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A study of relative accommodative responses: The Apple Macintosh computer vs hard copy

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Abstract

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Harold M. Haynes

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A STUDY OF RELATIVE ACCOMMODATIVE RESPONSES: THE APPLE MACINTOSH COMPUTER VS HARD COPY

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Erik D. Christianson
Michael J. Fleming

A
H Haynes

INTRODUCTION

The recent increase in the utilization of computers by business, industry and the general public has created a need for increased awareness by optometrists of the unique visual environment in which millions of people function daily. Recent estimates indicate as many as twenty-two million people are using computer screens on a daily basis.[1] Many of these people experience significant visual symptoms associated with video display terminals (VDTs).

Visually related symptoms frequently reported by VDT users include tirednesss, blurred vision, burning, watery, irritated or painful eyes, and ocular headaches. It has been reported that significantly higher levels of visual and musculoskeletal symptoms are associated with VDT versus non-VDT users.[2,3]

Many investigators have attempted to pin-point the specific cause of such complaints. Factors such as glare, poor contrast, improper ambient room illumination, working distance, posture, angle of the screen, color of the screen, resolution and definition of the screen, chair design, etc. have been implicated in VDT-related asthenopia.[4]

Many non-VDT users also experience similiar asthenopia related to prolonged near work.[5] These people would probably experience asthenopia if working exclusively with VDTs instead of hard copy (printed material).

It is interesting to speculate on why a person who can function without asthenopia in a nearpoint environment with hard copy begins to experience asthenopia when working with VDTs. VDT operators, in general, experience visual symptoms in excess to those working only with hard copy.[6,7] What causes these people to experience significantly more visual asthenopia? Many people have suggested accommodative malfunction as an influencing factor in VDT-related asthenopia and visual fatigue. Kurimoto, et al,[8] reported that accommodation was inhibited more by VDT work than by conventional hard copy work. Ostberg, et al,[9] reported significantly less accommodation to near targets in air traffic controllers as compared to office workers dealing exclusively with hard copy. He suggests that a disruption in accommodative function is a factor influencing visual complaints in VDT operators. Murch, et al,[10] states that the human eye cannot focus on the images projected by a computer screen with the same accuracy as it can to standard printed images. He goes further to suggest that the eye focuses somewhere between the screen and the individual's dark field accommodative response when preset for near. The poorer the stimulus to accommodation, the closer the eye focuses to the dark field response and this difference can be used to evaluate the quality of the acommodative stimulus. Wolf,et al,[11] using a laser optometer reported no difference in accommodative response to computer generated stimuli and hard copy. Apodaca, et al,[12] using retinoscopy to measure accommodative function reported a larger lag to VDT stimuli as compared to conventional hard copy.

Haynes[13], presented a model which could explain many of the differences in the above reports. He has described seven patterns of accommodative response using a combined MEM-LN retinoscopy technique under binocular viewing of printed materials. Depending upon the incidence of these patterns in the subjects used for the above studies, variations in results could be expected. That is, some people would show no difference while others would show less accommodative response under slightly reduced accommodative stimulus conditions.

It is apparent then, that there is much controversy as to whether a significant difference in accommodative function really exists when comparing computer generated visual stimuli and standard printed material.

PROBLEM

This study was designed to determine if significant group and/or individual differences in accommodative performance are present when performing the same visual discriminative task while viewing the Macintosh computer screen as compared to viewing hard copy printed on the Apple ImageWriter and the LaserWriter using two different print sizes. The results of two different contrast levels on the Macintosh screen were also investigated. The Apple Macintosh computer was chosen for its superb image resolution, screen definition and excellent graphics capability. We believe the high quality targets produced using the computer graphics may be an excellent accommodative stimulus.

DESIGN OF STUDY

MEASUREMENT OF ACCOMMODATIVE POSTURE

Accommodative posture was measured by the Canon Autorefractor Model R-1; an infrared optometer able to obtain a best focus in three meridians within 200 milliseconds. The Canon R-1 was designed to allow quick assessment of the refractive error of the eye by both dynamic and static means. Sphere and cylinder readings are printed by a thermal printer. It has been shown that the Canon Autorefractor can accurately measure accommodative behavior and that it is only negligibly effected by off axis gaze. [14,15]

Two corneal reflex dots from one eye (in our study the dominant eye) of the subject were monitored by the operator on an adjacent television screen and focus was manipulated using a joystick. The operator engages the optometer when the corneal reflex dots are seen on the monitor to be centered and as small as possible.[16]

TARGET DISPLAY

The Apple Macintosh 512K model computer was used to both generate and to present the targets used in this study. This computer was chosen because it has excellent image resolution, plenty of memory, and a wide variety of software. The software allowed us to: store and do statistics on experimental data; design and present targets on the Macintosh screen; and print these same optotypes on two different types of printers. The computer also has an adjustment for contrast built into the screen so that contrast could be controled experimentally.

EXPERIMENTAL SET-UP

The Canon Autorefractor uses a partially reflective plate set at 45 degrees in front of the subject to direct the infrared measuring beams into the pupil. This plate has a 91% luminous transmittance at 45 degree incidence (**Appendix I**). The Autorefractor allows presentation of targets in real space at any distance with little interference from the instrument itself.

The Apple Macintosh computer was placed at a distance of 50 cm from the subject's outer canthus and at eye level. All targets were generated by the computer and either were viewed on or were pressed onto the computer screen. This allowed both hard copy and VDT targets to be presented at a constant 50 cm distance with the same head and eye posture.

The lighting conditions necessary to meet all contrast conditions were carefully recorded and kept constant during the entire study.

TARGETS

The targets were designed by Professor Haynes using the MacPaint program with the "fat bits" by counting pixels. The target optotypes were "Landolt" broken squares (**Figure I.).** Gap orientation for these several targets were determined by using a table of random numbers. These optotypes were of two sizes, approximately 9 pt. and 24 pt. type, having a Snellen acuity equivalent of 20/45 and 20/180 respectively. The squares were arranged in a 5X5 array which included some closed squares.

