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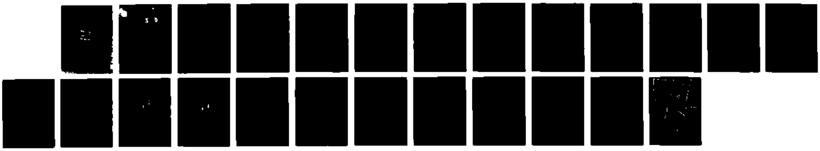

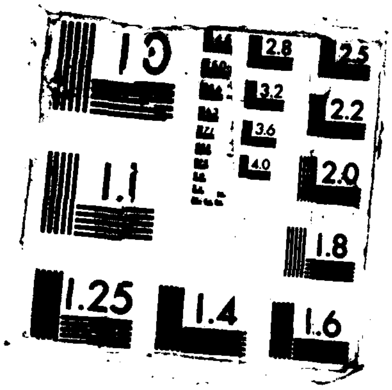
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VISUAL INPUT REQUIREMENTS RELATING TO PURSUIT TRACKING ACCURACY

Kenneth R. Bloom, BA
and
Harry Zwick, PhD

Division of Ocular Hazards

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The interaction between visual function and pursuit tracking performance was measured in 10 human volunteers who participated in three daily 1-hr sessions involving two target sizes (18 min arc & 6 min arc -- 1 min arc = 0.28 mrad), two target intensities (photopic = 25 cd/m^2, mesopic = .76 cd/m^2), and two directions of horizontal target motion. Pursuit tracking performance was measured by a computerized video digitizing system, developed at LAIR, during 20-sec tracking trials. Analysis of variance showed significant main effects for target luminance and under mesopic target conditions, target size on pursuit tracking accuracy, pointing to the need to delineate the visual requirements of visual motor tasks to assess the effects of battlefield laser exposure.

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ABSTRACT

Military tasks requiring accurate pursuit tracking performance for target acquisition and designation are vulnerable to countermeasures from exposure to moderate or intense light. Recent work has shown that various aspects of the target configuration bear directly on the interaction between light exposure and visual function. In this study, leading to an understanding of light effects on tracking performance, we have explored the interaction between visual function and pursuit tracking performance. Ten human volunteers participated in three daily 1-hour sessions involving 2 target sizes (18 min arc and 6 min arc -- 1 min arc = .28 mrad), 2 target intensities (photopic = 50 cd/m^2, mesopic = 1.58 cd/m^2), and 2 directions of horizontal target motion. Pursuit tracking performance was measured by a computerized video digitizing system, developed at LAIR, during 20 second tracking trials. Analysis of variance showed significant main effects for target size and target luminance on pursuit tracking accuracy, pointing to the need to delineate the visual requirements of visual-motor tasks to assess the effects of battlefield laser exposure.

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PREFACE

We would like to express our appreciation to Walter Golz for his invaluable assistance in design and construction of the computer programmable ramp generator and video digitizing systems which made this study possible. We also thank Jerry Molchany and SP4 Charles Barba for their help in the data analysis, and Virginia Gildengorin, PhD, for her assistance in designing the statistical evaluation of the data.

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INTRODUCTION

Survival on the modern, integrated battlefield will depend, in great measure, on the ability of the soldier to use sophisticated target detection and weapon delivery systems. Such devices place heavy demands on the capability to accurately acquire and maintain sighting on targets that will be highly mobile and difficult to see. In many cases, acquisition and tracking tasks place further stress on the visual system by involving movement of both the target and the aiming platform. For mission success, accurate tracking may be required over a significant period of time. The TOW (Tube Launched, Optically guided, Wire controlled) missile system, for example, requires the operator to visually acquire a target, most likely a moving armored vehicle, and maintain the crosshair position on a vulnerable location on the target for as long as 15-20 seconds. Other currently fielded systems such as the GLLD (Ground Laser Locator Designator) and laser rangefinders also require the ability to maintain an aiming point (i.e. the crosshairs of a telescopic sight) on a moving target. This type of military task places a premium on the ability to coordinate visual input and motor performance. The coordination involved in such aiming and tracking performance requires the skill referred to as pursuit tracking.

