Viewing distance affects reaction time to discriminate letters of a constant, small size

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Continuous physiological fluctuations in visual accommodation may affect the ability to sustain resolution of small-letter stimuli. To investigate this possibility, the experimenter had subjects view a small letter that was subtly transformed into another letter at a random time during a 12-sec viewing interval. Reaction time (RT) to detect the letter change was measured for stimuli of a constant size and brightness viewed at different distances. RTs were shortest at and around an individually determined optical distance and rose to over 1 sec as the difference between the viewing distance and this point increased, for both far and near optical distances. The data suggest that the ability to sustain an accommodative response during a 12-sec interval varies as a function of the optical distance of the stimuli and that transient accommodative inaccuracies are sufficient to impair letter recognition.

Visual discrimination of stimuli subtending small angles on the retina requires, among other things, the availability of a well-focused, high-quality retinal image. Since image quality can depend heavily on the accuracy of visual accommodation, factors that determine accommodative accuracy can affect visual detection and discrimination. The most important stimulus parameter determining the effectiveness of an accommodative response is viewing distance. When stimulus size, intensity, and contrast are held constant, changes in viewing distances can produce significant changes in accommodative accuracy (Johnson, 1976) and, consequently, reductions in Snellen acuity (Blackwell, 1948), grating acuity (Johnson, 1976), and contrast sensitivity (Lindblad, Raymond, Leibowitz, & MacDuffee, 1984).

Recent research on accommodative function has shown that the relationship between viewing distance and accommodative accuracy is not a simple function of the optical distance between observer and stimulus (Johnson, 1976). Rather, it depends on the relative distance between the stimulus position and an observer characteristic known as the resting position of accommodation. It has been clearly established that accommodation assumes an individually characteristic resting, or tonus, position under a number of specific conditions: for example, in the absence of visual contours, when the stimulus to accommodation is degraded, or when the accommodative feedback loop is opened (Leibowitz & Owens, 1978). This position varies widely among individuals and typically corresponds to an intermediate viewing distance. Johnson (1976) found that ac-

commodation was most accurate when stimuli were viewed at a distance that corresponded to the individual's resting position. As stimulus distance relative to the resting position was increased, accommodative accuracy decreased, being biased toward the observer's resting position and thus producing the often-observed "lead" and "lag" of accommodation (Toates, 1972).

Johnson (1976) used a laser optometer to measure accommodation. This device relies on a psychophysical procedure that typically requires at least 30 sec for a single estimate. Since visual accommodation exhibits continuous fluctuations and drifts (Campbell, Robson, & Westheimer, 1959), laser optometer measurements most likely reflect an average, rather than a single, position of accommodation. The fluctuating nature of accommodation, which must produce continuous changes in retinal image quality (particularly when the pupil size is large and depth of field is consequently shallow), should thus result in fluctuations of stimulus detectability and discriminability. While the time-averaged estimates of accommodative accuracy obtained with a laser optometer may be useful in predicting visual resolution for temporally stable stimuli that are viewed until detection occurs, they may not adequately predict *momentary* accuracy of the focusing response or, therefore, the discriminability of a stimulus at a given instant in time.

Recently, Raymond, Lindblad, and Leibowitz (1984) examined the effect of accommodative fluctuations on the visibility of stimuli by asking subjects to view a high-contrast, high-spatial-frequency sine-wave grating pattern for a 1-min interval and to operate a timer whenever the grating was visible. They found that, under normal viewing conditions, detection of the grating was intermittent during the viewing interval but that when accommodation was paralyzed, stimulus detectability remained stable. Fluctuations of grating visibility were attributed, therefore, to transient losses of accommodative accuracy

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rather than to Troxler fading or contrast adaptation. Furthermore, the ability to sustain detection of the high-spatial-frequency grating was found to vary as a function of viewing distance (Raymond & Leibowitz, 1985). Sustained detection was maximal at and around the observer's resting position of accommodation and was reduced substantially as the difference between the viewing distance and the resting position increased, for both far and near optical distances. Since individual subjects had different resting positions, the position in depth at which detection could be maximally sustained also varied among observers.