During the initial stages of target design several other forms of optotypes were considered. We passed over a wide range of target ideas and some of these included: 1) optotypes printed over a background pattern to increase attention by disrupting figure/ground, 2) Snellen E's at random orientation, and 3) a random sequence of letters. These target designs were dropped because of familiarity and complexity of task problems. The "Landolt" squares were chosen after consideration of presentation problems, task equality, recording of the response, simplicity of design, and the relative unfamiliarity of the targets.

Each subject was presented eight near-point targets, four of which were presented on the computer screen in 9 pt. and 24 pt. type. The other four were identical Macintosh printout (hard copy) targets. The eight targets were the following: 1) A maximum (93%) contrast Macintosh sceen presented target, **VDT-93**; 2) An 85% contrast Macintosh sceen presented target, **VDT-85**; 3) An 85% contrast printout using the Macintosh LaserWriter (hard copy), **LAS-HC-85;** 4) A standard draft printout using the Macintosh ImageWriter (hard copy), **STD-HC-85**. The targets VDT-93 and VDT-85 were displayed by the computer. The targets LAS-HC-85 and STD-HC-85 were mounted on a cardboard backing and attached to the computer screen using double- stick tape.

TARGET PRESENTATION

Nine groups of autorefractor readings (through habitual correction) were taken on each subject passing the screening.

The first group, the farpoint, was performed while the subject viewed a white muscle-light at 6m in dim illumination.

The presentation sequence of the near targets was balanced to prevent any motor hysteresis effect (response biased by preceeding tasks). Twenty-four subjects were presented sequence 1 and twenty-four subjects were presented sequence 2. The two task directions, given below for sequence 1, remained constant for the identical target in sequence 2, see Tables 1 and 2.

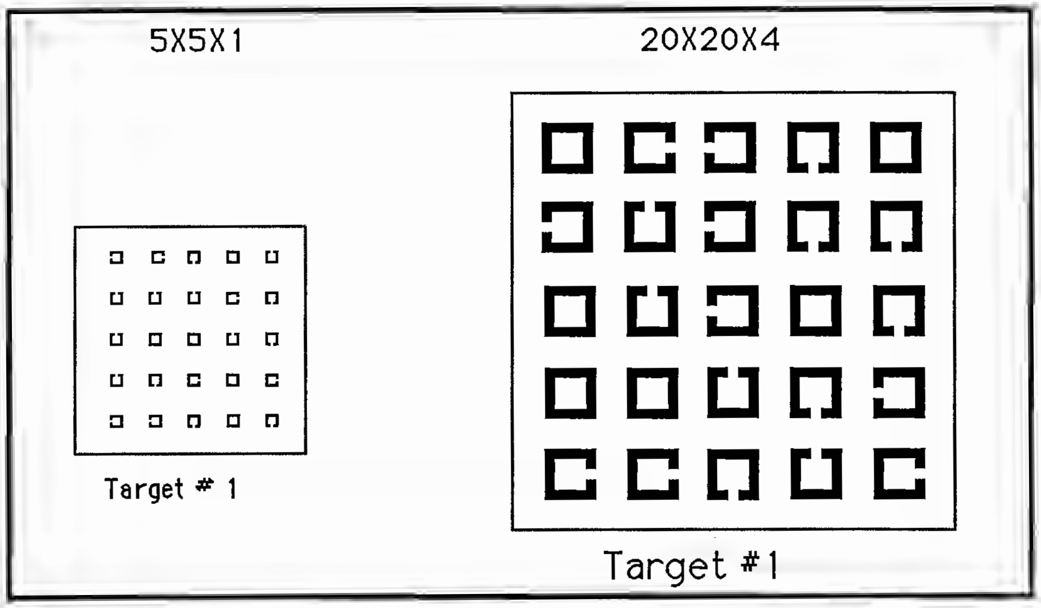

FIGURE 1. Example of targets used for visual discriminatory task. Visual acuity is approximately 20/45 and 20/180.

TARGET CONDITIONS

	MACINTOSH SCREEN		HARD COPY	
TARGET ORIGIN	MacPaint Program		LaserWriter (high quality)	ImageWriter (standard quality)
CONTRAST	93% MAXIMUM	85%	85%	85%
MODE	VDT	VDT	LAS	STD
TYPE	9 pt 24 pt	9 pt 24 pt	9 pt 24 pt	9 pt 24 pt

TABLE 1

PRESENTATION SEQUENCE

SEQUENCE 1				SEQUENCE 2			
ORDER	TYPE	MODE	TASK	ORDER	TYPE	MODE	TASK
1	9 pt	VDT-93	U & D	1	9 pt	LAS-85	U & L
2	24 pt	LAS-85	U & D	2	24 pt	VDT-85	U & L
3	9 pt	STD-85	D & R	3	9 pt	VDT-85	L & R
4	24 pt	STD-85	D & L	4	24 pt	VDT-93	U & D
5	9 pt	LAS-85	U & L	5	9 pt	VDT-93	U & D
6	24 pt	VDT-85	U & L	6	24 pt	LAS-85	U & D
7	9 pt	VDT-85	L & R	7	9 pt	STD-85	D & R
8	24 pt	VDT-93	U & D	8	24 pt	STD-85	D & L

TABLE 2

PHOTOMETRIC INSTRUMENTATION

The Ambient illumination and target luminance levels (L1 and L2) were measured using a Tektronix J-16 Photometer/Radiometer coupled to a TEK J-6511 Illiminance Probe for the former, and to a Tektronix J-6523 Luminance Probe for the latter values.

Contrast levels of the computer screen were varied between the maximum setting and the 85% setting for each subject. Because the Tektronix system was not regularly available the 85% contrast levels were monitored routinely using a Photo Research Corporation Spectra Candela portable light meter to register the background luminance (L1) of the screen in arbritrary units corresponding to the desired contrast (85%). The contrast knob was turned until the correct arbritary reading was shown on the light meter (7 units). This method gave contrast settings repeatable to +/-1%. For individual measures of L2 and L1, contrast calculations, and equations see **Appendix I.**

SUBJECTS

The subjects used in this study were all volunteers from the Forest Grove, Oregon area. All of the subjects used showed visual acuities of 20/20 or better, ocular structures free from observable pathology, and normal binocular vision as defined in **Appendix II.** A screening was done on all potential subjects to determine if any of the above areas were anomalous. All subjects failing a particular screening test were dropped from the study (for screening criteria see **Appendix II**). The total number subjects screened was 55 and 7 subjects were dropped due to failure in one or more screening areas.