Precise visual-motor performance may be vulnerable to accidental or intentional exposure of troops to high-intensity light sources. Studies on the effects of temporary obscuration of a tracked object in a pursuit tracking task (1-3) have demonstrated that obscuration of targets, for as short as 2 seconds, results in significant degrees of tracking error during the periods of obscuration. Tracking accuracy, however, recovered quite rapidly, within 1 second, as soon as the target was made visible. It is unclear from these studies, however, how variation in target parameters would affect the recovery of tracking performance. These studies did not involve actual light exposure, but blanked the image of the tracking target for variable times during the periods of tracking. Exposure to sources of intense light can result in quite a different outcome, depending on the nature and intensity of the source, and the type of task being measured.

Analysis of the effects of incoherent flash exposures on tracking performance in a laboratory setting (4) has shown significant degradation in the accuracy and stability of pursuit tracking. Initial experiments employing fixed target size, contrast, and angular velocity made flash exposures over large retinal fields, greater than 15°, with durations of approximately 170 microseconds. The white light flashes were filtered at 538 nanometers (green) to be near the peak of photopic spectral sensitivity. Energy levels per pulse were below the Maximum Permissible Energy (MPE) level required by laser safety standards such as TB MED 279 (5) to be within the range of nonhazardous exposure energies. The exposures disrupted tracking performance under bright, daylight conditions, as well as under mesopic (dawn or dusk) light levels. Field studies involving actual laser exposures using a modified TOW missile launcher also demonstrated that tracking performance can be significantly degraded (6).

The studies of flash effects on pursuit tracking were not intended to assess the effects of variations in the target stimulus, other than target luminance level. When target stimulus conditions were modified in studies of the effects of laser exposure on the visual function of nonhuman primates, however, significant reductions in basic visual capability resulted from low to moderate energy level exposures.

In this laboratory we have reported substantial decrements in visual acuity following exposure to Q-switch pulsed, visible wavelength lasers (7-9). The energy levels found to produce such changes varied from that capable of producing a minimal ophthalmoscopically visible retinal burn (ED_{50}) to levels as low as two log units below the ED_{50}. Following laser exposure, increases in the amount of target contrast required for discrimination tasks have also been observed for small targets requiring better than 20/20 acuity, as well as for large targets requiring less than 20/200 acuity (Snellen notation). Recovery time to reachieve preexposure contrast thresholds following exposure to a Q-switched visible laser typically was shorter than recovery to baselines measured for high contrast visual acuity (10).

Although it is evident that exposure to both coherent and incoherent light can result in changes in basic visual function and in the accuracy of pursuit tracking, a clear explanation of the mechanisms involved in the degradation in the performance and the relationship between visual function and tracking performance is lacking. Understanding the effects of light exposure on basic visual function is a necessary step toward such an explanation, but more information on the basic visual input requirements in pursuit tracking tasks is essential. The present study represents an initial investigation into the relationship between pursuit tracking performance and visual function.

METHODS

Subjects:

Ten male soldiers and Department of Army civilian employees served as volunteers in this study. All subjects were determined to be within normal limits on ophthalmological and visual function examination.

Stimuli:

Targets consisted of projected, negative contrast 35 mm slides of 2 size rings. The center of mass within the annulus formed by the ring served as the unmarked aiming point. Two target sizes were studied: 18 and 6 min arc. These visual angles represent the inside diameter of the annuli. Target luminance was adjusted to provide photopic (daylight) and mesopic (dawn/dusk) levels. The photopic level was 50 cd/m^2, and the mesopic condition was 1.58 cd/m^2. For both luminance conditions the target/background contrast was maintained at better than 90%.

Apparatus:

Pursuit tracking performance was measured in an apparatus consisting of a large cubicle and a laser "designator." The front wall of a cubicle (approximately 3'W X 3'D X 4'H) was replaced with a viewing aperture restricting the volunteer's view of a curved white screen to the area across which the targets moved. This screen (200 cm wide by 76 cm high, placed approximately 4 meters in front of the cubicle) subtended a horizontal visual angle of approximately 30 degrees. Beneath the view restricter was the laser "designator," mounted on a viscous damped tracking head (O'Connor Fluid Head, O'Connor Eng. Lab.).

