	63	.899	8.97	.1 %
SAB	126	.115	1.17	NS
SAT	126	.095	.97	NS
SLB	126	.136	1.39	1.0 %
SLT	126	.103	1.05	NS
SBT	252	.135	1.38	.5 %
ALB	54	.307	3.13	.1 %
ALT	54	.115	1.17	NS
ABT	108	.287	2.93	.1 %
LBT	108	.099	1.01	NS
SALB	378	.130	1.33	.1 %
SALT	378	.075	.77	NS
SLBT	756	.065	.66	NS
ALBT	756	.080	.82	NS
SABT	324	.080	.82	NS
SALBT	2268	.067	.68	NS
$e_{ijk\ell m}$	6272	.098		
Total	12544			

A summary of results for the Decision Plus Response Time substudy is presented in Table 4. More detailed data tabulated by subject, is given in Appendix D.

Table 4. Decision Plus Response Time

Averages for all Subjects (in seconds)

Acuity	Illumination 58 fc $\bar{x}$	58 fc σ	14.5 fc $\bar{x}$	14.5 fc σ	1.45 fc $\bar{x}$	1.45 fc σ	.145 fc $\bar{x}$	.145 fc σ
20/20	.678,	.201	.557,	.106	.669,	.181	1.041,	.411
20/30	.552,	.106	.497,	.031	.533,	.071	.657,	.122
20/40	.479,	.044	.431,	.032	.449,	.033	.547,	.072
20/80	.405,	.043	.396,	.037	.424,	.045	.451,	.034

The two elderly subjects, ages 67 and 68, were tested with an Orthor-Rater and were found to have at least 20/30 corrected vision. In the main study it was found that neither of the two senior subjects could respond to the following test condition:

1. 20/20 targets
2. 20/30 targets
3. 20/40 targets at the lowest illumination level
4. 20/40 targets at two or three feet for all illumination levels
5. 20/80 targets at two feet for all illumination levels

Since the resulting data set was very limited, it was not used in the general ANOVA model. A comparison of the mean response times of the age 19 - 35 subjects and the elderly subjects is given in Table 5.

Table 5. Mean Response Time, Comparison for Elderly Subjects

Acuity	Age Range (Years)	Illumination 58.0 fc	14.5 fc	1.45 fc	.145 fc
20/40	19 - 35	.6739 sec	.6682 sec	.6816 sec	.8409 sec
	> 65	.8154	.8147	.8455	---
20/80	19 - 35	.5188	.5308	.5385	.5908
	> 65	.6371	.6601	.6711	.8063

CHAPTER V

DISCUSSION

First Order Effects

Figure 11 presents the mean response times for the following first order variables: S_i, A_j, L_k, B_ℓ and T_m. The results are given for the 19 - 22 and 30 - 35 age groups only.

Subjects

Subject factors were statistically significant at an α level of .001. The mean RT of individual subjects ranged from .671 to .936 second. The subject points are plotted chronologically from left to right in Figure 11a.

Acuity

Target acuity was found to be statistically significant at an α level of .001. Generally, as the target size increased, the RT decreased as shown in Figure 11b. The change in mean RT when comparing 20/20 to 20/30 and 20/30 to 20/40 targets was much greater than when comparing 20/40 to 20/80 targets. It is believed that the 20/20 and 20/30 targets are more difficult to see under the test conditions while the 20/40 and 20/80 targets were much easier to see and of about equal difficulty. The gains with increasing target size are felt to deminish after some critical size is reached, in this case it was the 20/40 target.

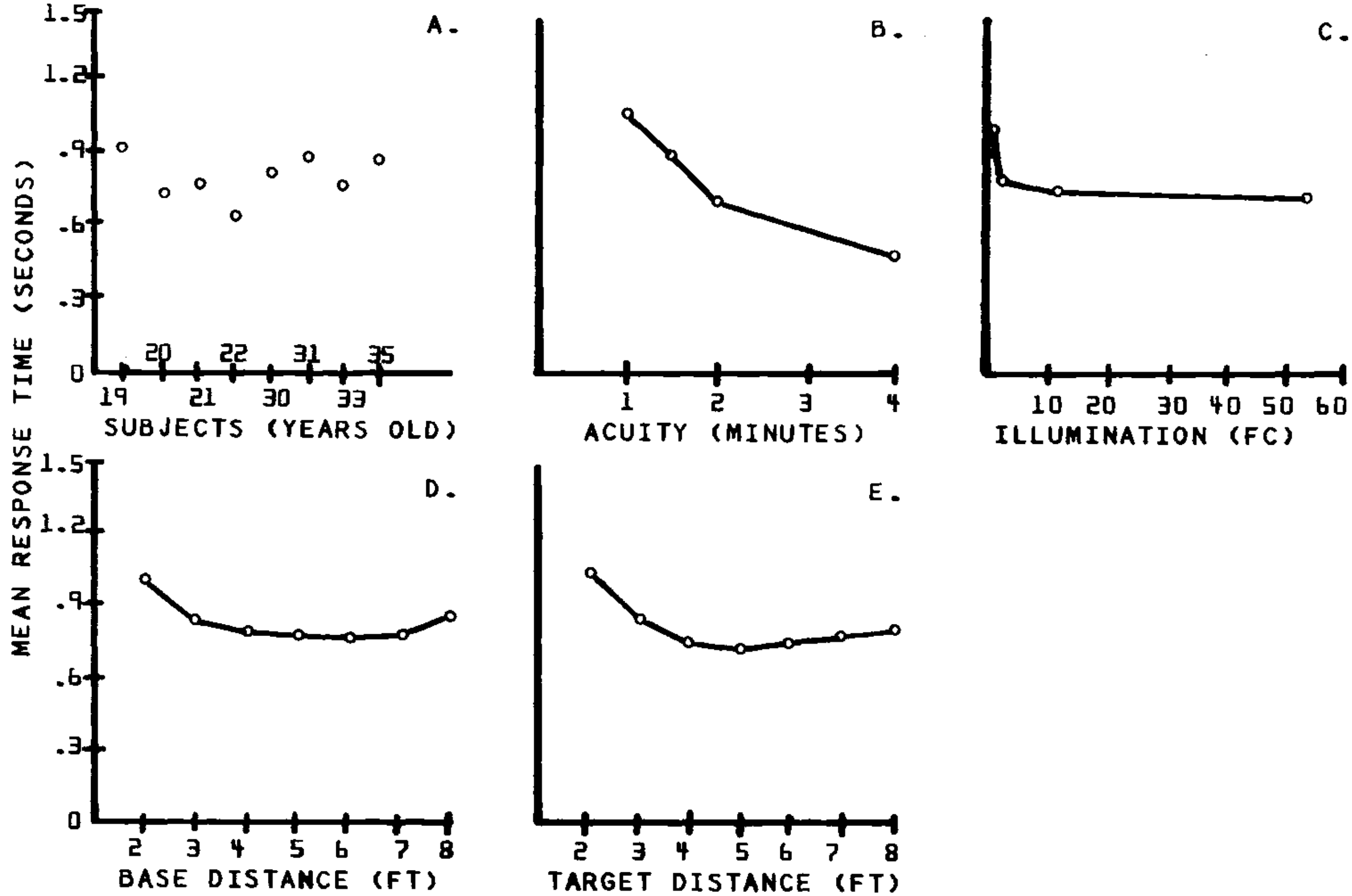

Figure 11. First Order Effects

Illumination

Illumination level was statistically significant at an α level of .001. As shown in Figure 11c, the lowest illumination level (.145 fc or .1347 mL) resulted in an appreciably long RT than the other three illumination levels. A possible explanation is that the lowest illumination level boarders on the range where cone vision drops off and rod vision plays a more dominant role in seeing.

Another aspect of Figure 11c is that at the brightest illumination level (58.0 fc or 53.9 mL) RT was found to be slightly longer than for the middle two illumination levels. In questioning the subjects, it was learned that with the 20/20 and to a lesser extent the 20/30 targets there was a small amount of irradiation around the rings. This irradiation effect could have made the visual discrimination task more difficult.

Base Distance and Target Distance

Base distance and target distance were both found to be statistically significant at an α level of .001. The mean response time as a function of these variables is shown in Figures 11d and 11e. The bowed shape of these curves may be an artifact of the experimental design. Consider Figure 11d, the point plotted for the 2 foot base distance was derived from the following test conditions: 2' - 2', 2' - 3', 2' - 4', 2' - 5', 2' - 6', 2' - 7' and 2' - 8'. The corresponding change in feet is 0, 1, 2, 3, 4, 5 and 6. The average distance change being 3 feet. Similarly, the dioptric values are 0, .55, .82, .98, 1.09, 1.17 and 1.23. The average dioptric change is .86. Repeating the above calculations, results in the following:

Base Distance	Average Change in Distance feet	diopters
2	3.00	.8353
3	2.29	.4447
4	1.86	.3275
5	1.71	.3041
6	1.86	.3197
7	2.29	.3532
8	3.00	.3950

The large response time for the 2 foot base distance may simply reflect that, on the average, a larger change in distance was evaluated. The actual effect of base distance and target distance is considered subsequently when discussing the BT interaction terms.

Interactions

Acuity X Illumination

Figure 12 presents the relation between target size (acuity) and illumination level. These interaction terms were found to be statistically significant at an α level of .001. As target size increased, RT decreased for all illumination levels. The curves for each acuity level follow the same form as was seen in Figure 11c.

Figure 13 presents the same data in a three dimensional plot to show the relationships more clearly. The reader should note the effect of irradiation as reflected by the 20/20 at 58 fc condition having a longer RT than the 20/20 at 14.5 fc condition.