TASK

Each subject was instructed to count the number of broken squares with the opening in the appropriate direction. The task was to count two directions (i.e., "breaks pointing left and breaks pointing up") and maintain a single running total until the task was completed. When the subject finished they were instructed to close their eyes and report a single answer. This answer was recorded for each target presentation mode and entered into the data block for later analysis.

INSTRUCTIONAL SET

The subjects were seated in front of the autorefractor which was raised above the line of sight of the computer display (turned-off). The room lights were then turned off. The fixation light remained on through-out the far-point section of the experiment. The subjects were told:

> "Look at that light out there keeping your head still and blink normally. I'm going to take shots that sound like a camera. (Far point shots taken)."
>
> The lights were turned-on, autorefractor lowered, and the near task was explained:
>
> "You will have a task to perform while I take more shots. (Holding a 24 pt. target). Your task is to count the number of squares with an opening in the appropriate direction. You will count two directions and maintain one running total. For example, right plus left (experimenter points to and counts all of those squares opened to the right and left). Do you understand? Count silently to yourself and when you are finished close your eyes. When you are done I will ask you for the answer.

> Please do not talk or move during the task. Before we begin each task look at the upper left-hand figure while I line you up with the autorefractor. I will tell you when to begin counting."
>
> The experiment begins...
>
> "Ok, for this target, count the number of squares opened to the...,ie right and left, etc."

Each subject was instructed to relax and remove his/her head from the chin rest between target presentations. The experimenter changed the targets by recalling the stored computer targets or by placing the hardcopy targets on the computer display glass area (computer display "off").

STATISTICAL TREATMENT

Normal descriptive statistics including: mean and mean of the difference; standard deviation and standard deviation of the difference; t-test, and F-test were used to analyze the data. The usual null hypothesis formulation was used with the alpha level set at 5% (p = .05; two-tailed). For a description of the statistical methods refer to **Appendix IV.**

RESULTS

DATA AQUISITION/SELECTION

Forty-eight volunteer subjects out of a group of 55 were acceptable based on entrance criteria. There were 15 females and 33 males. Subjects ranged in age from 20 to 32 years of age with a mean age of 24 years.

All autorefractor data was obtained from the dominant eye. The first series of autorefractor shots, the habitual farpoint, was performed to establish a baseline for the acceptance of all other nearpoint measurements. **Appendix V** contains the form used to record each screening test result for each subject.

To ensure on axis readings and to sift out erroneous data, the mean of the subjects' farpoint cylinder readings plus or minus 0.25 D was the range of data considered acceptable for the eight near target conditions. Homer[17] has shown previously that the Canon autorefractor (model R-1) sphere reading alone is a valid measure of the accommodative response when the cylinder reading is within the range of acceptability. The acceptable near target autorefractor readings were then averaged for each subject and placed on a Multiplan Spreadsheet program for later analysis

After the cylinder criteria described above was used there were a few individual subjects where there were gross deviations in a single measurement. These were apparent errors of measurement or momentary fluctuations in accommodation. In order to eliminate averaging the gross erroneous readings each subject's acceptable readings were averaged and standard deviation calculated. Any recorded responses greater than two standard deviations away from the mean reading were discarded and a new mean calculated.

ERROR ANALYSIS

An error analysis for each experimental condition was performed to determine if accuracy of response in describing the gap orientation of the broken squares varied. All subject responses were graded (#correct/#reported: Larger value in the denominator) and the mean grade (Mean), standard deviation (SD), standard error of the mean (SE), maximum (Max), and the minimum score (Min) are shown in **Table 3.**

Tables 3 and 4 display the results of comparing perfromances on the broken-square gap orientation task under two levels of contrast under hard copy and VDT screen viewing conditions. The results indicate that the null hypothesis is rejected; the task performances are not equal according to each statistical test row where a "Y" appears in **Table 4.**

TABLE 3. ERROR ANALYSIS: STATISTICAL SUMMARY

ERROR ANALYSIS: STATISTICAL SUMMARY*									
9 POINT						24 POINT			
TARGET	VDT 93%	VDT 85%	LASER 85%	Std 85%		VDT 93%	VDT 85%	LASER 85%	Std 85%
MEAN	0.96	0.98	0.92	0.88		0.97	0.95	0.95	0.92
SD	0.09	0.05	0.12	0.13		0.04	0.09	0.07	0.11
SE	0.01	0.01	0.02	0.02		0.01	0.01	0.01	0.02
MAX	1.00	1.00	1.00	1.00		1.00	1.00	1.00	1.00
MIN	0.57	0.78	0.40	0.50		0.89	0.71	0.67	0.45
*#Reported Vs # Correct: Larger in the Denominator									

TABLE 4. SUMMARY OF ERROR ANALYSIS

TABLE 4.		ERROR ANALYSIS FOR 'GAP' DISCRIMINATION TASK				
9 POINT TYPE						
	VDT[85-93%]	VDT[93]-LASER[85]	VDT[85]-LASER[85]	STD[85]-LASER [85	VDT[93]-STD[85]	VDT[85]-STD[85]
T- VALUE*	1.31	1.8	3.05	1.53	3.47	4.85
SIGNIFICANT	NO	NO	YES	NO	YES	YES
F-TEST **	2.74	2.01	5.5	1.14	2.29	6.25
SIGNIFICANT	YES	YES	YES	NO	YES	YES
ΔAr	None	>LAS	>LAS	None	None	>STD
SIGNIFICANT	NO	YES	YES	NO	NO	YES
24 Point Type						
T-VALUE *	1.49	1.71	0	1.52	2.77	1.44
SIGNIFICANT	NO	NO	NO	NO	YES	NO
F-TEST **	3.73	2.18	1.71	3.02	6.6	1.77
SIGNIFICANT	YES	YES	NO	YES	YES	NO
ΔAr	None	None	>LAS	None	>STD	>STD
SIGNIFICANT	NO	NO	YES	NO	YES	YES
* *						
*Significance at or above the 5% confidence level.						
**Significance at or above the 5% confidence level.						