The "designator" was composed of a Helium-Neon laser mounted coaxially with a miniature CCD video camera (Mdl XC-37, Sony Corp.). The laser spot size subtended a visual angle of 2.78 min arc. Under the photopic target condition the luminance of the laser spot was 150 cd/m^2, while for the mesopic trials the laser was adjusted to 47.4 cd/m^2. A single arm with a handle projected from the tracking head into the volunteer's cubicle, serving as the means to control the horizontal position of the laser pointer. Horizontal target movement, left to right and right to left, at an angular velocity of 1 degree/sec was controlled by a mirror galvanometer driven by a computer programmable ramp generator. The position of the target in the field of view of the 100-mm lens mounted on the camera was determined by a microcomputer controlled video digitizing circuit. Target position was sampled at a rate of 21 Hz, with a resolution of .42 min arc. Software was written to control the experimental procedure, and provide on-line determination of the aiming position and on/off-target status of each sample, as well as analysis of tracking accuracy and variability.

Procedure:

The study was conducted over a three day period, beginning with two training sessions and concluding with the test session. Each approximately 1-hour session consisted of forty 20-second trials, 10 in each of 2 target luminance and 2 target motion direction conditions.

The volunteers were required to acquire the target by placing the laser spot on the center of mass of the target. A few volunteers mentioned, following the study, that they had had difficulty under the mesopic condition due to the relative brightness of the laser to the target. Their perception was that they had to move their aiming position more just to get a clearer view of the target. Post hoc tests with the laser reduced by an additional 0.5 OD revealed results similar to those in the main study. When the position sample was determined to be within the predetermined on-target window, a background masking noise was turned off to indicate an on-target aiming position. At the end of 1 second the noise resumed and the target began the horizontal movement. Volunteers were instructed to maintain the laser spot as close as possible to the center of mass position for the entire 20-second trial. Percent time-on-target scores were provided to the volunteers following each tracking trial, providing a means for the subject to judge his performance criterion. Target size, luminance and tracking direction were presented in a counterbalanced order, across subjects and sessions. A 5-minute adaptation period was provided in the transition between target luminance conditions.

Statistical Design and Analysis:

Digitized time-sampled data from 5 seconds after the start of the trial to 15 seconds from the time of acquisition were used in the analysis to eliminate error due to inaccuracies in initial acquisition of the target. Mean absolute aiming error, standard deviation of the horizontal error, mean absolute root mean square error (RMS), maximum absolute error and percent time-on-target were analyzed with separate analyses of variance (ANOVA), performed with the BMDP-2PV program for multifactorial mixed designs (11), assuming a fixed effects model with repeated measures for the three factors (target size, target luminance level and tracking direction). The dependent variables were selected in order to evaluate the influence of target size and luminance condition on the ability to maintain a center of mass aiming point (mean aiming error, maximum aiming error, and percent time-on-target). Mean standard deviation of the horizontal tracking error and mean absolute RMS tracking error were determined to provide an indication of the variability of aiming position about the mean aiming point and about the actual target center. Separate paired t-tests were performed to evaluate the mean differences for target size/luminance level conditions, for the dependent variables which reach significance in the ANOVAs. A probability of less than 0.05 was required for determination of statistical significance.

RESULTS

Target Luminance Effects:

Tracking accuracy and variability within each target size was determined as a function of luminance condition. The ANOVA revealed significant main effects for luminance level for all 5 measures of performance. Analysis of the results from individual t-tests (summarized in Table I) indicates significant elevations in both mean absolute aiming error and in the variability of the horizontal aiming error. The mean absolute horizontal aiming error shown in Figure 1 and the standard deviation of the horizontal aiming error in Figure 2 are representative of the trends in the remaining measures of performance. The average absolute aiming error (disregarding whether the error is a lead or lag error) is significantly lower for the photopic target luminance for both the 18 min arc and the 6 min arc targets.

The variability of the aiming error, without regard to the magnitude of error from the target center, is represented by the standard deviation of the horizontal error in Figure 2. As with the mean aiming error, tracking the photopic target produces a smaller variability than tracking the mesopic target for both target sizes. RMS error, which is a measure of the variability of the aiming error in relation to the actual target center, was greater than the standard deviation error, but results were in the same direction.

The maximum aiming error was also significantly larger for both size targets under the mesopic light level. The ability to maintain the aiming point on-target was reduced significantly under the mesopic condition only for the small target. No significant difference in the percent time-on-target between the two target luminance levels was evident for the large tracking target.

Effects of direction of target motion were found to be significant only during the early phases of training, with no differences found in the test session. All data presented in this paper represent tracking performance of the fully-trained volunteers during the third session.