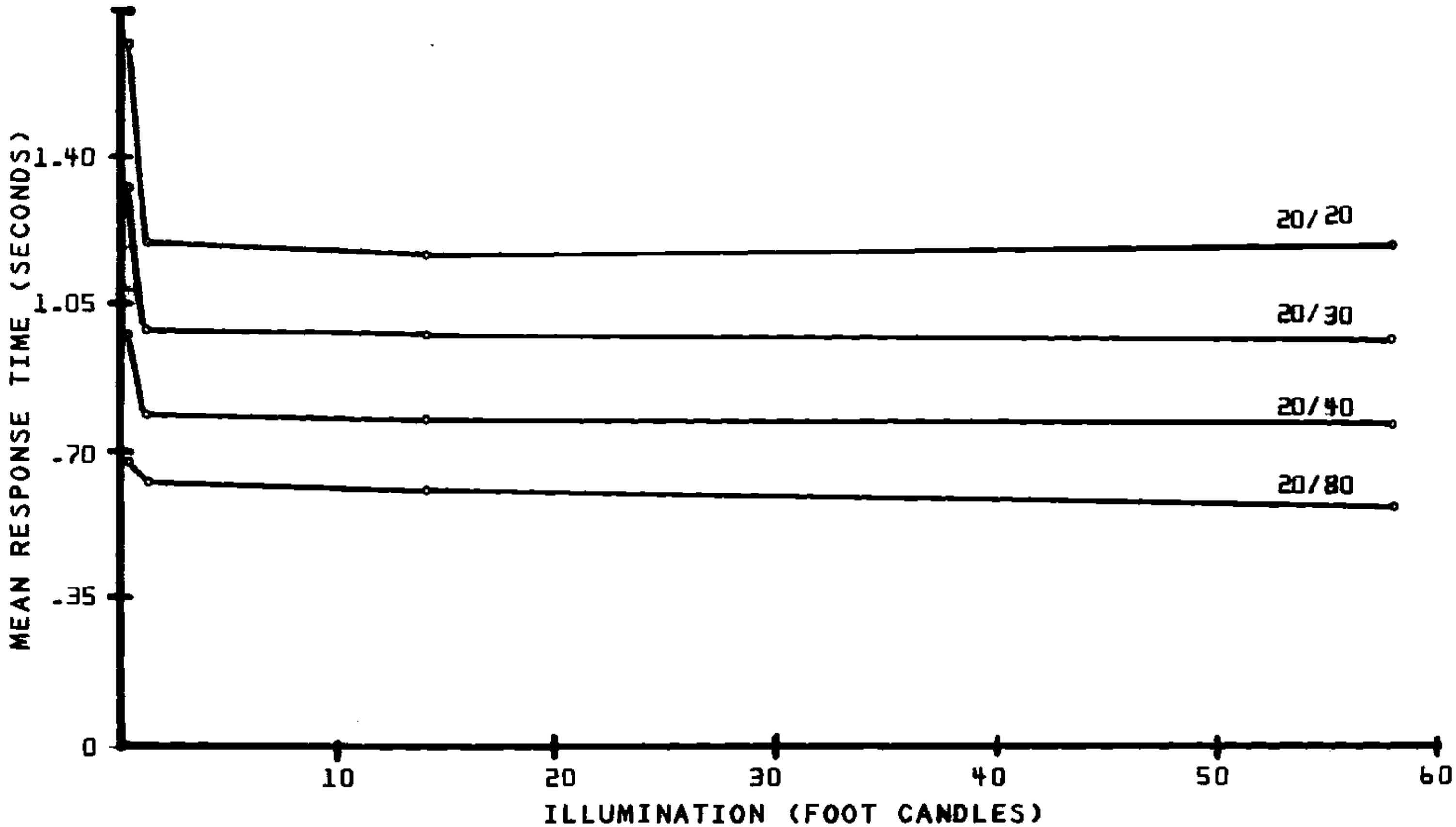

Figure 12. Acuity x Illumination Interaction

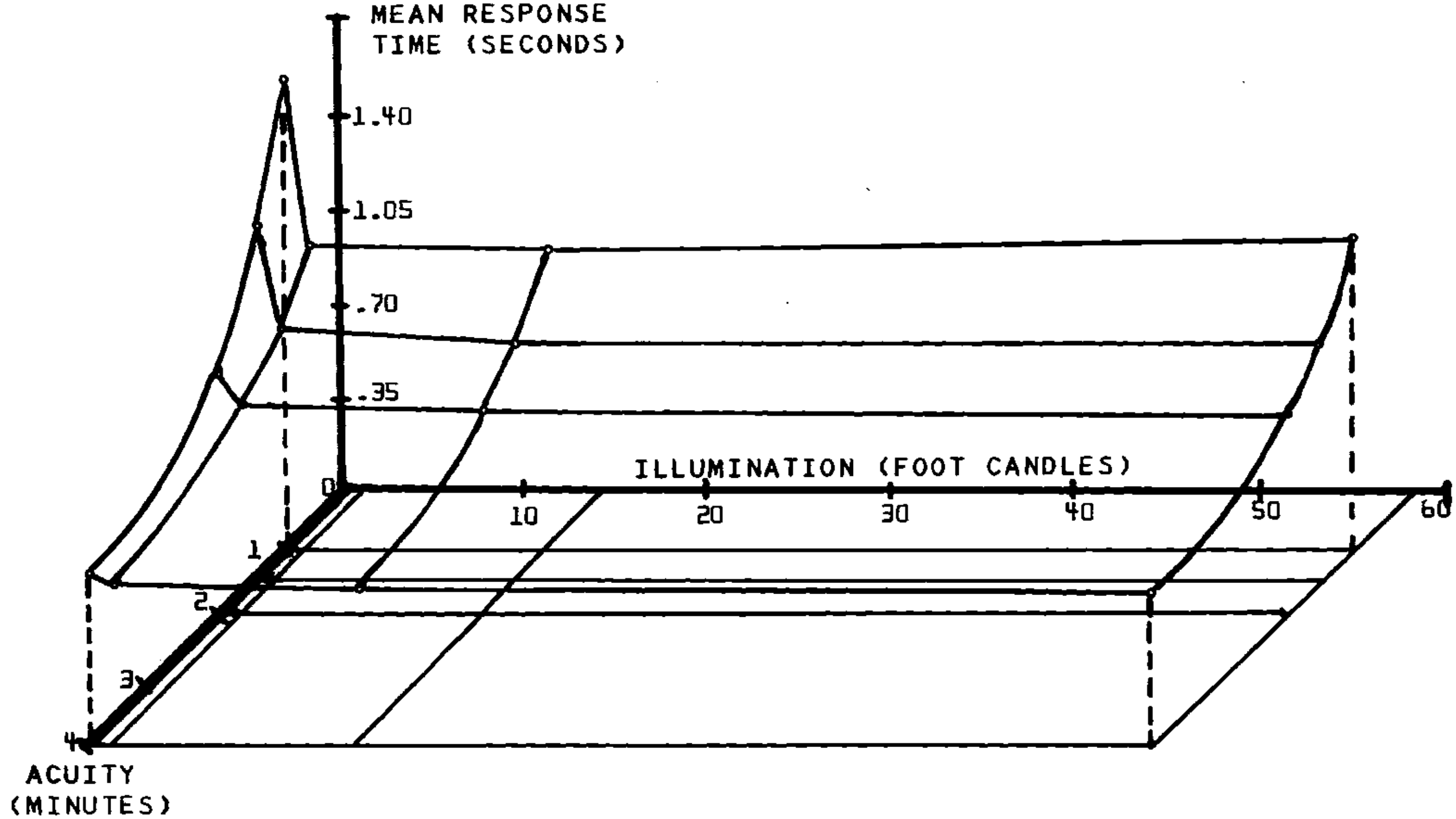

Figure 13. Acuity x Illumination Interaction

Base Distance X Target Distance

Figure 14 presents the relation between base distance and target distance in terms of RT. These interaction terms were found to be statistically significant at an α level of .001. It is clearly shown that RT was a minimum when base distance equaled target distance. The reason for this is that no refocusing was required.

The elevated 2 foot base curve in Figure 14 can be attributed to one of several factors. It may be an artifact of the experimental design. Test conditions of 2' - 3' and 7' - 8' both correspond to a one foot distance change, but the dioptric change is .55 and .06, respectively. Many of the dissimilarities in the curves in Figure 14 can be eliminated if a dioptric axis is used instead of the base distance and target distance variables (this is done in Figure 17). The implication being that response time is more directly related to the change in lens curvature (as measured in diopters) than do the change in absolute distance.

It can be deduced from Figure 14 that the rate of change in lens curvature is not a linear function of the change in diopters. A 2' - 3' test and a 3' - 6' test both require a .55 dioptric change, but as can be seen in Figure 14, the response time is not the same. The time required to change the shape of the lens seems to increase if the lens is already very curved or bulged. This is a second possible explanation for the elevated 2 and 3 foot data points in Figure 14.

Third and finally, there may be a measurement error imbedded in the data. There is a possibility that the subjects did not maintain

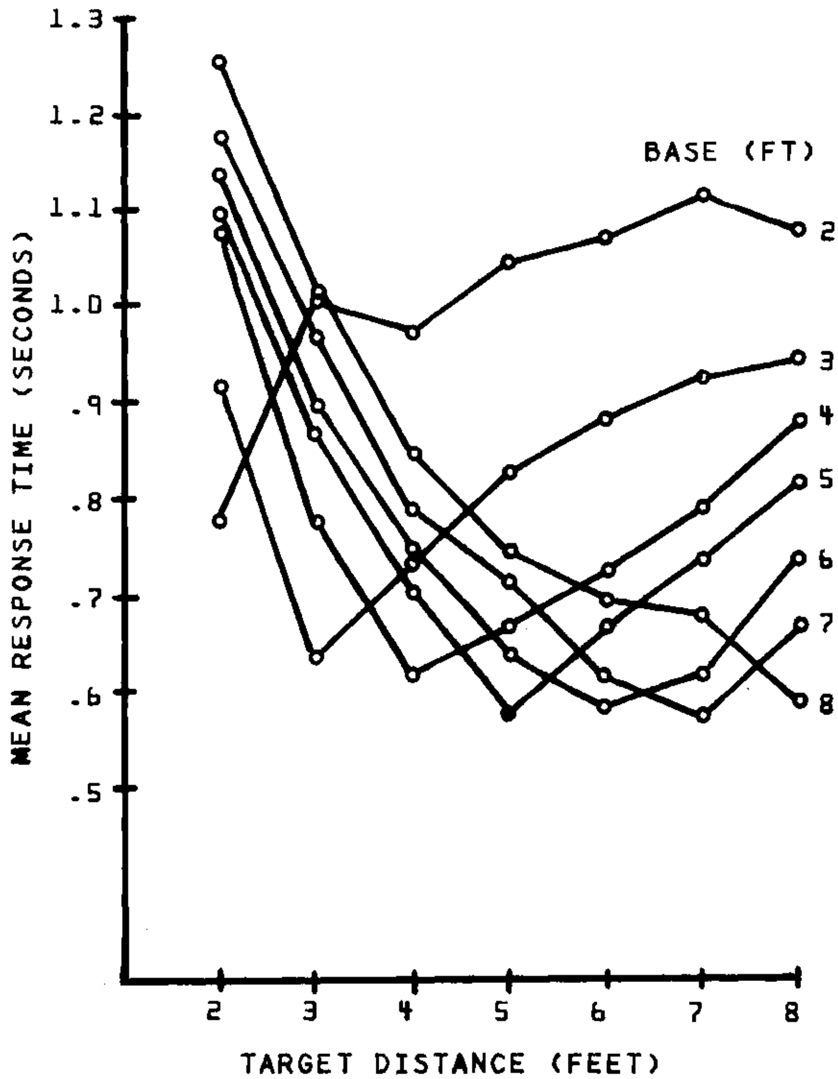

Figure 14. Base Distance x Target Distance Interaction

sharp focus on the short distance base targets. The 2 foot base plane is very restrictive and the subject may relax his eyes while waiting for the target to change. His plane of focus may drift outward. When the ready command is given, the subject will shift his plane of focus back but may be in a state of transient focus when the target changes. As a result, there may be a slight increase in response time.