ACCOMMODATIVE POSTURE ANALYSIS

For an emmetrope viewing the near targets, an autorefractor reading of -2.00 D would indicate the subject was accommodating at the plane of the target. Any reading less in minus would indicate a motor response lag of accommodation (-MRLa) behind the target and a reading more in minus would show a +MRLa (focus in front of the the target).

Subjects wore their habitual correction during the experimental portion of this study. Even with their correction in place many of the subjects were not optically "emmetropic". However, this is immaterial since the measurements were analyzed for the change in accommodative response as measured by the autorefractor during the various contrast and task conditions.

Columns 7-11 and 17-20 (**Appendix III**) are average autorefractor sphere readings (in terms of lens correction) which are within the range of acceptability defined above.

Columns 12-15 and 21-24 are the mean difference between the targets. Shown at the bottom of **Appendix III** are the mean of the mean difference , the S.D. of the mean difference (SD), the minimum mean difference (Min), the maximum mean difference (Max), the standard error of the mean difference (SE), and the z-score of the mean differences (z)

Table 5 shows that there is a significant difference of accommodative response between the following targets:

1. VDT-93 vs LAS-HC-85; 9pt
2. VDT-85 vs LAS-HC-85; 9pt
3. VDT-85 vs LAS-HC-85; 24pt
4. VDT-85 vs STD-HC-85; 9pt
5. VDT-93 vs STD-HC-85; 24pt
6. VDT-85 vs STD-HC-85; 24pt

In **Table 5** the sign on the "mean " reveals which targets produced a relatively larger accommodative response. All nearpoint autorefractor readings are in <u>minus</u> , therefore , a larger subtrahend would produce a positive "mean". For example, a "mean" of <u>plus</u> indicates that the subtrahend (#being subtracted) has a larger accommodative response. Therefore, the second target in the column (the subtrahend) had the larger autorefractor reading and a larger accommodative response (better accommodative stimulus).

Table 3 shows that the average score on all tasks (except the 9 pt. STD-85) was above the 90th percentile. Implied is that the relative task accuracy in descriminating the gaps in the targets played a negligible role in influencing the relative differences measured in accomodative response.

The error analysis shows that there is neither a significant difference between the 24 pt VDT-85 and the 24 pt STD-85 tasks nor a significant difference between the LAS-85 and the STD-85 tasks. The accommodative posture analysis shows that the 24 pt STD-85 target has a relatively larger accommodative response than the 24 pt VDT-85 . It also shows that there is <u>no</u> significant difference in accommodative response between the LAS-85 and the STD-85 targets. The only difference between the latter is resolution (target quality). Contrast and accuracy of discrimination are not significantly different for all of the above;

target characteristics were different.

A relatively small but consistent pattern of change in accommodative behavior was found. The accommodative response for the VDT screen was significantly less when the contrast ratio was maintained at 85% under both the LaserWriter hard copy and the ImageWriter (standard print) hard copy. This statement applies to both print types used, approximately 9pt and 24 pt type. No VDT difference was obtained between 93% and 85% contrast in the accommodative response with either the 9 pt or 24 pt letters. Apparently much greater differences in contrast would have to be employed if this variable were to prove to be effective in changing short-term accommodative behavior.

TABLE 5. STATISTICAL SUMMARY OF DIFFERENCES

TABLE 5.	STATISTICAL SUMMARY OF DIFFERENCES -- VDT SCREEN and HARD COPY					
9 Point Type						
	VDT[93-85%]	VDT[93]-Laser[85]	VDT[85]-Laser[85]	Std[85]-Laser[85%]	VDT[93]-Std[85%]	VDT[85]-Std[85%]
MEAN Δ	-0.01	0.11	0.12	0.03	0.08	0.09
SD Δ	0.22	0.27	0.25	0.23	0.32	0.27
MIN Δ	-0.50	-0.37	-0.25	-0.50	-0.50	-0.62
MAX Δ	0.63	1.25	0.75	0.75	1.75	1.12
SE Δ	0.03	0.04	0.04	0.03	0.05	0.04
Z	-0.33	2.70	3.19	0.79	1.69	2.25
ΔAr	No Difference	> Laser [85%]	> Laser	No Difference	No Difference	> Std
Significant	NO	YES	YES	NO	NO	YES
24 Point Type						
MEAN Δ	-0.05	0.02	0.07	-0.08	0.10	0.15
SD Δ	0.21	0.26	0.22	0.28	0.27	0.25
MIN Δ	-0.75	-0.75	-0.63	-1.12	-0.38	-0.38
MAX Δ	0.30	0.38	0.67	0.50	1.12	1.25
SE Δ	0.03	0.04	0.03	0.04	0.04	0.04
Z	-1.60	0.55	2.18	-1.96	2.59	4.10
ΔAr	No Difference	No Difference	> Laser	No Difference	> Std	> Std
Significant	NO	NO	YES	NO	YES	YES

* *

Table 5. Algerbraic differences in the accommodative response [ΔAr] are tabulated for print size and for percentage of contrast.

DISCUSSION

Our results suggest that when task and contrast are controlled there is something inherent within the computer display itself which produces objectively smaller accommodative responses relative to hardcopy targets under the task conditons imposed. The relatively smaller accommodative response to the VDT-85 (computer screen) as compared to the STD-85 (hard copy) and the lack of a significant difference between the STD-85 and LAS-85 hard copy targets, implies that this difference is not due to resolution (optotype quality) characteristics of the video screen display.

This study shows that the relative differences in accommodative response between the computer screen and the hard copy were not influenced by task performance or resolution of the two print sizes. These differences in accommodative response were not of sufficient magnitude to influence discriminatory ability. The computer screen produced a relatively smaller accommodative response in both of the contrast conditions (matched and maximum computer contrast) indicating it is a poorer accommodative stimulus compared to hard copy.

The relatively smaller accommodative response measured while viewing the computer screen could be due to some inherent, unidentified characteristics within the computer screen. Some of these could be: 1) "refresh rate" (flicker rate) of the cathode ray tube, 2) curvature of the screen, and 3) the spectral components of the emitted light (X-rays, visible spectra, etc.). Another possibility could be the perceptual (learned) judgement of depth associated with the apparent depth changes seen while viewing television.