The present experiment extends this work by investigating the effect of viewing distance on the detectability of temporally unpredictable visual events. Many tests of visual function (e.g., contrast sensitivity, Snellen acuity) permit the subject to view an unchanging stimulus for a relatively long period of time. Performing these tests requires only that the subject accommodate to the stimulus just long enough to permit detection or discrimination at some point in the viewing interval. Thus, fluctuations in accommodation would not substantially degrade performance. However, the rapid detection of temporally unpredictable changes in the form of a stimulus should be sensitive to accommodative fluctuations. Since adjustment of accommodation is a relatively slow process (requiring several hundred milliseconds), reaction time (RT) to detect a change in stimulus form should be substantially lengthened by the presence of temporary accommodative inaccuracies. Thus, by measuring RT to detect the transformation of one letter into another as a function of viewing distance, the presence of fluctuations in accommodation and their impact on perception can be investigated.

METHOD

Subjects

Participants were 11 undergraduate students (5 males and 6 females) ranging in age from 20 to 30 years (mean = 23.4). All subjects were naive as to the purpose of the experiment and were inexperienced at the task. All subjects had corrected or uncorrected 20/20 visual acuity. Where required, the subjects ($N=6$) wore their visual corrections during the experiment.

Apparatus

Alphanumeric stimuli were produced in the center of a green phosphor, 30.5-cm monitor (Zenith ZVM-121) with the aid of a microcomputer (Apple IIe), using high resolution graphics software. The four alphanumeric stimuli used throughout the experiment were E, 3, 2, or S. These stylized stimuli each consisted of 17 pixels. The stimulus size as it appeared to the observer corresponded to a 20/30-size Snellen letter (subtending 0.52° of visual angle in height). As illustrated in Figure 1 (Panel A), the transformation of one symbol to any other required switching the pixels used to create the vertical segments of the symbol. The computer program was written so that on all trials, the two pixels critical for the vertical segments of the symbol were simultaneously darkened and, 16 msec later, the locations necessary for the letter change were brightened. This was performed even on blank trials when the letter did not change and the disruption in the image was not detect-

Figure 1. Panel A: The four alphanumeric symbols used as stimuli. Panel B: A diagram of a sample trial. A symbol, for example, an E, appeared initially and, after several seconds, was replaced by a second symbol, for example, a 3. The subject's response that the letter had changed, as indicated by the arrow, terminated the trial.

able. The luminance of the symbols, as measured at the monitor face with a spot meter (SEI), was approximately 43.1 cd/m^2 . The luminance of the background was approximately 0.2 cd/m^2 .

The stimuli produced on the monitor were monocularly observed through a single-channel optical system (Figure 2) employing a Badal lens and a minifying lens. The Badal lens was used to permit manipulation of the accommodative stimulus distance of the symbols without altering image size (Ogle, 1968). The subject's right eye was positioned 20.0 cm anterior to the 5-diopter (D) Badal lens. The object of the Badal lens consisted of the virtual image of the symbol formed by a minifying -10-D lens positioned 20.0 cm anterior to the monitor screen. The monitor and minifying lens were mounted on a movable platform that allowed precise movement of the virtual image within the Badal optical system. A field stop (1.4 cm in diameter) was positioned 6.8 cm anterior to the Badal lens and was sufficiently close to the subject's eye so that its edges could not be easily focused. The subject's head position was stabilized with a chinrest and forehead restrainer. The room lights were extinguished during the experiment, making the ambient illumination low. Pupil diameter was not measured.

The microcomputer was programmed to control stimulus presentation times, to determine the symbol to be presented on a given trial, and to time and record the subject's RT. Timing measurement error of the device was approximately 1 msec. The subjects made their responses by depressing a button on a commercially made microcomputer game paddle (Apple).

Figure 2. A schematic of the optical system.

Procedure

At the start of each session, the observer read written instructions regarding the task, was positioned appropriately in the optical system, and was given seven practice trials, which were identical to the trials used in the experiment. All viewing was monocular (right eye); the left eye was occluded with an eye patch.