Acuity X Base Distance X Target Distance

Figure 15 presents the relation between acuity and target distance with a plot for each base distance. The triple interaction was statistically significant at an α level of .001. The plots show in detail the effects of acuity, base distance and target distance on RT. RT is again seen to decrease as target size (acuity) increased. For the most part, RT was a minimum when base distance equaled target distance for each acuity.

Illumination X Base Distance X Target Distance

Figure 16 presents the relation between illumination level and target distance with a plot for each base distance. This triple interaction was not statistically significant. The illumination level effect is clearly shown with the .145 fc level (I4) having noticably longer RT's. The other three brighter levels of illumination are clustered together. The three brighter levels, well within the photopic range, are seen to have a nominal affect on RT. The reader should note that the base - equals - target distance relationship was not affected by illumination level.

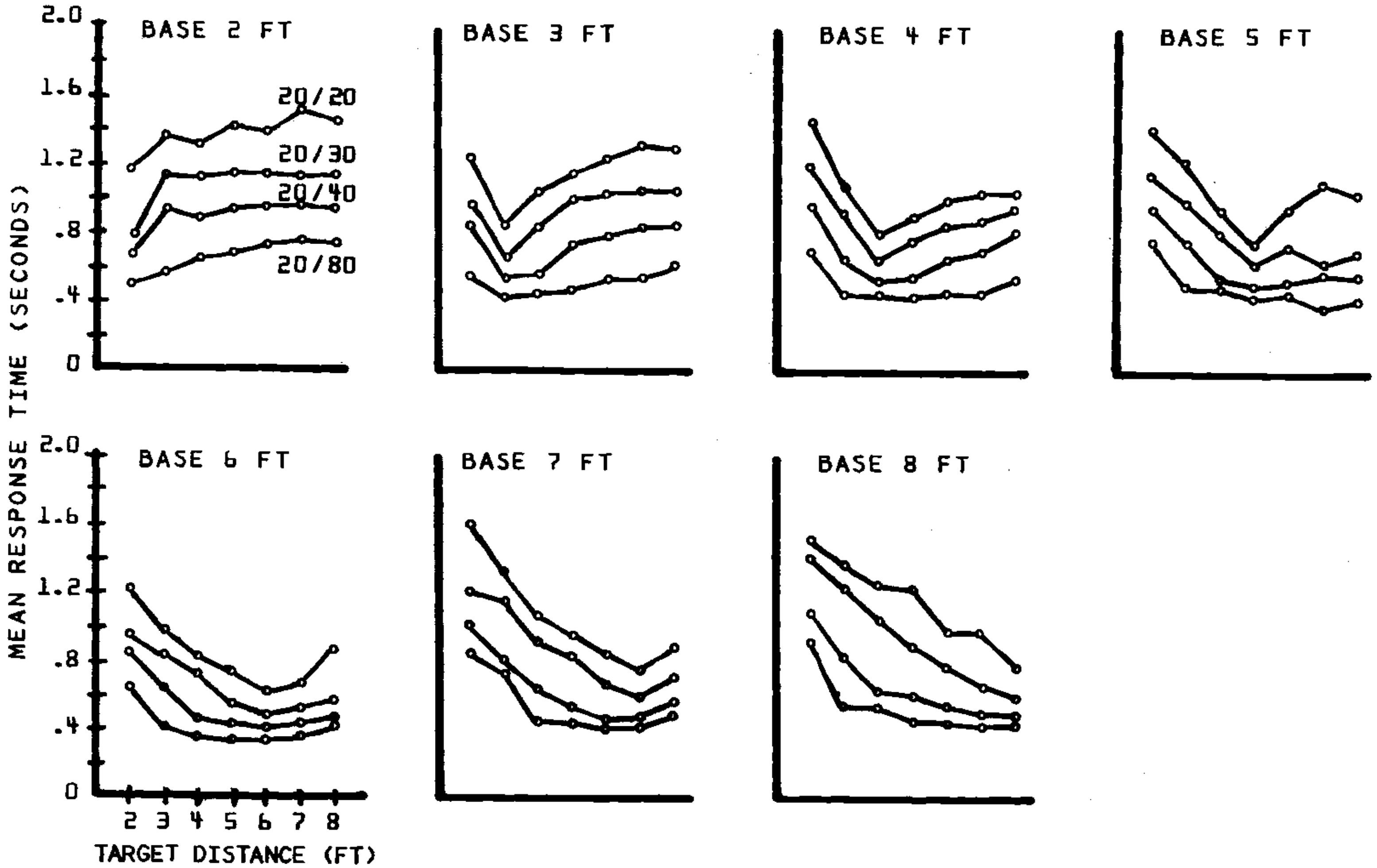

Figure 15. Acuity x Base Distance x Target Distance Interaction

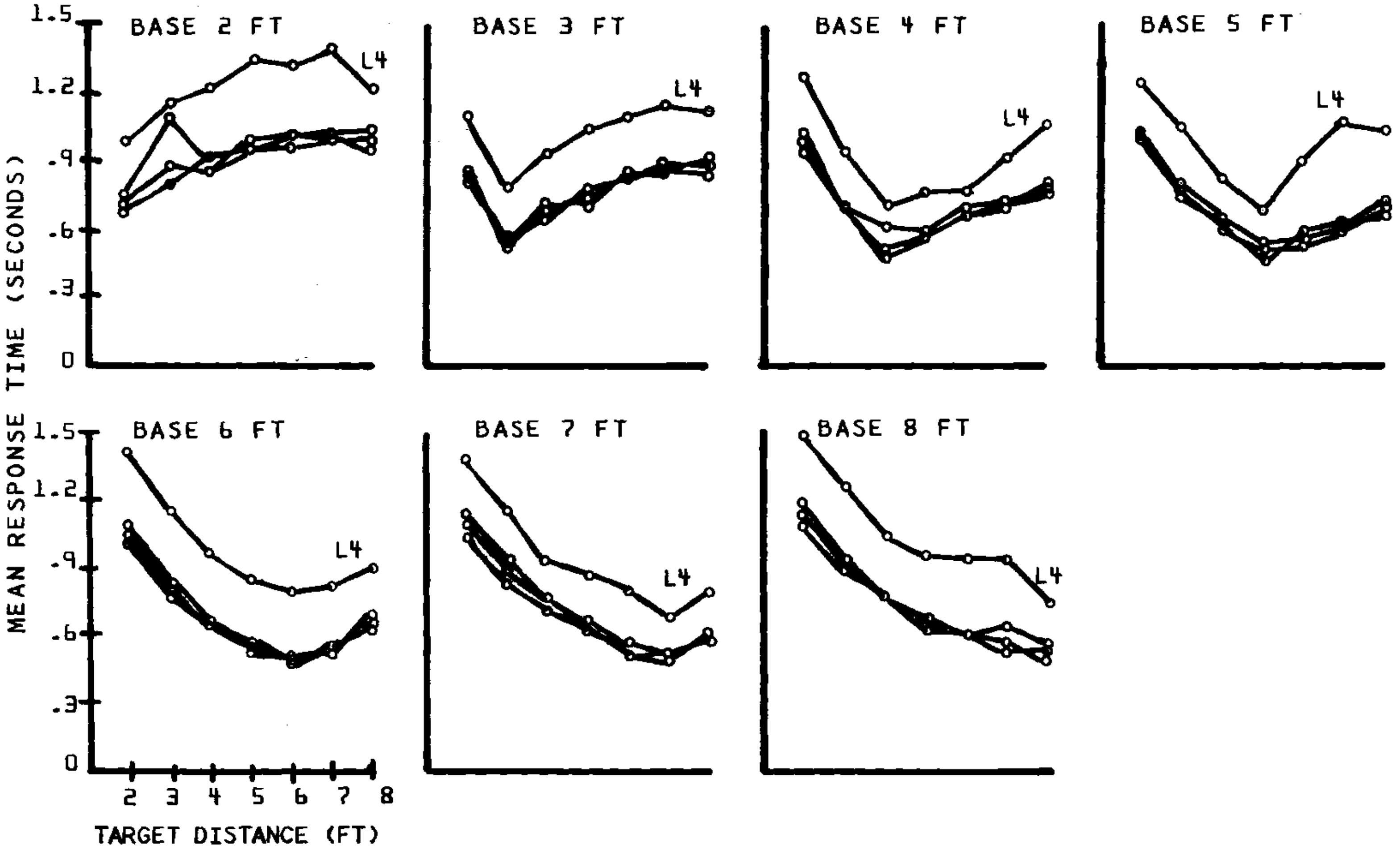

Figure 16. Illumination x Base Distance x Target Distance Interaction

Base Distance X Base-to-Target Distance Change

Figure 17a presents the relation between base distance and the distance change, in diopters, in going from a near base to a distant target (Near to Far). Figure 17b presents the relation between base distance and the distance change in going from a distant target to a near target (Far to Near). There is an obvious linearly increasing trend in both plots. As the distance change in diopters increases, RT increases.

When accommodating from near to far, the ciliary muscles relax causing the lens to flatten. When accommodating from far to near, the ciliary muscles contract allowing the lens to bulge. A comparison of Figures 17a to 17b could suggest that the ciliary muscles contract at a more continuous rate than when they relax. This would account for the more erratic form of Figure 17a.

Acuity X Illumination X Base-to-Target Distance Change

Figures 18a-d present the relation between acuity and illumination level when going from near (two feet) to far. Figures 18e-h present the relation between acuity and illumination when going from far (eight feet) to near. The ALBT interaction was not found to be statistically significant.

The linearly increasing trend that was seen in Figure 17 continues to hold for each acuity and illumination level. The effects of low illumination is evident in the variability of the 20/20 and 20/30 curves in Figures 18d and h.