It should be noted that not all subjects showed changes in accommodative response under the various viewing conditions. There was inter-subject variability present. This is not surprising because these same variations were seen in other studies on accommodative behavior.[18-22] Intra-subject variability was also present and was limited to a relatively small number as compared to the overall subject population. The subjects who showed the most variability in accommodative response probably fall into one of several accommodative response patterns discussed by other authors.[23-24] Haynes[25] has shown that these people show a larger MRLa when the accommodative stimulus quality decreases. These subjects who show this large variation in accommodative response to the varying stimulus conditions may respond in a similar fashion as those "symptomatic VDT operators.

The results from this study indicate a need for further research. Areas of investigation include inverse contrast, varying the refresh rate of the computer screen, comparing various computers, investigating accommodative changes due to sustained task, and the effect of lenses (various nearpoint prescriptions, tint, coatings, etc.) on accomodative behavior.

SUMMARY

The relative changes in accommodative response were measured at 0.50 meters using the Canon Autorefractor model R-1 on forty-eight subjects who ranged in age from 20 to 32 years old.

Accommodative responses were measured while subjects performed a visual-discriminatory task viewing eight nearpoint targets. The targets were 9 pt. and 24 pt. optotype with a broken square task under the following conditions: 1) maximum contrast on the Macintosh computer VDT-93, 2) 85% contrast on the Macintosh computer VDT-85, 3) 85% contrast Macintosh laser printout LAS-85, (hard copy), 4) 85% contrast Macintosh standard printout STD-85 (hard copy).

An analysis of the task scores show that all the tasks are approximately equal with the exception of the 9 pt. STD-85 which showed more errors and greater variance.

The accommodative posture analysis shows that the hardcopy LAS-85 target ellicits a significantly larger accommodative response from the subjects than does the VDT-85 computer target for both 9 pt. and 24 pt. optotype. (targets matched for contrast and task).

This study has shown that the source of the decreased accommodative response measured from the subjects viewing a Macintosh computer screen is neither minor changes in contrast, task performance, nor target resolution. The specific source of which has yet to be identified.

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APPENDIX I. ILLUMINATION SPECIFICATIONS

DESCRIPTION	VALUES	EXPLANATION
Ambient Illumination	86 lux (8 fc)	Measured with the VDU "on" and at the top of the Autorefractor headrest
Contrast values and calculation		
A. Equation	units = cd/m2 cd = candela	Contrast = 1- L2/L1 Where L1 = luminance of the background (light area). L2 = luminance of the figure (dark area).
B. Hard Copy	L1 = 14.6 cd/m2 L2 = 2.45 cd/m2 C = 83%	The contrast of the hard copy as figured by the above equation is .83 or 83%.
C. VDT MAX	L1 = 121.7 cd/m2 L2 = 8.3 cd/m2 C = 93%	The VDT MAX contrast is equal to .93 or 93% VDT MAX is the screen set for maximum contrast.
D. VDT 85%	L1 = 23.6 cd/m2 L2 = 3.7 cd/m2 C = 85% +/- 1%	The L1 and L2 values were manipulated using the contrast adjustment knob on the base of the MacIntosh VDU screen.
Miscellaneous measures		
A. Transmittance of the semireflecting plate.	91%	The transmittance was measured to determine the actual amount of light reaching the patient's pupil The plate is used to reflect the infrared measuring light into the subject's eyes and then back into the Autorefractor.

APPENDIX II

SCREENING TESTS AND SELECTION CRITERIA FOR EXPERIMENTAL SUBJECTS

1. VISUAL ACUITY: Snellen acuities were taken a far (6 m) and near (40cm). Subjects were to have better than 20/20 acuities at both distances to pass this section of the screening. Both eyes were also to have equal acuities.

2. DOMINANT EYE: The dominant eye test was done using the "hole in the card" method. Three trials were used to determine the subject's prefered eye. We used the determined dominant eye for all autorefractor readings.

3. ACCOMMODATION: The Donder's Push-up method was used to determine the amplitude of accommodation. The letter size in this screening section was 6 pt type. The subject's accommodative amplitude had to be equal to or greater than the expected amount for the subjects age. The expected amount was determined by using the Hofstetter equation: AA = 15- (.25 x age in yrs).

4. VERGENCE: The near point of convergence was measured using a bead with a letter placed on it. The letter was to be kept clear and single. Using the bead both the convergence amplitude and vergence system recovery were measured. The subject had to meet or exceed the accepted norm for convergence Bk/Rec (from Harold Haynes normative data 2"/3").

5. PHORIC POSTURE: The cover-test at 6m and 40cm was used to estimate the phoric postures of the experimental subjects. All subjects with a measured tropia were excluded from the study. Subjects with the following phorias were also excluded: Far Exo > 5, Near Exo > 10, Far Eso > 5 (visible), Near Eso > 5 (visible).

6. BINOCULARITY: The Randot stereo test was used to determine if the subjects were binocular. It has been shown that stereo ability is a good screening measure for binocularity. Subjects were dropped from the study if their stereo acuity as measured by the Randot was less than 80 arcsec.

APPENDIX II (cont'd)

7. REFRACTIVE ERROR: Distance retinoscopy was performed over the subjects prescription (if one was worn) to determine if any uncorrected refractive error existed. The following criteria were used to determine if the subjects over refraction was acceptable: Anisometropia < .50, Myopia < .50, Cylinder < .75, Hyperopia < 1.00. Subjects failing any of these were dropped from the study.

The records were obtained on those subjects corrected with a prescription and the powers recorded in a table. Subjects with a correction for myopia and hyperopia greater than 5.00 diopters wereput in a seperate group for data analysis.

8. CASE HISTORY: Several questions were asked of each potential subject in the screening. The question gave us information on the following: a.) Prior eye surgery, b.) Diagnosed strabismus, c.) Diagnosed amblyopia, and d.) Prior visual training. The responses to these questions were used to further aid in subject selection.