Target Size Effects:

The effect of variation in target size within a target luminance level is summarized in Table II for mean aiming error and standard deviation of the horizontal tracking error. Tracking under mesopic target luminance levels results in significantly poorer performance for the 6 min arc target. This *significant* difference between the larger and smaller mesopic targets was also present across the other (RMS error, maximum error, and percent time-on-target) performance measures. Under the photopic conditions, a similar trend (i.e. tracking accuracy improves with increased target size) is evident across all measures; however, only the percent time-on-target reveals a statistically significant superiority for tracking the large target.

Luminance X Size Interaction:

Although tracking accuracy and stability improved significantly with increased target size within each target luminance level, the results of the ANOVA revealed a target size/luminance level interaction. Individual t-tests indicated that the advantage of target size is overshadowed by the influence of target luminance. As presented in Figures 1 and 2, within the photopic and mesopic conditions, the 18 min arc target provided more accurate and stable tracking than the 6 min arc target. However, tracking was better for the smaller photopic target than the larger mesopic target. All measures of tracking performance, except maximum aiming error,

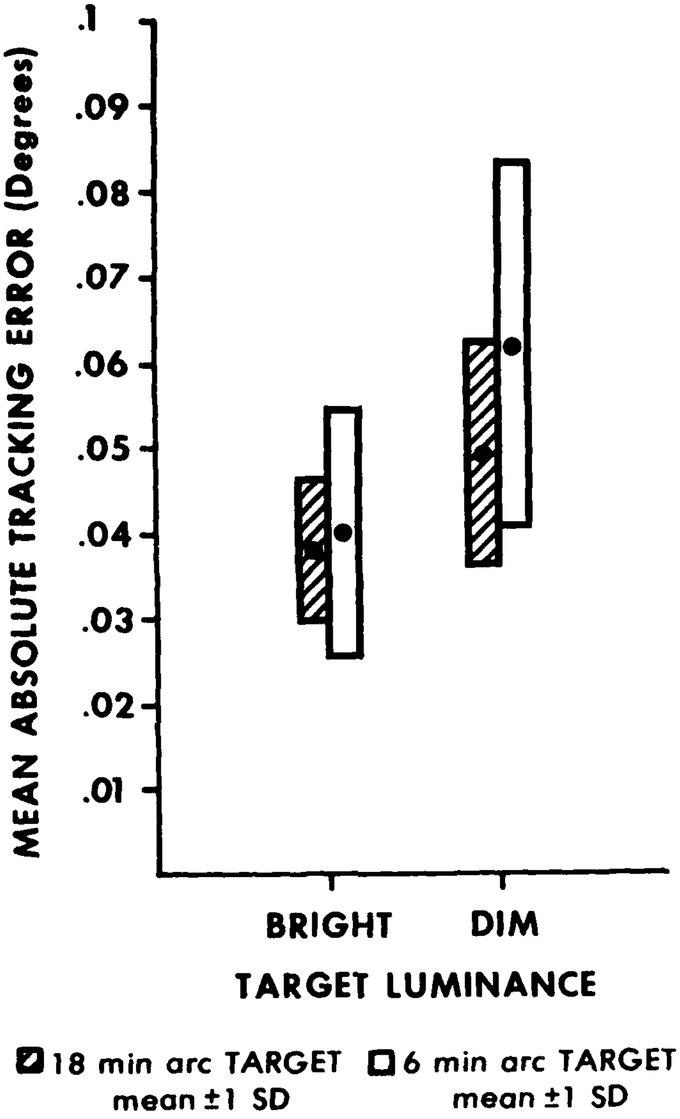

Figure 1. *The aiming position relative to the calibrated target center was calculated at a rate of 21 Hz for the 5- to 15-second period of each trial. Significant differences appeared within each target size, across target luminance level. Under bright target conditions, mean aiming error was not significantly different for the two target sizes, whereas tracking the small target under the mesopic condition resulted in significantly larger average aiming errors than for the larger mesopic target.*