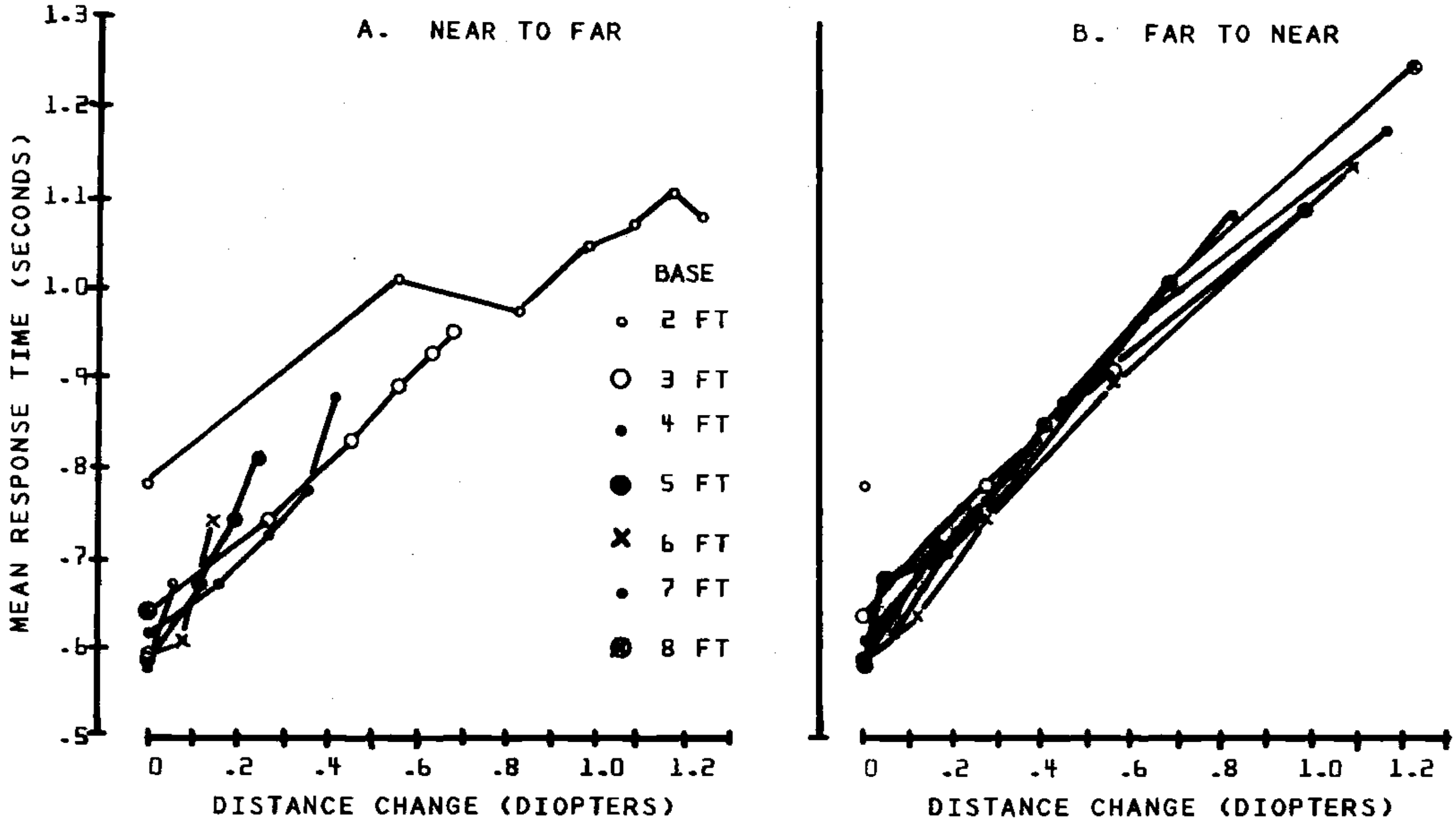

Figure 17. Base Distance x Base to Target Distance Change

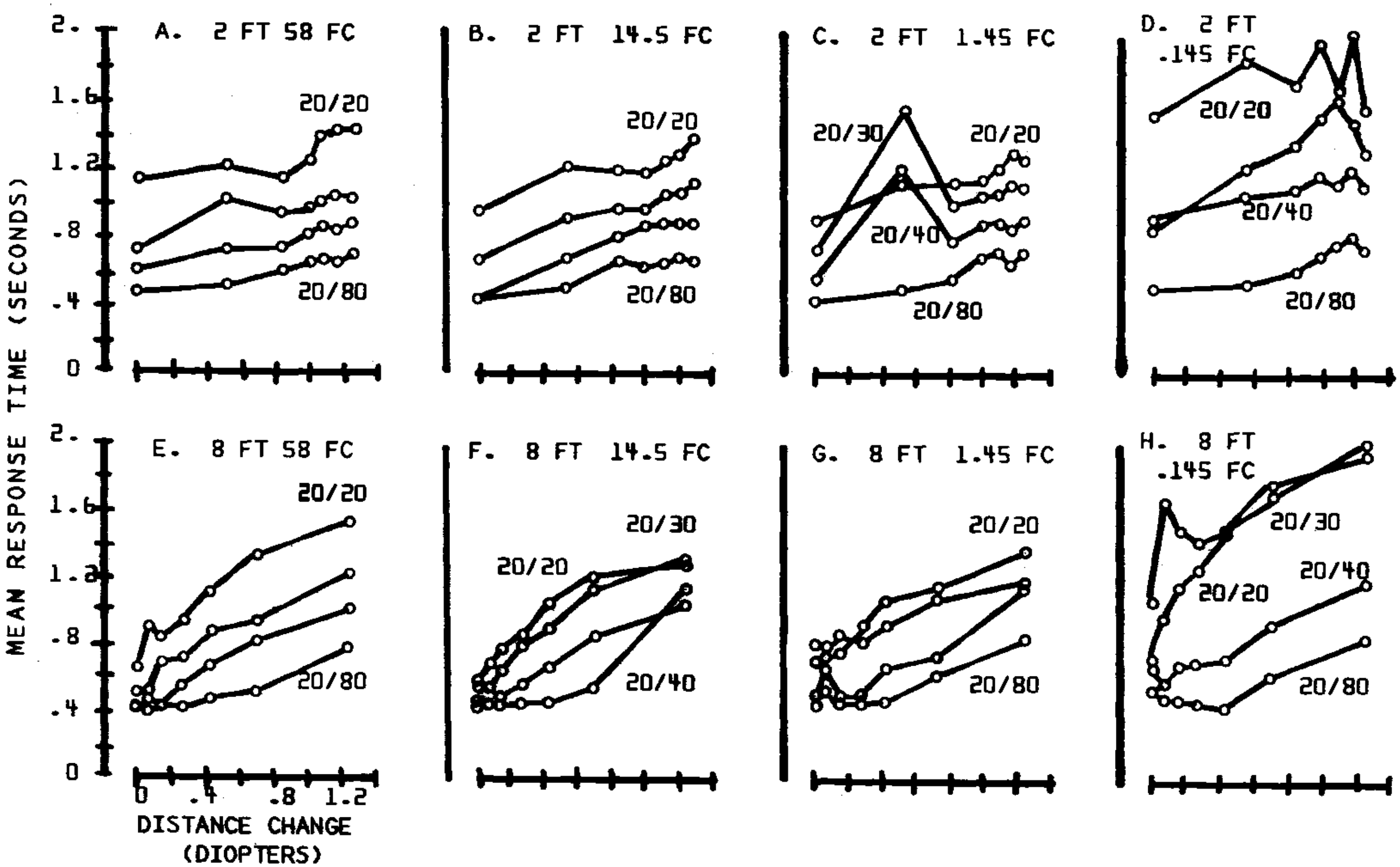

Figure 18. Acuity x Illumination x Base to Target Distance Change Interaction

Effects of the Variables on Eye Focus Time

A hypothetical model of the accommodation process is presented in Figure 19. For discussion purposes, response time is broken down into its components; Eye Focus, Accommodative Latency, Accommodative Movement, Decision Time, Movement Time and Residual Accommodation.

Accommodative Latency, AL

AL is defined as the time interval between when the stimulus is presented and when the lens begins to change shape. AL is felt to be constant under most of the imposed conditions. At the lowest illumination and for the smaller targets, AL may increase slightly. The base to target change is difficult to perceive. The result is that the focusing mechanism may require more time to determine the correct direction of change and initiate that change. This may partially account for the dispacement of the I4 curves in Figure 16.

AL is felt to increase for the two feet base or target distance. As stated in reference to Figure 14, the lens is deformed or curved to a great extent at the two feet or 1.6410 distance. It is believed that the lens requires a longer time to begin to change shape at this level of accommodation. An increased AL for the two feet distance may account for the increased RT associated with that distance as was seen in Figures 11d and e.

Accommodative Movement, AM

AM is the time interval between when the lens begins to change shape and when the oscillations reach steady-state about the new dioptric level. Both the amount and the direction of change affect AM. A change from two to three feet is a .547 D change while going from seven to