APPENDIX III. DATA SUMMARY

NAME	AGE	SEX	DOM	#4: OD	#4: OS	FARPT #1	MAX 9 PT	VDT 9 PT	LASER 9 PT	STD 9 PT	Column Differences [9 point]					
			EYE	EQ SPH	EQ SPH	AVG	AVG	AVG	AVG	AVG	[8-9]	[8-10]	[9-10]	[11-10]	[8-11]	[9-11]
T.N.	23	M	OD	-0.25	0.00	1.00	-0.87	-0.75	-1.50	-0.75	-0.12	0.63	0.75	0.75	-0.12	0.00
J.H.	20	M	OD	-0.25	0.00	1.00	-1.00	-1.37	-1.12	-1.00	0.37	0.12	-0.25	0.12	0.00	-0.37
I.K.	22	F	OS	0.75	1.00	0.62	-1.62	-1.62	-1.37	-1.62	0.00	-0.25	-0.25	-0.25	0.00	0.00
L.B.	22	F	OD	0.25	0.25	0.50	-1.37	-1.25	-1.50	-1.12	-0.12	0.13	0.25	0.38	-0.25	-0.13
J.G.	23	M	OS	-0.25	-0.50	0.37	-1.12	-1.00	-1.00	-1.12	-0.12	-0.12	0.00	-0.12	0.00	0.12
C.J	23	M	OD	0.25	0.25	0.12	-1.65	-1.70	-1.87	-1.89	0.05	0.22	0.17	-0.02	0.24	0.19
H.H.	22	M	OD	0.25	-0.25	0.12	-1.50	-1.50	-1.62	-1.75	0.00	0.12	0.12	-0.13	0.25	0.25
S.O.	26	M	OS	0.25	-0.25	0.12	-1.42	-1.25	-1.54	-1.50	-0.17	0.12	0.29	0.04	0.08	0.25
K.D.	25	M	OS	0.25	-0.25	0.05	-1.28	-1.27	-1.20	-1.45	-0.01	-0.08	-0.07	-0.25	0.17	0.18
P.W.	23	M	OD	-0.25	-0.25	0.00	-1.50	-1.00	-1.75	-1.50	-0.50	0.25	0.75	0.25	0.00	0.50
T.F.	25	M	OD	0.00	-0.25	0.00	-1.50	-1.87	-1.62	-1.50	0.37	0.12	-0.25	0.12	0.00	-0.37
L.W.	23	F	OD	0.25	0.25	0.00	-1.25	-1.12	-1.50	-1.37	-0.13	0.25	0.38	0.13	0.12	0.25
S.S	22	M	OD	-0.50	0.25	-0.12	-1.37	-1.62	-1.50	-1.62	0.25	0.13	-0.12	-0.12	0.25	0.00
K.O.	25	M	OS	-0.25	-0.25	-0.12	-1.37	-1.50	-1.50	-1.75	0.13	0.13	0.00	-0.25	0.38	0.25
M.M.	24	M	OD	-0.25	0.00	-0.12	-1.62	-1.62	-1.87	-1.75	0.00	0.25	0.25	0.12	0.13	0.13
M.B.	25	F	OD	-0.25	-0.25	-0.17	-0.62	-0.85	-1.02	-1.06	0.23	0.40	0.17	-0.04	0.44	0.21
H.M.	24	M	OS	-1.00	-0.75	-0.19	-1.47	-1.58	-1.57	-1.62	0.11	0.10	-0.01	-0.05	0.15	0.04
G.P	21	F	OD	-1.75	-1.75	-0.25	-1.75	-1.62	-1.62	-1.75	-0.13	-0.13	0.00	-0.13	0.00	0.13
R.I.	25	M	OD	0.00	-0.25	-0.32	-1.87	-1.72	-1.81	-2.00	-0.15	-0.06	0.09	-0.19	0.13	0.28
D.S.	25	M	OS	-0.25	-0.50	-0.32	-1.90	-1.62	-1.70	-1.87	-0.28	-0.20	0.08	-0.17	-0.03	0.25
C.D.	20	F	OD	-0.50	-0.25	-0.40	-1.44	-1.65	-1.71	-1.56	0.21	0.27	0.06	0.15	0.12	-0.09
J.B.	25	M	OS	-0.25	-0.50	-0.45	-1.56	-1.57	-1.34	-1.35	0.01	-0.22	-0.23	-0.01	-0.21	-0.22
C.M.	24	M	OD	0.00	-0.25	-0.75	-1.50	-1.50	-1.50	-1.50	0.00	0.00	0.00	0.00	0.00	0.00
D.M.	22	F	OD	-0.25	-0.25	-0.87	-1.32	-1.50	-1.75	-1.65	0.18	0.43	0.25	0.10	0.33	0.15