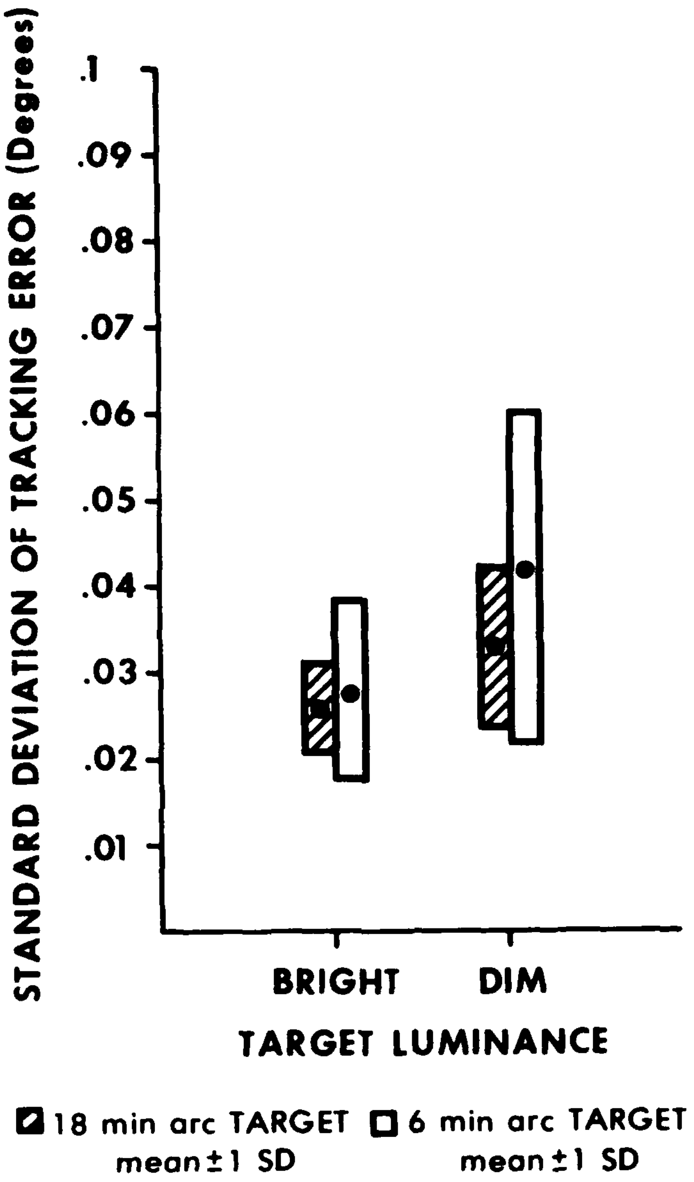

Figure 2. *The standard deviation of the horizontal aiming error indicates the stability with which the aiming point can be maintained; however, it does not indicate the variability of the aiming position in relation to the actual center of the target. This measure indicated significant differences between target sizes as a function of target luminance, as well as target luminance differences within a given target size. The interaction between target luminance and target size can be noted in the lower variability of the small photopic target in comparison to that of the large, mesopic target.*

TABLE I

Summary of paired t-tests for light level mean differences for mean aiming error and standard deviation of horizontal aiming error

	Photopic		Mesopic				
	Mean	SD	Mean	SD	df	t-value	Prob
			Mean Aiming Error				
18 min	.038	5.94^{-5}	.049	1.69^{-4}	9	3.59	<.05
6 min	.040	1.84^{-4}	.060	2.05^{-4}	9	7.53	<.05
			Standard Deviation of Horizontal Aiming Error				
18 min	.026	2.44^{-5}	.033	7.66^{-5}	9	3.84	<.05
6 min	.028	1.08^{-4}	.039	1.71^{-4}	9	4.68	<.05

TABLE II

Summary of paired t-tests for target size mean differences for mean aiming error and standard deviation of horizontal aiming error

	18 min arc		6 min arc				
	Mean	SD	Mean	SD	df	t-value	Prob
			Mean Aiming Error				
Photopic	.038	5.94^{-5}	.040	1.84^{-4}	9	.56	NS
Mesopic	.049	1.69^{-4}	.060	2.05^{-4}	9	3.04	<.05
			Standard Deviation of Horizontal Aiming Error				
Photopic	.026	2.44^{-5}	.028	1.07^{-4}	9	.43	NS
Mesopic	.033	7.66^{-4}	.039	1.71^{-4}	9	2.82	<.05

revealed this dominance of target luminance over target size.