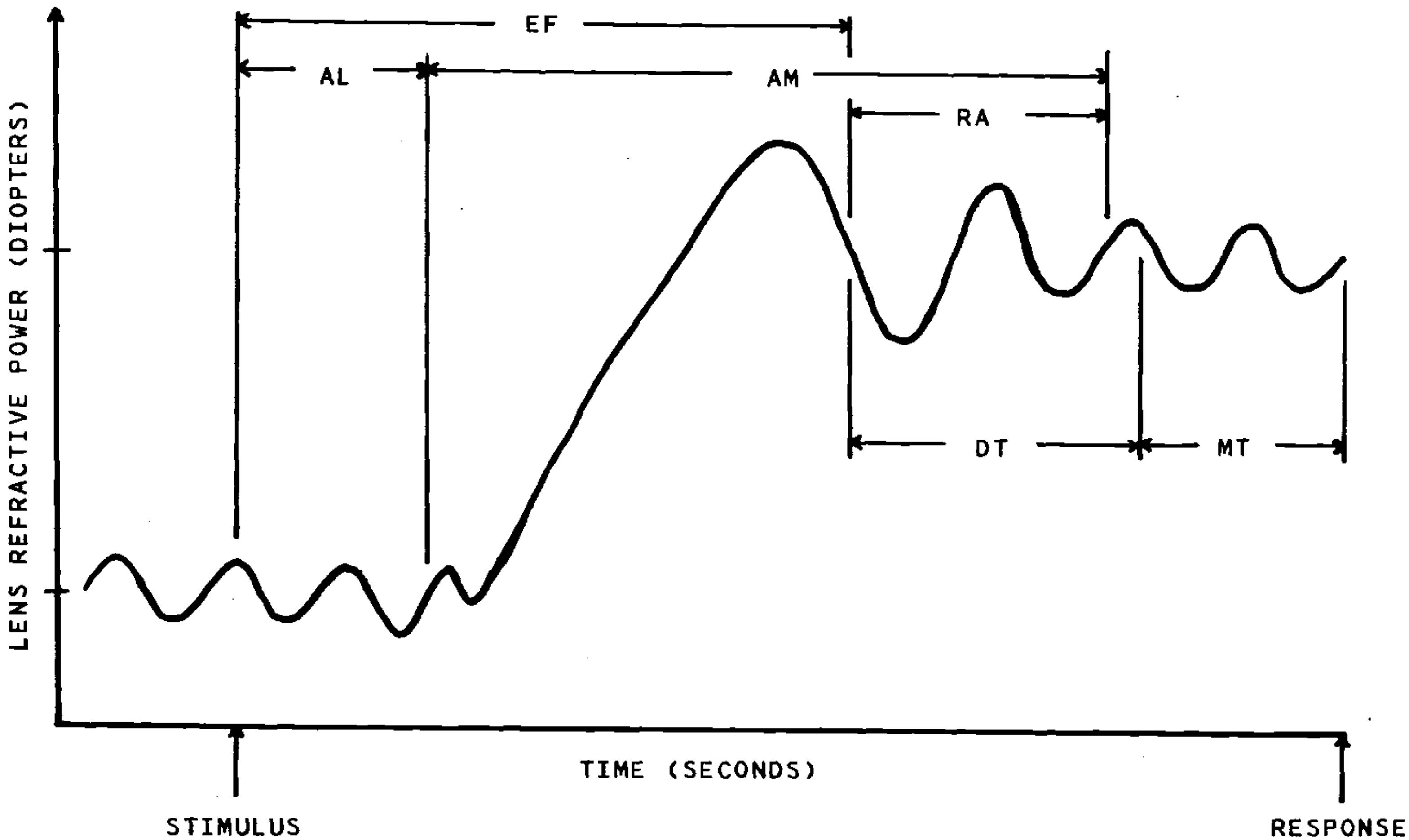

Figure 19. Model of Accommodation: AL - Accommodative Latency; AM = Accommodative Movement; EF - Eye Focus; DT - Decision Time; MT - Movement Time; RA - Residual Accommodation

eight feet is a .059 D change. Distance changes, not being linear, illicit non-linear deformations of the lens. Distance changes to or from a short distance from the eyes represent a large dioptric change resulting in longer AM times. AM increases as the dioptric change increases. The near to far and far to near relationships mentioned above will result in different AM times for an equal dioptric change. The lens changes shape faster when the ciliary muscles contract (far to near) than when they relax (near to far).

Decision Time, DT

DT is the time interval between when the target is in clear enough focus to discern the gap position and when the response movement is initiated. Acuity and illumination level are both felt to affect DT. The 20/20 and 20/30 targets were small enough to introduce some uncertainty in most of the subjects, increasing DT. The uncertainty was increased for all targets under the lowest illumination level.

Movement Time, MT

MT is the time it took a subject to throw the response switch either left or right. MT is believed to be fairly constant for each subject but different between subjects. MT was found to range between .18 and .25 second.

Residual Accommodation, RA

The introduction of the term, RA, is due to Eye Focus being defined as the time interval between when the stimulus was presented (base changed to target) and when the subject could initiate his decision. RA is the time interval between when the subject can initiate his decision and when the accommodation process reaches steady-state.

It is believed that RA increases as target size increases. The smaller targets require the subject to refocus to nearly the exact dioptric level before the decision phase can be initiated, making RA short. The large targets (20/80) do not require the subject to reach precise focus before the decision phase can be initiated, making RA longer.

Finding Eye Focus Time, EF

EF was calculated by subtracting from the mean Acuity X Illumination response times given in Appendix C the mean decision plus movement times given in Table 4. In terms of the components given above, EF can be expressed as follows: EF = RT - DT - MT. RA is not included in the formulation because it is derived from EF, RA = AL + AM - EF. Table 6 presents the results of calculating Eye Focus Time.

Table 6. Eye Focus Time

Acuity	Illumination				Mean
	58.0 fc	14.5 fc	1.45 fc	.145 fc	
20/20	.360 sec	.414 sec	.346 sec	.489 sec	.402 sec
20/30	.278	.340	.316	.525	.365
20/40	.195	.237	.233	.294	.240
20/80	.114	.135	.115	.140	.126
Mean	.237	.282	.253	.362	
Grand Mean					.283

CHAPTER VI

CONCLUSIONS

Summary

It was found that target size, illumination level and distance changes all had statistically significant affects on eye focus time. Eye focus time was found to decrease as target size increased. Low or mesopic illumination levels result in longer eye focus times. Distance changes will affect eye focus time in a non-linear manner.

General Conclusions

The following are the conclusions that were drawn from the results of the study.

1. Target size or acuity has the greatest affect on eye focus time. As target size increases, eye focus time will decrease at a decelerating rate. As target size increases, a subject requires less precise focus before responding.

2. Low, mesopic, illumination levels will greatly increase eye focus time while not affecting the target size relationship. Brighter or photopic illumination levels have little or no affect on eye focus time.

3. Eye focus time is longer for distance changes in the zero to three feet range than for equal dioptric changes further from the eyes. Accommodative latency is longer for distance changes from initially

large dioptric levels.

4. Distance changes affect eye focus time in a non-linear fashion due to dioptric changes being the inverse of the distance changed, in meters. Refocusing from far to near takes less time than refocusing from near to far.

Future Research

The results of this study suggest several areas for future research to verify findings, resolve uncertainties and provide data in areas were no conclusions could be drawn.

One area of interest is what effects age has on eye focus time. While this topic was approached in the current study, no conclusions could be drawn. Using the same method used in the current study, the expansion of the number of age groups between the ages of 18 and 70 would provide the data needed to arrive at a conclusion.

Another area that should be studied in greater detail is the base distance effect. By concentrating on base distances between one and three feet, the resulting data could be compared with data for equal dioptric changes from bases further than three feet from the eyes.

The use of targets other than Landolt Rings but of equal complexity could be used to verify the results of the current study and eliminate the occurrance of irradiation with the small targets. The effects of contrast on eye focus time could also be studied by varying the opaqueness of such new targets.

There are many variables that were not treated in the current study that are important. Such variables as sex differences, alcohol, cigarette smoking and other drugs, eye movement and moving targets could be studied as to their affects on eye focus time.

APPENDIX A

ILLUMINATION RECEIVED AT THE EYES THROUGH THE TARGETS

Introduction

This appendix is presented to show that the amount of light that reaches the eyes is the same for all targets at different distances from the plane of the eyes.

Terms, Notation and Units

Terms

Flux (Φ). In physical terms, radiant flux is the rate of flow of radiant energy from the source to the receiver. In psychological terms, flux or luminous flux is radiated energy that induces the impression of light in the eyes.

Illumination (E). E is the amount of luminous flux falling on a unit area of surface (S). (See Figure 20).

Luminous Intensity (I). I is the amount of luminous flux distributed in a section of space; previously called the candlepower of the source.

Solid Angle (ω). A term used to describe a conical section of space. In this case, ω describes a solid wedge. (See Figure 21).

Notation

$$E = \Phi/S = I/d^2$$

$$\omega = S_p/d^2$$

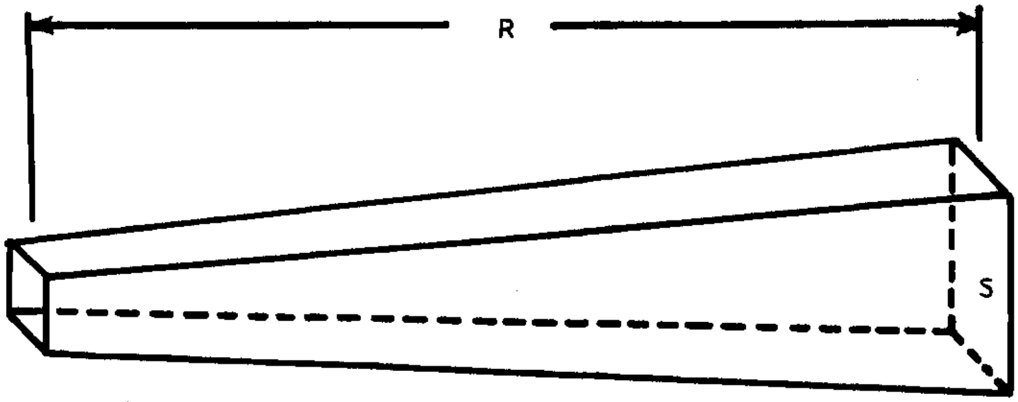

Figure 20. Illumination (E)

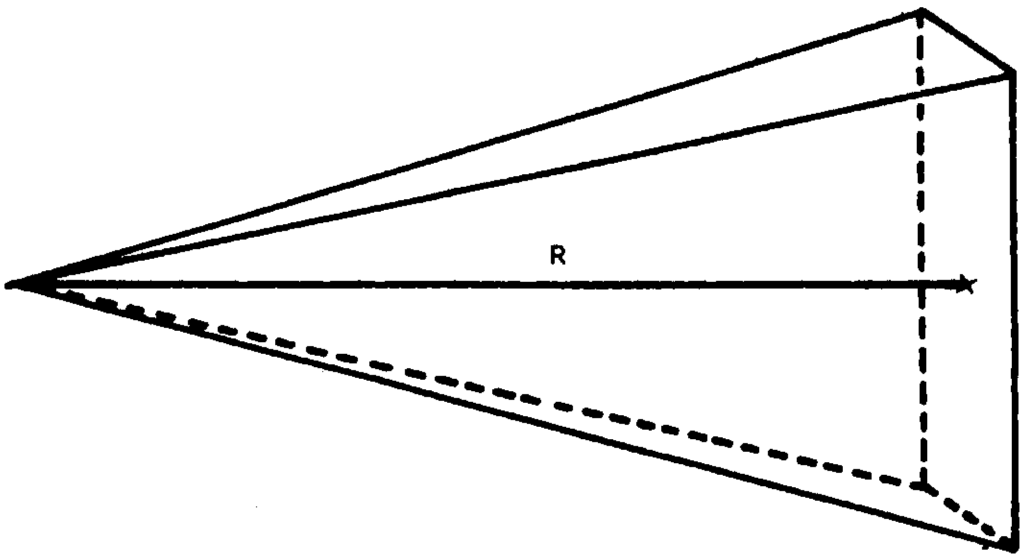

Figure 21. Solid Angle (ω)

S_p = the flat surface area of the source.

d = the distance from the source to the plane of the eyes.

$$I = \Phi/\omega$$

Units

Candela (cd). One sixtieth of the luminous intensity of one sq. cm. of the surface area of a black body at the temperature of solidifying platinum.