T.J.L.	24	M	OD	-0.25	-0.25	-0.62	-1.75	-1.75	-1.62	-1.75	0.00	-0.13	-0.13	-0.13	0.00	0.00
S.K.	24	M	OS	-0.75	-0.75	-0.50	-2.12	-1.75	-1.75	-1.62	-0.37	-0.37	0.00	0.13	-0.50	-0.13
S.B.	27	M	OD	0.00	0.25	-0.50	-1.75	-1.87	-2.00	-1.25	0.12	0.25	0.13	0.75	-0.50	-0.62
N.P.	22	F	OD	-0.50	0.00	-0.37	-2.12	-2.00	-2.25	-2.12	-0.12	0.13	0.25	0.13	0.00	0.12
I.D.	28	M	OD	0.00	0.00	-0.37	-2.00	-2.00	-2.00	-2.12	0.00	0.00	0.00	-0.12	0.12	0.12
M.N.	26	M	OD	0.00	0.50	-0.30	-2.15	-1.65	-2.14	-2.20	-0.50	-0.01	0.49	-0.06	0.05	0.55
R.B.	23	M	OS	0.25	0.00	-0.25	-1.62	-1.75	-1.62	-1.62	0.13	0.00	-0.13	0.00	0.00	-0.13
E.H.	32	M	OD	-0.50	-0.50	-0.25	-1.62	-1.67	-1.75	-1.75	0.05	0.13	0.08	0.00	0.13	0.08
F.R.	25	M	OS	-0.50	-0.25	-0.12	-1.87	-1.37	-1.75	-1.62	-0.50	-0.12	0.38	0.13	-0.25	0.25
S.S.	27	M	OD	0.00	-0.25	-0.12	-1.82	-1.82	-2.00	-2.00	0.00	0.18	0.18	0.00	0.18	0.18
D.D.	26	M	OS	0.00	0.00	0.00	-1.75	-1.62	-1.62	-1.25	-0.13	-0.13	0.00	0.37	-0.50	-0.37
P.I.	21	F	OD	-0.25	-0.25	0.00	-1.87	-1.87	-2.00	-1.87	0.00	0.13	0.13	0.13	0.00	0.00
D.H.	22	M	OS	-0.50	-0.50	0.00	-1.62	-1.62	-1.50	-1.75	0.00	-0.12	-0.12	-0.25	0.13	0.13
R.C.	24	M	OD	0.00	0.00	0.00	-1.50	-1.50	-1.50	-1.50	0.00	0.00	0.00	0.00	0.00	0.00
C.E.	23	F	OD	0.25	0.50	0.00	-1.62	-1.62	-1.87	-1.75	0.00	0.25	0.25	0.12	0.13	0.13
S.L.	22	F	OD	0.25	0.00	0.12	-1.37	-1.25	-1.25	-1.25	-0.12	-0.12	0.00	0.00	-0.12	0.00
D.Y.	24	M	OD	0.00	-0.25	0.12	-1.50	-1.62	-1.50	-1.62	0.12	0.00	-0.12	-0.12	0.12	0.00
K.L.	21	F	OS	0.00	-0.25	0.12	-1.37	-1.50	-1.75	-1.50	0.13	0.38	0.25	0.25	0.13	0.00
J.M.	27	M	OD	0.50	0.25	0.25	-1.37	-1.62	-1.62	-1.62	0.25	0.25	0.00	0.00	0.25	0.00
B.M.	26	F	OD	-0.25	-0.25	0.25	-1.25	-1.37	-1.37	-1.37	0.12	0.12	0.00	0.00	0.12	0.00
S.S.	26	M	OD	1.00	0.50	0.37	-1.75	-1.50	-1.50	-1.75	-0.25	-0.25	0.00	-0.25	0.00	0.25
P.P.	22	F	OD	0.00	0.25	0.37	-1.37	-1.37	-1.50	-1.37	0.00	0.13	0.13	0.13	0.00	0.00
G.H.	27	M	OS	0.25	0.25	0.50	-0.37	-1.00	-1.62	-2.12	0.63	1.25	0.62	-0.50	1.75	1.12
L.M.	27	F	OS	1.25	1.25	0.87	-1.00	-0.75	-1.50	-1.37	-0.25	0.50	0.75	0.13	0.37	0.62
										MEAN Δ	-0.01	0.11	0.12	0.03	0.08	0.09
										SD Δ	0.22	0.27	0.25	0.23	0.32	0.27
										MIN Δ	-0.50	-0.37	-0.25	-0.50	-0.50	-0.62
										MAX Δ	0.63	1.25	0.75	0.75	1.75	1.12
										SE Δ	0.03	0.04	0.04	0.03	0.05	0.04
										Z	-0.33	2.70	3.19	0.79	1.69	2.25