DISCUSSION

A basic component in the pursuit tracking task is the ability of the subject to resolve the magnitude and direction of error. The visual mechanism for such error detection is that of visual acuity (12). Visual acuity for moving targets, termed Dynamic Visual Acuity (DVA), decreases with increasing target velocity (13,14). Ludvigh and Miller (13) described the degraded acuity as the inability to accurately match eye movements with the target motion, resulting in the smearing of the retinal image, producing a reduction in the effective target contrast. Gilson et al (15) demonstrated a tracking performance decrement, as measured by time-on-target, due to retinal smearing, caused by nystagmus-induced image movement across the retina. Such results are consistent with the findings in the present study, suggesting that dynamic acuity is a major factor in pursuit tracking accuracy. Within a target luminance condition, across all measures of performance, tracking is enhanced with the larger (18 min arc) target. Similar findings have been seen in other studies (16-18) looking at time-on-target accuracy. It is not surprising that performance as measured by percent time-on-target would be better for larger targets because any decrement in dynamic visual acuity would be less disruptive with a large target area.

Our results are in line with the concept of tracking relying on an underlying acuity mechanism based on dynamic visual acuity processes. The importance of target luminance, a basic factor in acuity, has been established both in studies of DVA (19) and tracking (18,20,21) where increases in target brightness resulted in enhanced visual acuity and maximal tracking proficiency. Data from the present study also demonstrated consistently better tracking performance under a photopic target luminance condition. Such increases in target brightness would provide an elevation in the effective target contrast, thus ameliorating some of the negative effects of contrast reduction due to target motion on the retina.

The majority of the tracking studies examining the roles of target size and intensity have used percent time-on-target as the measure of proficiency. The importance of dynamic visual acuity is easily seen with such a measure, where spatial separation between two points is being analyzed and where merely an on/off-target visual determination is required. If one looks at another index of tracking performance, i.e. variability of aiming position, the role of acuity is less clear.

A somewhat paradoxical improvement in the stability of pursuit tracking when there is a less well-defined aiming point, as occurs when we increase the target size, points to the need for an additional explanation of the mechanisms underlying tracking performance. Standard deviation of the horizontal aiming error and mean absolute RMS error both show that tracking the 18 min arc target results in lower error rates than tracking the 6 min arc target. The target size differences are similar in direction under both luminance conditions, but reach significance only with the mesopic targets. We had expected that, because the large target provided an ill-defined central aiming point, critical aiming would be more difficult than aiming at the small target where the relationship between the laser aiming spot and the center of the ring defined a very critical aiming point.

An explanation for this target-size dependent effect may rest on the concept, espoused by Green (16), of multidimensional mechanisms underlying pursuit tracking. Acquiring a target and staying on target may require quite different visual-motor processes. Getting on target may rely more on acuity mechanisms, where determination and correction of spatial differences/errors are paramount. Staying on target, however, may rely on a purer "tracking" response where error correction is secondary to anticipation of target course and prevention of error. While both elements are undoubtedly present regardless of target size, the relative contribution of each may explain many target size effects.

Variation in target size may elicit not only a distinction between "tracking" versus acuity mechanisms, but also differences between acuity mechanisms. It is possible that the acuity mechanism underlying the "tracking" response for larger targets may be a hyperacuity or vernier process. Measures of vernier acuity have yielded resolution thresholds on the order of seconds of arc, finer than the visual angle subtended by a single foveal cone photoreceptor. Pursuit tracking of different size targets appears to stimulate functionally different resolution processes, with center of mass tracking, required with large targets and ill-defined aiming points, inducing the finer resolution of vernier acuity.

CONCLUSIONS

We have shown that human pursuit tracking performance is related to conditions that affect visual resolution processes for moving targets. On-target tracking is better under brighter target conditions, as is visual acuity, and with larger targets, as is contrast sensitivity.

Somewhat paradoxical, however, is our finding that the variability in aiming position is also better for larger targets. If, however, target acquisition and maintenance of aiming point rely on more than one mechanism, the advantage of the larger target in terms of both time-on-target and variability of aiming position may be understandable. Acquisition, depending on determination and correction of errors resolved as spatial differences, may be most sensitive to dynamic visual acuity mechanisms. However, when the subject is actually attempting to maintain the spot of laser light in the center of the large test target, continuous estimates of center of mass may be better mediated by vernier acuity processes that may in part provide for Green's "tracking" mechanism. The lower variability in tracking error with larger targets indeed suggests that tracking variability is mediated via vernier acuity mechanisms optimized for larger vs smaller targets.

In summary, an analysis of the relationship between properties of visual stimuli and tracking proficiency may provide an understanding of the mechanisms leading to degradation of tracking performance following exposure to intense light.

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