Steradian (sterad). A solid cone of unit radius from the apex and having a spherical surface area equal to the unit radius squared.

Lumen (lm). A candela radiated in one sterad.

Foot-candle (fc). A lumen incident on one sq. ft.

Analysis of Illumination Versus Target Size and Distance

Presented below are the equations used in the sample calculations that show the illumination level is equal for all targets at each distance.

Notation

E_s = the radiance of the source, in fc.

S_u = the surface area of the source used, in sq. ft.

Φ_t = the luminous flux associated with target, t, in lm.

ω_t = the solid angle associated with t, in sterad.

I_t = the luminous intensity associated with t, in cd.

Equations used

To Calculate S_u. (See Figure 22).

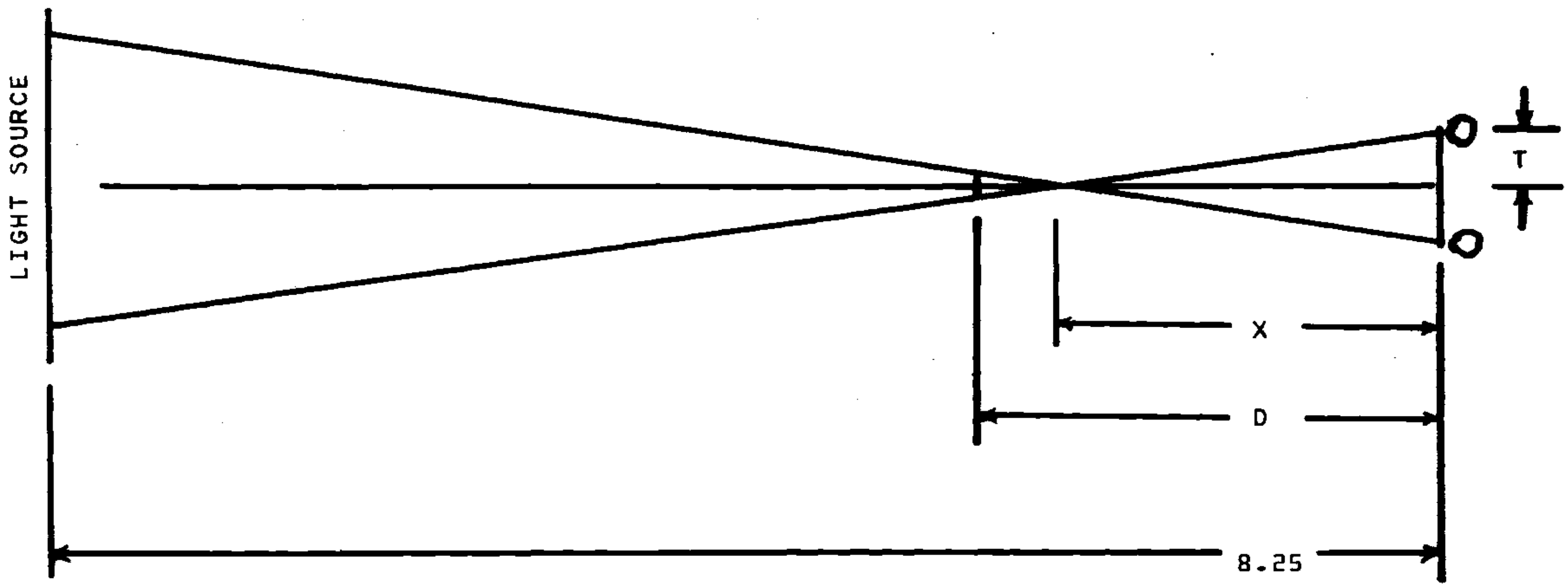

Figure 22. Illumination that Reaches the Eyes

$$\frac{t}{d - x} = \frac{.125}{x}$$

$$x = \frac{d(.125)}{t + .125}$$

$$\tan \alpha = \frac{t}{d - x} \qquad \text{(radians)}$$

$$\tan \alpha = \frac{s}{8.25 - x} = \frac{t}{d - x}$$

$$s = \frac{t(8.25 - x)}{d - x} \qquad \text{(feet)}$$

<u>Area of the Source (1 ft. x .1667 ft.) Used</u>

$$S_u = (2s)^2, \text{ if } 2s \leq .1667 \text{ ft.}$$

$$S_u = 2s(.1667), \text{ if } 2s > .1667 \text{ ft.}$$

<u>Combined Formula.</u>

$$S_u = \left[\frac{t}{d - x} (8.25 - x)2 \right] x \begin{matrix} [\quad], \text{ if } [\ ] \leq .1667 \text{ ft.} \\ .1667, \text{ if } [\ ] > .1667 \text{ ft.} \end{matrix} \quad \text{(sq. ft.)}$$

<u>Assumed</u>. The distance between the eyes is .25 ft.

Sample Calculations

20/20 Target at Two Feet

$$t = .0029 \text{ ft.} \qquad E_s = 345.8 \text{ fc}$$

$$x = \frac{d(.125)}{t - .125} = \frac{2(.125)}{.0029 + .125} = 1.9547 \text{ ft.}$$

$$S_u = \frac{.0029}{2 - 1.9547}(8.25 - 1.9547)2 \times .1667 = .1333 \text{ sq. ft.}$$

$$\Phi_t = E_s \times S_u = 345.8 \times .1333 = 46.0951 \text{ lm}$$

$$\omega_t = S_u/(8.25)^2 = .1333/68.0625 = .00196 \text{ sterad}$$

$$I_t = \Phi_t/\omega_t = 46.0951/.00196 = 23517.91 \text{ cd}$$

$$E = I_t/(8.25)^2 = 23517.91/68.0625 = 345.6 \text{ cd/ft}^2$$

20/80 Target at Eight Feet

$$t = .0464 \text{ ft.} \qquad E_s = 345.8 \text{ fc}$$

$$x = \frac{d(.125)}{t + .125} = \frac{8(.125)}{.0464 + .125} = 5.8343 \text{ ft.}$$

$$S_u = \left[\frac{.0464}{8 - 5.8343}(8.25 - 5.8343)2\right]^2 = .0107 \text{ sq. ft.}$$

$$\Phi_t = E_s \times S_u = 345.8 \times .0107 = 3.7001 \text{ lm}$$

$$\omega_t = S_u/(8.25)^2 = .0107/68.0625 = .000157 \text{ sterad.}$$

$$I_t = \Phi_t/\omega_t = 3.7001/.000157 = 23537.53 \text{ cd}$$

$$E = I_t/(8.25)^2 = 23537.53/68.0625 = 345.8 \text{ cd/ft}^2$$

Note: E = 145.2 in the experiment due to the beam-splitter.

Conclusion

According to theory, E should be the same for both targets and with round-off error taken into account, E is the same for both targets. In the above examples, notice that ω_t for the 20/20 target at two feet, which has a field size of 2.89×10^{-5} sq. ft., is much larger than the ω_t for the 20/80 target at eight feet which has a field size of 7.8×10^{-3} sq. ft. It is this fact that enables the equal illumination for each target.

APPENDIX B

INSTRUCTIONS

Main Task

There will first be a ring with the gap turned up which you are to focus on. Once you are combortable, I will then say "ready". About one second after I say "ready" the target (gap position) will have changed. You are to respond as quickly as possible by throwing the switch in your hand in the correct direction of the gap as soon as you see it. Tell me if you make an error, then return the switch to the center position. The process will then be repeated.

There will be trials during the session to get an estimate of your reaction time. There will also be 20 practice runs to familiarize you with the process to begin with.

You are to keep your head against the head rest the entire time. When I change sets of slides you may relax for a few minutes.

RT with Decision Time

You are now going to perform six trials during which the target distances will not change, only the gap position. Respond to the change in gap position as quickly as possible.

RT

You are now going to perform six trials during which the target change will consist of going from gap up to a blank, light field. You are to flip the switch in either direction as quickly as possible.

In other words, when the gap up target disappears, throw the switch.

APPENDIX C

FIRST ORDER AND INTERACTION CELL MEANS

This appendix presents the grand mean, all first order effect means and most of the interaction cell means.

Grand Mean

μ = .831

Subject Effect, S_i

(i = 1, RC; 2, TW; 3, GM; 4, TR; 5, TS; 6, RS; 7, TLS; 8, BC)

S_1 = .671 S_2 = .746 S_3 = .936 S_4 = .823

S_5 = .899 S_6 = .854 S_7 = .915 S_8 = .800

Acuity Effect, A_3

(j = 1, 20/20; 2, 20/30; 3, 20/40; 4, 20/80)

A_1 = 1.138 A_2 = .924 A_3 = .716 A_4 = .544

Illumination Effect, L_R

(k = 1, 58 fc; 2, 14.5 fc; 3, 1.45 fc; 4, .145 fc)

L_1 = .765 L_2 = .751 L_3 = .770 L_4 = 1.035

Base Distance Effect, B_ℓ

(ℓ = 1, 2 ft.; 2, 3 ft.; 3, 4 ft.; 5, 6 ft., 6, 7 ft.; 7, 8 ft.)

B_1 = 1.009 B_2 = .842 B_3 = .792 B_4 = .781

B_5 = .768 B_6 = .789 B_7 = .833

Target Distance Effect, T_m

(m = 1, 2ft.; 2, 3 ft.; 3, 4 ft.; 4, 5 ft.; 5, 6 ft., 6, 7ft.; 8 ft.)