APPENDIX III. DATA SUMMARY

NAME	AGE						MAX 24 PT	VDT 24 PT	LASER 24 PT	STD 24 PT	Column Differences					
							AVG	AVG	AVG	AVG	[17-18]	[17-19]	[18-19]	[20-19]	[19-22]	[20-22]
T.N.	23						-1.00	-1.00	-1.25	-1.50	0	0.25	0.25	-0.25	0.5	0.5
J.H.	20						-1.00	-1.00	-0.87	-0.62	0	-0.13	-0.13	0.25	-0.38	-0.38
I.K.	22						-1.50	-1.37	-1.37	-1.50	-0.13	-0.13	0	-0.13	0	0.13
L.B.	22						-1.25	-1.25	-1.37	-1.50	0	0.12	0.12	-0.13	0.25	0.25
J.G.	23						-1.12	-1.12	-1.37	-1.25	0	0.25	0.25	0.12	0.13	0.13
C.J	23						-1.52	-1.62	-1.87	-1.70	0.1	0.35	0.25	0.17	0.18	0.08
H.H.	22						-1.62	-1.50	-1.62	-1.75	-0.12	0	0.12	-0.13	0.13	0.25
S.O.	26						-1.33	-1.40	-1.37	-1.21	0.07	0.04	-0.03	0.16	-0.12	-0.19
K.D.	25						-1.16	-1.27	-1.30	-1.07	0.11	0.14	0.03	0.23	-0.09	-0.2
P.W.	23						-1.50	-1.32	-1.50	-1.75	-0.18	0	0.18	-0.25	0.25	0.43
T.F.	25						-2.00	-1.75	-1.62	-1.87	-0.25	-0.38	-0.13	-0.25	-0.13	0.12
L.W.	23						-1.25	-1.12	-1.25	-2.37	-0.13	0	0.13	-1.12	1.12	1.25
S.S	22						-1.32	-1.62	-1.50	-1.50	0.3	0.18	-0.12	0	0.18	-0.12
K.O.	25						-1.50	-1.50	-1.50	-1.37	0	0	0	0.13	-0.13	-0.13
M.M.	24						-1.50	-1.62	-1.75	-1.87	0.12	0.25	0.13	-0.12	0.37	0.25
M.B.	25						-0.73	-0.90	-1.00	-1.15	0.17	0.27	0.1	-0.15	0.42	0.25
H.M.	24						-1.48	-1.59	-1.52	-1.64	0.11	0.04	-0.07	-0.12	0.16	0.05
G.P	21						-1.50	-1.50	-1.62	-1.75	0	0.12	0.12	-0.13	0.25	0.25
R.I.	25						-1.37	-1.50	-1.70	-1.87	0.13	0.33	0.2	-0.17	0.5	0.37
D.S.	25						-1.90	-1.87	-1.50	-1.70	-0.03	-0.4	-0.37	-0.2	-0.2	-0.17
C.D.	20						-1.77	-1.65	-1.53	-1.75	-0.12	-0.24	-0.12	-0.22	-0.02	0.1
J.B.	25						-1.45	-1.46	-1.18	-1.44	0.01	-0.27	-0.28	-0.26	-0.01	-0.02
C.M.	24						-1.37	-1.37	-1.50	-1.37	0	0.13	0.13	0.13	0	0
D.M.	22						-1.75	-1.75	-1.50	-1.75	0	-0.25	-0.25	-0.25	0	0
T.J.L.	24						-1.75	-1.62	-1.75	-1.75	-0.13	0	0.13	0	0	0.13
S.K.	24						-1.50	-1.50	-1.75	-1.25	0	0.25	0.25	0.5	-0.25	-0.25
S.B.	27						-2.12	-1.62	-1.87	-1.87	-0.5	-0.25	0.25	0	-0.25	0.25
N.P.	22						-2.00	-2.00	-2.00	-2.12	0	0	0	-0.12	0.12	0.12
I.D.	28						-2.00	-1.82	-2.37	-2.12	-0.18	0.37	0.55	0.25	0.12	0.3
M.N.	26						-2.00	-2.02	-2.30	-2.10	0.02	0.3	0.28	0.2	0.1	0.08
R.B.	23						-1.37	-1.62	-1.62	-1.75	0.25	0.25	0	-0.13	0.38	0.13
E.H.	32						-1.75	-1.50	-1.75	-1.62	-0.25	0	0.25	0.13	-0.13	0.12
F.R.	25						-1.25	-1.50	-0.87	-1.87	0.25	-0.38	-0.63	-1	0.62	0.37
S.S.	27						-1.75	-2.00	-2.00	-2.00	0.25	0.25	0	0	0.25	0
D.D.	26						-2.25	-1.75	-1.50	-1.87	-0.5	-0.75	-0.25	-0.37	-0.38	0.12
P.I.	21						-1.75	-1.75	-1.75	-1.87	0	0	0	-0.12	0.12	0.12
D.H.	22						-1.75	-1.62	-1.50	-1.75	-0.13	-0.25	-0.12	-0.25	0	0.13
R.C.	24						-1.25	-1.25	-1.37	-1.50	0	0.12	0.12	-0.13	0.25	0.25
C.E.	23						-1.62	-1.62	-1.75	-1.75	0	0.13	0.13	0	0.13	0.13
S.L.	22						-1.25	-1.25	-1.62	-1.37	0	0.37	0.37	0.25	0.12	0.12
D.Y.	24						-1.62	-1.44	-1.44	-1.87	-0.18	-0.18	0	-0.43	0.25	0.43
K.L.	21						-1.37	-1.62	-1.75	-1.62	0.25	0.38	0.13	0.13	0.25	0
J.M.	27						-1.25	-1.25	-1.37	-1.50	0	0.12	0.12	-0.13	0.25	0.25
B.M.	26						-1.37	-1.12	-1.37	-1.25	-0.25	0	0.25	0.12	-0.12	0.13
S.S.	26						-1.82	-1.50	-1.75	-1.67	-0.32	-0.07	0.25	0.08	-0.15	0.17
P.P.	22						-1.25	-1.37	-1.37	-1.37	0.12	0.12	0	0	0.12	0
G.H.	27						-1.50	-1.00	-1.67	-1.50	-0.5	0.17	0.67	0.17	0	0.5
L.M.	27						-1.62	-0.87	-1.00	-1.37	-0.75	-0.62	0.13	-0.37	-0.25	0.5
										MEAN Δ	-0.05	0.02	0.07	-0.08	0.10	0.15
										SD Δ	0.21	0.26	0.22	0.28	0.27	0.25
										MIN Δ	-0.75	-0.75	-0.63	-1.12	-0.38	-0.38
										MAX Δ	0.30	0.38	0.67	0.50	1.12	1.25
										SE Δ	0.03	0.04	0.03	0.04	0.04	0.04
										Z	-1.60	0.55	2.18	-1.96	2.59	4.10

APPENDIX IV

We will test the null hypothesis with both the students' t-test (mean 1 - mean 2 = $m_{diff} = 0$) and the F-test.

The t-values in Table #4 are derived using a two-tailed students' t-distribution table and the following equation:

$$Z = \frac{\text{mean 1} - \text{mean 2}}{\sqrt{SE_1^2 + SE_2^2}}$$

where $SE = \frac{SD}{\sqrt{N-1}}$, N = 48 and Std. Dev.

The students' t-test assumes a normal distributuion and standardizes the reported value relative to the mean and S.D. of the sample. Any value equal to or greater than 1.96 is significant to at least the .05 level or within the 95% confidence level.

The F-value is the ratio of two sample variances (S.D.) of two different sample populations; therefore, it uses two degrees of freedom, df1 and df2, but in this application df1 = df2 = N-1 = 47.

The F-value is calculated using the following equation:

$$F = \frac{SD_1^2}{SD_2^2}$$ where $SD_1 > SD_2$, and SD = Std. Dev.

Whether or not this value is significant to the .05 level is determined using an .025 level F-distribution table since we are not speculating on the outcome. Any value equal to or greater than 1.84 (interpolated from the F-distribution table using df1 = df2= 47) is significant to at least the .05 level.

APPENDIX V

SCREENING FORM

Canon Autorefractor Data

SEQUENCE # 1 (begin)

a. 50 cm with Laser copy
(24 PT type)

1.
2.
3.
4.
5.

b. 50 cm with Standard Draft
(9 PT type)

1.
2.
3.
4.
5.

c. 50 cm with Standard Draft
(24 PT)

1.
2.
3.
4.
5.

SEQUENCE # 2 (begin)

a. 50 cm w/ Laser copy
(9 PT type)

1.
2.
3.
4.
5.

b. 50 cm w/ VDT target
(24 PT type)

1.
2.
3.
4.
5.

c. 50 cm w/ VDT target
(9 PT)

1.
2.
3.
4.
5.

Mistakes in stress portion

SEQUENCE #1

a.

b.

c.

a.

b.

c.

SEQUENCE #2

a.

b.

c.

a.

b.

c.