Each trial began with a short tone, which immediately preceded the onset of an alphanumeric stimulus presentation. At a randomly determined interval between 2 and 12 sec after the onset of the stimulus, a symbol change could occur (see Figure 1, Panel B). The subject was instructed to press the button as soon as a change in the symbol was detected. This buttonpress terminated the trial. If the subject failed to detect a symbol change, the trial was terminated 4 sec after the change actually occurred. There was a 2-sec rest between trials. The experimental session consisted of 10 blocks of seven trials each. Of the seven, two randomly distributed trials were blank trials (i.e., no symbol change). Each block was conducted with the monitor placed at one of five possible optical stimulus distances (0.00, 0.75, 1.50, 2.25, or 3.00 D) so that each viewing distance was tested on two blocks. The order of optical distance tested was determined randomly for each subject.

RESULTS

Mean RT to detect a symbol change for each optical stimulus distance tested was calculated for each subject. RTs as a function of optical stimulus distance for 4 typi-

cal observers are illustrated in Figure 3. For 9 of the 11 subjects tested, RT reached a clear minimum at an individually determined viewing distance and rose as the difference between the viewing distance and this point increased, for both far and near optical distances. The remaining 2 subjects showed less variation in RT with viewing distance. As can be seen in Figure 3, some subjects showed a minimum RT for close viewing distances; others did so for intermediate or far viewing distances. Furthermore, subjects varied somewhat in the steepness of the rise in RT on each side of the minimum.

The viewing distance that produced the minimum RT probably reflected the individual resting position of accommodation. As found in a previous experiment, an individual's ability to sustain detection of a grating pattern was maximal at a viewing distance corresponding to his/her resting position of accommodation (Raymond & Leibowitz, 1985). Assuming RT in the present experiment is determined by the ability to sustain resolution of the letter stimulus, the viewing distance that produced the minimum RT value should be indicative of the individual resting position of accommodation. Thus, if the effect of accommodative effort on RT is to be assessed, RT as a function of optical distance *relative* to this individual value rather than absolute optical stimulus distance must be ex-

Figure 3. Reaction time to detect the symbol change as a function of the optical distance of the stimulus. Panels A through D represent the results from 4 typical subjects. The solid squares indicate the subject's mean RT. The hatched area indicates ± 1 SD of the mean.

amined. The results from all 11 subjects were therefore averaged by normalizing for the function mathematical minimum.¹ The resulting symmetrical, U-shaped group mean curve is shown in Figure 4. The mean RT rose from a low value of 555 msec, found at the distance corresponding to the RT minima, to a high value of over 900 msec as the difference between the viewing distance and the distance corresponding to the RT minima reached 1.5 D for both farther and nearer optical distances.

A second characteristic of the data is that the variance in each subject's RT scores also changed as a function of viewing distance. Figure 5 shows the group mean standard deviation of the RT measured for each subject as a function of the optical stimulus distance relative to the distance corresponding to the RT minima. For the viewing distance that produced the lowest RT, the average standard deviation was also relatively low (127.4 msec, *SD*

Figure 4. The group mean RT plotted as a function of the optical distance relative to the optical distance corresponding to the RT minima. Positive D values indicate an optical distance closer than the optical distance corresponding to the RT minima; negative values indicate a farther optical distance. The vertical bars represent ± 1 SE, and the numbers in parentheses above each point indicate the number of subjects contributing to that point.

Figure 5. The group mean standard deviation of RT scores measured for each subject as a function of the optical distance relative to the distance corresponding to the RT minima. Positive D values indicate an optical distance closer than the distance corresponding to the RT minima; negative values indicate a farther optical distance. The vertical bars represent ± 1 SE, and the numbers in parentheses above each point indicate the number of subjects contributing to each point.