$T_1 = 1.063$ $T_2 = .882$ $T_3 = .774$ $T_4 = .747$

$T_5 = .754$ $T_6 = .776$ $T_7 = .817$

Acuity x Illumination, AL_{jk}

Illumination (fc)	Acuity 20/20	20/30	20/40	20/80
58	1.038	.829	.673	.518
14.5	.971	.836	.668	.530
1.45	1.014	.848	.681	.538
.145	1.529	1.182	.840	.590

Acuity x Base Distance, $AB_{j\ell}$

Acuity	Base Distance (feet) 2	3	4	5	6	7	8
20/20	1.371	1.164	1.075	1.090	1.051	1.089	1.126
20/30	1.114	.949	.896	.859	.824	.869	.956
20/40	.904	.739	.691	.653	.675	.661	.687
20/80	.647	.517	.505	.521	.519	.538	.562

Acuity x Target Distance, AT_{jm}

Acuity	Target Distance (feet) 2	3	4	5	6	7	8
20/20	1.421	1.219	1.054	1.019	1.035	1.099	1.119
20/30	1.114	1.018	.899	.855	.844	.832	.875
20/40	.955	.768	.644	.630	.638	.659	.715
20/80	.730	.522	.500	.485	.499	.515	.559

Illumination x Base Distance, $LB_{k\ell}$

Illumination (fc)	Base Distance (feet) 2	3	4	5	6	7	8
58.0	.934	.777	.731	.699	.696	.766	.749
14.5	.910	.778	.732	.700	.686	.699	.755
1.45	.954	.778	.753	.716	.710	.723	.759
.145	1.238	1.036	.953	1.009	.978	.968	1.067

Illumination x Target Distance, LT_{km}

Illumination (fc)	Target Distance (feet) 2	3	4	5	6	7	8
58.0	1.004	.807	.709	.680	.688	.697	.768
14.5	.978	.788	.705	.671	.677	.691	.750
1.45	.988	.844	.723	.679	.688	.710	.760
.145	1.281	1.088	.961	.959	.963	1.007	.989

Base Distance x Target Distance, $BT_{\ell m}$

Target Distance	Base Distance (feet) 2	3	4	5	6	7	8
2 ft.	.780	1.007	.975	1.046	1.072	1.105	1.075
3	.913	.638	.738	.832	.894	.928	.953
4	1.084	.775	.615	.669	.734	.787	.880
5	1.090	.872	.705	.580	.673	.738	.808
6	1.144	.903	.745	.644	.586	.613	.739
7	1.179	.972	.790	.712	.623	.581	.670
8	1.248	1.006	.853	.746	.696	.683	.594

Acuity x Illumination x Base Distance, $ALB_{jk\ell}$

Acuity	Illumination (foot candles)	2	3	4	5	6	7	8
		Base Distance (feet)						
20/20	58.0	1.305	1.026	.916	.928	.920	1.117	1.052
	14.5	1.221	1.025	.905	.945	.850	.920	.929
	1.45	1.172	1.075	1.107	.943	.923	.911	.968
	.145	1.784	1.529	1.374	1.542	1.513	1.407	1.554
20/30	58.0	.998	.862	.825	.773	.769	.790	.789
	14.5	.982	.891	.893	.754	.725	.752	.857
	1.45	1.116	.857	.778	.758	.757	.845	.826
	.145	1.360	1.187	1.088	1.151	1.045	1.091	1.351
20/40	58.0	.800	.724	.697	.609	.599	.640	.645
	1.45	.808	.689	.653	.591	.650	.623	.661
	1.45	.895	.672	.643	.628	.660	.611	.659
	.145	1.112	.870	.771	.786	.792	.769	.784
20/80	58.0	.633	.495	.485	.488	.497	.519	.511
	14.5	.627	.509	.476	.508	.518	.502	.572
	1.45	.632	.507	.483	.534	.501	.526	.583
	.145	.695	.558	.578	.555	.561	.605	.581

Acuity x Illumination x Target Distance, ALT_{jkm}

Acuity	Illumination (foot candles)	Target Distance (feet) 2	3	4	5	6	7	8
20/20	58.0	1.316	1.133	.938	.910	.936	.968	1.062
	14.5	1.218	1.033	.931	.861	.880	.895	.978
	1.45	1.293	1.082	.956	.899	.910	.941	1.019
	.145	1.587	1.627	1.392	1.403	1.412	1.594	1.417
20/30	58.0	1.105	.898	.796	.736	.736	.735	.798
	1.45	1.078	.914	.787	.755	.743	.769	.808
	1.45	1.027	1.006	.845	.758	.748	.749	.805
	.145	1.367	1.253	1.170	1.171	1.148	1.074	1.091
20/40	58.0	.904	.698	.718	.597	.596	.610	.691
	14.5	.881	.703	.609	.604	.603	.603	.671
	1.45	.936	.771	.589	.576	.602	.620	.674
	.145	1.101	.902	.761	.742	.750	.804	.824
20/80	58.0	.689	.499	.483	.476	.484	.474	.523
	14.5	.735	.502	.492	.461	.482	.497	.542
	1.45	.697	.516	.504	.484	.491	.530	.543
	.145	.798	.571	.520	.519	.540	.558	.627

Acuity x Base Distance x Target Distance, $ABT_{j\ell m}$

Acuity	Base Distance (feet)	Target Distance (feet) 2	3	4	5	6	7	8
20/20	2	1.175	1.360	1.308	1.400	1.391	1.525	1.435
	3	1.238	.850	1.050	1.156	1.248	1.323	1.283
	4	1.442	1.088	.796	.901	.996	1.100	1.203
	5	1.453	1.232	.943	.746	.982	1.111	1.160
	6	1.500	1.237	1.020	.914	.766	.837	1.086
	7	1.599	1.389	1.084	.991	.881	.778	.900
	8	1.540	1.376	1.179	1.022	.978	1.020	.767
20/30	2	.784	1.192	1.091	1.153	1.215	1.200	1.164
	3	.990	.684	.846	1.000	1.031	1.034	1.058
	4	1.214	.904	.672	.771	.844	.888	.979
	5	1.146	.998	.817	.640	.739	.797	.876
	6	1.193	1.026	.893	.681	.617	.634	.725
	7	1.253	1.096	.921	.839	.664	.596	.716
	8	1.430	1.224	1.057	.900	.797	.675	.607
20/40	2	.666	.938	.874	.953	.961	.967	.968
	3	.863	.546	.581	.705	.786	.825	.864
	4	.978	.635	.541	.554	.637	.688	.803
	5	.986	.761	.546	.494	.521	.586	.679
	6	1.075	.825	.604	.542	.520	.532	.628
	7	1.017	.828	.666	.557	.492	.498	.569
	8	1.099	.846	.699	.604	.548	.518	.496

Acuity x Base Distance x Target Distance (Continued)

Acuity	Base Distance (feet)	2	3	4	5	6	7	8
20/80	2	.496	.539	.630	.780	.720	.728	.734
	3	.560	.472	.476	.467	.150	.531	.606
	4	.701	.473	.449	.450	.459	.470	.536
	5	.775	.495	.514	.442	.449	.457	.518
	6	.807	.525	.463	.437	.439	.447	.517
	7	.846	.573	.488	.461	.454	.451	.496
	8	.924	.580	.479	.459	.464	.521	.504

Illumination x Base Distance x Target Distance, $LBT_{k\ell m}$

Illumination (fc)	Base Distance (ft)	Target Distance (ft) 2	3	4	5	6	7	8
58.0	2	.763	.890	.883	.931	1.006	1.023	1.042
	3	.856	.564	.651	.781	.821	.848	.916
	4	1.022	.700	.559	.599	.694	.727	.814
	5	1.003	.814	.625	.543	.574	.610	.725
	6	1.055	.811	.683	.555	.514	.525	.731
	7	1.184	.961	.765	.674	.592	.555	.634
	8	1.141	.907	.796	.675	.615	.590	.518
14.5	2	.679	.846	.919	.931	.980	.988	1.027
	3	.865	.555	.674	.770	.830	.851	.904
	4	.986	.722	.544	.605	.697	.730	.837
	5	1.025	.781	.626	.512	.604	.631	.718
	6	1.044	.823	.663	.553	.508	.566	.643
	7	1.043	.843	.726	.645	.522	.521	.596
	8	1.203	.947	.872	.679	.600	.551	.522
1.45	2	.696	1.114	.888	.965	.987	1.009	1.017
	3	.839	.599	.684	.733	.825	.863	.901
	4	1.045	.720	.636	.634	.702	.740	.791
	5	1.026	.803	.688	.556	.571	.627	.740
	6	1.080	.860	.665	.583	.555	.550	.678
	7	1.081	.910	.726	.637	.568	.528	.615
	8	1.148	.901	.778	.647	.607	.652	.582

Illumination x Base Distance x Target Distance (Continued)

Illumination (fc)	Base Distance (ft)	Target Distance (ft) 2	3	4	5	6	7	8
.145	2	.983	1.179	1.213	1.359	1.315	1.400	1.215
	3	1.090	.833	.945	1.044	1.098	1.150	1.090
	4	1.282	.957	.719	.838	.844	.950	1.080
	5	1.306	1.089	.880	.710	.943	1.083	1.050
	6	1.396	1.117	.968	.883	.766	.810	.904
	7	1.407	1.172	.942	.891	.809	.718	.836
	8	1.502	1.270	1.058	.985	.964	.941	.753

Acuity x Illumination x Base Distance x Target Distance, $ALBT_{jk\ell m}$

Acuity	Illumination(fc)	Base(ft)	Target (ft) 2	3	4	5	6	7	8
20/20	58.0	2	1.169	1.212	1.152	1.241	1.414	1.467	1.480
		3	1.149	.767	.845	1.086	1.105	1.087	1.146
		4	1.180	.946	.673	.711	.876	1.003	1.025
		5	1.271	1.104	.820	.675	.763	.822	1.039
		6	1.268	1.089	.886	.702	.650	.671	1.171
		7	1.651	1.483	1.088	1.005	.897	.799	.897
		8	1.526	1.328	1.102	.953	.850	.925	.677
20/20	14.5	2	.985	1.221	1.199	1.190	1.252	1.298	1.405
		3	1.219	.657	.879	.996	1.119	1.123	1.180
		4	1.148	.933	.684	.689	.853	.929	1.096
		5	1.336	1.089	.837	.666	.861	.844	.982
		6	1.229	1.020	.842	.718	.596	.699	.848
		7	1.320	1.101	1.022	.907	.687	.667	.737
		8	1.287	1.210	1.053	.864	.793	.703	.597
20/20	1.45	2	.959	1.148	1.137	1.178	1.220	1.302	1.260
		3	1.136	.726	.996	1.022	1.137	1.202	1.309
		4	1.503	1.091	.863	.942	1.066	1.131	1.150
		5	1.350	1.097	.812	.689	.753	.861	1.042
		6	1.402	1.174	.862	.776	.685	.700	.861
		7	1.034	1.163	.960	.827	.725	.633	.769
		8	1.396	1.177	1.063	.861	.783	.755	.744
20/20	.145	2	1.588	1.858	1.743	1.989	1.678	20.34	1.594
		3	1.448	1.249	1.481	1.520	1.631	1.878	1.496
		4	1.940	1.382	.965	1.262	1.191	1.337	1.542
		5	1.855	1.639	1.304	.953	1.553	1.917	1.575
		6	2.099	1.664	1.489	1.461	1.133	1.279	1.466
		7	2.121	1.811	1.267	1.224	1.214	1.012	1.197
		8	1.950	1.789	1.497	1.412	1.485	1.697	1.049