Table 1
Coefficient of Relative Variation (*SD/M*)

Subject	Relative Optical Stimulus Distance (in Diopters)							
	-3.00	-2.25	-1.50	-0.75	0.00	0.75	1.50	2.25
1			0.30	0.26	0.33	0.20	0.18	
2		0.23	0.40	0.38	0.18	0.12		
3			0.24	0.25	0.13	0.32	0.50	
4		0.82	0.46	0.90	0.19	0.58		
5				0.35	0.12	0.30	0.71	0.52
6			0.30	0.21	0.14	0.35	0.19	
7	0.55	0.42	0.42	0.58	0.41			
8		0.31	0.47	0.31	0.18	0.91		
9	0.57	0.40	0.23	0.25	0.35			
10				0.36	0.20	0.28	0.52	0.55
11			0.35	0.53	0.15	0.23	0.39	
Mean	0.56	0.44	0.35	0.40	0.22	0.37	0.42	0.54

Table 2
Number of Errors

Subject	Relative Optical Stimulus Distance (in Diopters)							
	-3.00	-2.25	-1.50	-0.75	0.00	0.75	1.50	2.25
1			0	0	0	0	0	
2		0	0	0	1	0		
3			3	0	0	0	1	
4		4	0	0	0	0		
5				0	0	1	2	1
6			7	2	0	0	5	
7	6	2	1	0	0			
8		6	4	0	2	1		
9	1	0	0	0	0			
10				0	0	0	0	0
11			3	1	0	1	0	
Mean	3.50	2.40	2.00	0.27	0.27	0.33	1.33	0.5

= 91.2). As the difference between this point and the optical distance of the stimulus increased (for both nearer and farther viewing distances), the standard deviations also increased substantially. For some subjects, the extreme viewing distances produced standard deviations as great as 800 msec and mean RT values of over 1,000 msec. Thus, on some trials a subject could detect the letter change within 500 msec and on other trials at the same viewing distance the same subject could take as long as 3 sec to perceive that the symbol had changed. These differences in RT were not significantly correlated with the time in the trial the letter change actually occurred. The correlation coefficient relating a subject's average RT and the standard deviation for that mean for all subjects and viewing distances was highly significant ($r = .72$). However, since the mean and standard deviation are usually correlated for computational reasons, the group mean coefficients of relative variation are reported in Table 1 to demonstrate that the variance in the RT values at near and far relative optical distances was greater than expected from the size of the mean RTs obtained.

Similarly, the mean number of false alarms (responding to a letter change on blank trials) and the number of failures to detect an actual letter change were minimal for optical distances producing a short mean RT and increased as the difference between the viewing distance and this point increased, for both far and near optical distances. These results are shown in Table 2.

DISCUSSION

RT to detect a change in an alphanumeric stimulus of constant size and brightness was lowest at an individually determined optical stimulus distance and rose as the difference between the viewing distance and this point increased, for both far and near optical distances. Since the symbol was relatively small, detection of its subtle transformation would require adequate visual resolution, which, in turn, would depend heavily on an appropriate accommodative response. If accommodation were inaccurate at the instant of the letter change, the time needed to react would be the sum of (1) the time during which the stimulus was unresolvable and the change, therefore, not detectable, (2) the time required for accommodative adjustments permitting resolution, and (3) the time needed to process the necessary visual, cognitive, and motor information to execute the buttonpress response. If, on the other hand, accommodation were accurate at the time of the symbol change, only the latter components (i.e., the visual, cognitive, and motor processes) would contribute to RT. Thus, RT should be minimal when accommodation is most accurate and considerably longer when an accommodative adjustment is required, since accommodation is a process requiring several hundred milliseconds.

Two aspects of the data suggest that the variation in RT with optical stimulus distance has an accommodative basis. First, individual differences in the viewing distance that produced the minimum RT were readily observable. It has been well documented that there is substantial individual variation in the resting position of accommodation (Leibowitz & Owens, 1978). Since momentary focusing on stimuli at a location corresponding to an individual's resting position should require little or no accommodative effort, it follows that sustaining focus on such stimuli for a prolonged period is similarly effortless (Raymond & Leibowitz, 1985). In the context of the present experiment, in which the letter change could occur anytime during a 10-sec interval, this suggests that mean RT should be shortest at a viewing distance corresponding to the individual resting position of accommodation, since little time would be required to adjust accommodation. The observation that a specific stimulus distance produced a distinct RT minimum for most subjects and that this viewing distance varied among subjects is consistent with this notion.