Acuity	Illumination(fc)	Base(ft)	Target (ft) 2	3	4	5	6	7	8
20/30	58.0	2	.765	1.033	.977	.998	1.039	1.089	1.083
		3	.923	.608	.748	.862	.887	.998	1.005
		4	1.196	.802	.592	.683	.821	.811	.872
		5	1.140	.956	.722	.542	.637	.650	.762
		6	1.227	.921	.834	.623	.517	.550	.709
		7	1.266	1.010	.821	.709	.563	.520	.637
		8	1.215	.959	.881	.733	.690	.528	.516
20/30	14.5	2	.698	.933	.988	.997	1.080	1.072	1.107
		3	.955	.681	.886	.935	.916	.994	1.028
		4	1.277	.867	.560	.771	.896	.899	.981
		5	1.099	.898	.728	.523	.615	.709	.708
		6	1.091	.993	.745	.533	.514	.558	.642
		7	1.126	.946	.770	.721	.537	.552	.611
		8	1.302	1.160	.915	.805	.645	.599	.576
20/30	1.45	2	.778	1.584	1.024	1.083	1.089	1.138	1.116
		3	.857	.651	.756	.864	.951	.944	.974
		4	1.037	.754	.761	.622	.724	.759	.788
		5	1.017	.873	.692	.626	.619	.705	.775
		6	1.068	.928	.831	.628	.562	.560	.724
		7	1.247	1.179	.912	.749	.624	.548	.658
		8	1.185	1.072	.936	.731	.668	.590	.600
20/30	.145	2	.894	1.218	1.375	1.534	1.654	1.498	1.350
		3	1.225	.876	1.075	1.339	1.369	1.200	1.227
		4	1.346	1.194	.776	1.007	.936	1.083	1.276
		5	1.329	1.266	1.126	.869	1.083	1.124	1.259
		6	1.386	1.262	1.160	.939	.876	.867	.826
		7	1.372	1.249	1.180	1.177	.933	.765	.959
		8	2.020	1.706	1.496	1.333	1.184	.982	.737

Acuity	Illumination(fc)	Base(ft)	Target (ft) 2	3	4	5	6	7	8
20/40	58.0	2	.617	.773	.775	.814	.880	.851	.893
		3	.811	.468	.565	.709	.787	.797	.930
		4	1.044	.609	.540	.547	.646	.648	.843
		5	.899	.692	.538	.505	.463	.537	.626
		6	.935	.724	.554	.474	.460	.476	.572
		7	1.003	.800	.656	.550	.462	.475	.535
		8	1.016	.818	.699	.583	.473	.488	.435
20/40	14.5	2	.542	.696	.813	.900	.911	.886	.907
		3	.787	.510	.541	.696	.761	.740	.787
		4	.908	.640	.494	.548	.594	.646	.740
		5	.879	.661	.493	.448	.487	.524	.645
		6	1.033	.779	.612	.520	.512	.520	.572
		7	.946	.790	.644	.532	.446	.442	.561
		8	1.070	.844	.664	.587	.511	.464	.486
20/40	1.45	2	.581	1.212	.805	.900	.927	.904	.935
		3	.820	.519	.514	.571	.721	.779	.780
		4	.966	.582	.490	.540	.578	.625	.728
		5	.979	.772	.545	.486	.491	.505	.617
		6	1.123	.795	.534	.500	.521	.513	.634
		7	.962	.756	.573	.508	.468	.488	.523
		8	1.118	.761	.663	.525	.515	.526	.503
20/40	.145	2	.926	1.071	1.100	1.197	1.127	1.228	1.136
		3	1.036	.685	.705	.845	.875	.984	.957
		4	.996	.708	.639	.581	.739	.834	.899
		5	1.186	.921	.607	.539	.644	.780	.826
		6	1.211	1.002	.716	.674	.586	.621	.733
		7	1.157	.965	.790	.637	.590	.587	.654
		8	1.193	.961	.768	.720	.691	.593	.560

Acuity	Illumination(fc)	Base(ft)	Target (ft) 2	3	4	5	6	7	8
20/80	58.0	2	.503	.543	.627	.671	.691	.684	.713
		3	.542	.414	.445	.469	.506	.508	.581
		4	.669	.445	.431	.454	.436	.444	.516
		5	.700	.504	.422	.451	.431	.432	.473
		6	.790	.512	.456	.422	.427	.403	.472
		7	.815	.551	.497	.432	.445	.427	.466
		8	.805	.525	.501	.433	.449	.418	.443
20/80	14.5	2	.491	.532	.675	.636	.677	.694	.687
		3	.499	.450	.469	.451	.523	.548	.623
		4	.613	.447	.438	.411	.446	.445	.532
		5	.787	.477	.447	.412	.452	.448	.536
		6	.821	.500	.454	.439	.412	.486	.512
		7	.782	.536	.467	.419	.416	.423	.474
		8	1.153	.575	.494	.461	.451	.437	.430
20/80	1.45	2	.465	.510	.586	.698	.711	.692	.759
		3	.544	.500	.470	.475	.491	.529	.540
		4	.676	.455	.430	.432	.448	.444	.497
		5	.760	.468	.703	.424	.421	.439	.526
		6	.728	.545	.435	.429	.453	.428	.493
		7	.812	.541	.457	.464	.455	.445	.508
		8	.892	.594	.448	.470	.460	.736	.480
20/80	.145	2	.524	.571	.633	.714	.801	.841	.778
		3	.652	.523	.518	.474	.519	.539	.677
		4	.847	.543	.495	.504	.508	.545	.601
		5	.852	.529	.484	.480	.491	.511	.538
		6	.888	.541	.509	.460	.466	.471	.592
		7	.975	.663	.530	.528	.499	.508	.535
		8	.845	.625	.471	.474	.496	.493	.664

APPENDIX D

DECISION PLUS RESPONSE TIME DATA

Subject	Acuity	(Bases)	58 fc $\bar{x}$, (sec)	58 fc α (sec)	(Bases)	14.5 fc $\bar{x}$, (sec)	14.5 fc α (sec)	(Bases)	1.45 fc $\bar{x}$, (sec)	1.45 fc α (sec)	(Bases)	.145 fc $\bar{x}$ (sec)	.145 fc α (sec)
1	20/20	(3,8)	.438,	.130	(4,6)	.389,	.064	(5,7)	.453,	.047	(6,7)	.620,	.130
	20/30	(2,5)	.429,	.138	(7,8)	.469,	.076	(4,7)	.435,	.086	(6,8)	.435,	.073
	20/40				(5,6)	.392,	.068	(7,8)	.413,	.070	(4,5)	.454,	.062
	20/80	(4,5)	.318,	.056	(6,8)	.343,	.051	(6,8)	.342,	.036	(5,7)	.383,	.100
2	20/20	(3,4)	.534,	.099	(6,8)	.516,	.146	(5,7)	.556,	.080	(6,7)	.678,	.113
	20/30	(3,5)	.630,	.096	(6,7)	.494,	.092	(4,7)	.496,	.085	(6,8)	.595,	.048
	20/40	(2,3)	.536,	.067	(5,8)	.446,	.086	(7,7)	.439,	.053	(4,5)	.493,	.059
	20/80	(4,5)	.433,	.057	(6,8)	.383,	.053	(6,7)	.460,	.067	(7)	.453,	.063
3	20/20	(3,4)	.936,	.220	(6,8)	.613,	.108	(4,5)	.702,	.152	(6,7)	.125,	.279
	20/30	(2,5)	.604,	.107	(6,7)	.499,	.057	(4,8)	.551,	.150	(6,7)	.830,	.198
	20/40	(2,3)	.510,	.074	(5,6)	.452,	.054	(6,7)	.468,	.066	(4,5)	.590,	.088
	20/80	(4,5)	.428,	.035	(6,8)	.425,	.059	(6)	.441,	.079	(5,8)	.450,	.071
4	20/20	(3,4)	.629,	.114	(6,8)	.532,	.134	(5,7)	1.033,	.445	(4,6)	1.322,	.498
	20/30	(2,5)	.716,	.177	(6,7)	.531,	.100	(4,7)	.664,	.148	(6,8)	.568,	.102
	20/40	(2,3)	.494,	.090	(5,6)	.385,	.075	(6,7)	.479,	.084	(4,5)	.517,	.081
	20/80	(4,5)	.438,	.071	(6,8)	.426,	.119	(6,8)	.460,	.060	(4,7)	.430,	.139
5	20/20	(3,4)	1.015,	.409	(7,2)	.686,	.107	(5,6)	.588,	.121	(6,7)	.979,	.164
	20/30	(2,5)	.617,	.087	(6,7)	.498,	.111	(4,8)	.532,	.051	(6,7)	.694,	.133
	20/40	(6,8)	.457,	.087	(5,8)	.445,	.090	(6,7)	.441,	.066	(4)	.677,	.144
	20/80	(4,5)	.396,	.066	(4,6)	.403,	.040	(6,7)	.425,	.057	(7,8)	.483,	.058
6	20/20	(4,8)	.711,	.303	(4,6)	.552,	.095	(5,7)	.534,	.088	(5,8)	1.215,	.375
	20/30	(4,8)	.413,	.053	(6,7)	.465,	.061	(5,7)	.501,	.090	(5,6)	.729,	.119
	20/40	(5,8)	.420,	.063	(6,7)	.434,	.048	(6,7)	.394,	.063	(4,4)	.589,	.044
	20/80	(5,8)	.389,	.070	(4,7)	.381,	.035	(5,6)	.388,	.067	(6,7)	.459,	.065
7	20/20	(4,8)	.620,	.102	(5,7)	.698,	.133	(6,8)	.746,	.091	(6,7)	.957,	.213
	20/30	(4,8)	.505,	.091	(6,8)	.552,	.078	(4,7)	.596,	.080	(5,6)	.737,	.092
	20/40	(4,8)	.505,	.046	(6,8)	.481,	.051	(4,5)	.476,	.054	(5,6)	.565,	.071
	20/80	(4,8)	.449,	.049	(5,6)	.451,	.059	(6,7)	.476,	.034	(7,8)	.494,	.060
8	20/20	(8,8)	.540,	.089	(5,6)	.468,	.089	(5,7)	.738,	.241	(6,7)	1.795,	.554
	20/30	(5,8)	.506,	.164	(6,8)	.469,	.046	(4,7)	.488,	.075	(4,6)	.666,	.130
	20/40	(5,8)	.429,	.057	(6,8)	.415,	.067	(5,7)	.483,	.080	(4,6)	.493,	.090
	20/80	(4,5)	.385,	.062	(6,8)	.355,	.048	(4,8)	.398,	.086	(6,7)	.454,	.107

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