It is noteworthy that the minimum RT measured was typically around 550 msec, which is approximately 200 msec longer than would be expected for a simple RT to an easily detectable target (Egeth & Sager, 1977). This suggests that even at viewing distances that likely corresponded to the resting position of accommodation, some accommodative adjustments may have been necessary to detect the letter change. This is consistent with recent data reported by Johnson, Post, and Tsuetaki (1984). Using infrared continuous monitoring of accommodation, they found that, during a 10-sec recording interval, the resting position as measured in the dark exhibited substantial

low-frequency drifts. When high-contrast spatially wide-band stimuli were viewed at far or near distances, accommodation was well sustained. In the present experiment, the stimulus for accommodation was a letter on a computer screen (relatively narrow band) viewed under low light levels and in the absence of any sharp, high-contrast contours in the same plane as the stimulus. In general, the stimuli would be considered relatively poor for accommodation (Johnson, 1976) and hence might produce low-frequency drifts of accommodation similar to those found in the dark observed by Johnson et al. (1984). Indeed, Bour (1981) showed that when subjects viewed medium-contrast sine-wave grating patterns (also relatively poor stimuli for accommodation), accommodation to the target often drifted away from the target's optical distance during a 10-sec period. The RT data presented in Figures 3 and 4 of the present paper indirectly suggest that fluctuations in accommodation when degraded stimuli are viewed increase as the difference between the viewing distance and the resting position of accommodation increases.

The second aspect of the data that suggests an accommodative basis for the results is that the standard deviation (and the coefficient of relative variation) of the RT measure varied as a function of the optical distance of the stimulus relative to the stimulus position producing the RT minimum (i.e., the presumed "resting position") (see Figure 5). This variability can be explained in part by the continuous, low-frequency fluctuations exhibited by the accommodation system as described above (Campbell et al., 1959; Bour, 1981; Johnson et al., 1984). If such fluctuations were lower in amplitude for stimuli viewed at the resting position of accommodation, variability in RT should be lowest for stimuli at that distance because the primary source of variation would be in the cognitive and motor processes. At other viewing distances, accommodation would be expected to be in a continuous state of high-amplitude drift, especially in the somewhat degraded stimulus conditions of the experiment. On some trials, accommodation could be coincidentally accurate at the time of the letter change, producing RTs similar to those measured at the resting position, and on other trials, accommodation could be quite inappropriate, leading to RTs of several seconds. This same explanation can account for the greater number of detection errors (e.g., false alarms or misses) at distances producing long average RTs.

Two of the subjects showed little variation in either RT or standard deviation of the RT measure as a function of the accommodative stimulus distance (see Panel D of Figure 3). Moreover, the remaining subjects varied somewhat in the steepness of the U-shaped functions describing their results. One explanation is that subjects vary in their ability to sustain an accommodative response. However, a simpler explanation for these individual differences is variation in pupil size. Since this was not controlled during the experiment, subjects with smaller pupils would have had a greater depth of field and thus

would have been less hindered by accommodative inaccuracies. Thus, the effect of viewing distance on RT may depend on factors affecting pupil size, such as illumination level and age.

The findings of the present experiment indicate that the speed with which a subject responds to changes in a visual stimulus may depend on the viewing distance. While the differences in RT with stimulus distance should be small for stimuli subtending large visual angles, the effect is shown here to be substantial for smaller stimuli, which require a focused retinal image for recognition. The results suggest that the distance for optimal RT may be predictable on the basis of the subject's resting position. This indicates that viewing stimuli from a fixed viewing distance could produce markedly different RTs in different subjects. Moreover, the high variability observed at some optical distances suggests that detectability of a suprathreshold stimulus at one instant in time does not necessarily indicate detectability of the same stimulus by the same subject at a future moment.

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NOTE

1. To normalize the data, the distance corresponding to each subject's RT minimum was assigned a value of zero. Other viewing distances were given values equal to the differences between the RT minimum distances and their actual values. RT was then averaged across subjects for each relative distance value.

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