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ASSESSMENT AND DEVELOPMENT OF OCULOMOTOR FLYING SKILLS
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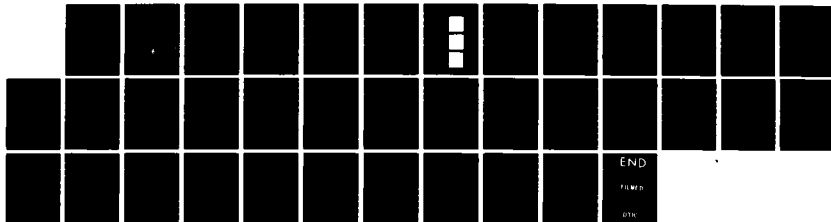
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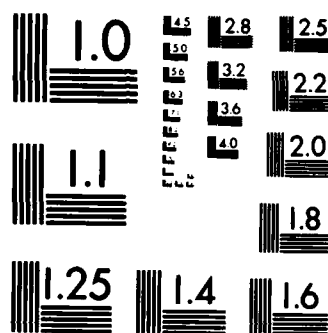
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ASSESSMENT AND DEVELOPMENT OF OCULOMOTOR FLYING SKILLS
BY THE APPLICATION OF THE CHANNEL THEORY OF VISION

FINAL REPORT - NOVEMBER 1983

BY D. REGAN

PREPARED FOR:

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
BOLLING AIR FORCE BASE, D.C. 20332

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) → Some camouflaged objects that cannot be seen when stationary are visible when moving. When visible, these objects are defined by motion contrast. In central vision, spatial receptive field area is 5 times larger and temporal integration time is 12 times longer for such objects than for objects defined by brightness contrast. Both object detection threshold and motion threshold vary logarithmically with eccentricity, the effect of eccentricity being less for larger targets. In contrast to the 100:1 increase in spatial summation area between 0° and 16° eccentricity, temporal summation changes by only 40%. (over)			

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> Visual sensitivity to boundaries defined by chromatic contrast alone falls when the retinal image is stabilized. Temporal modulation is essential for boundary visibility, but these changes can be either whole-field flicker or motion of the whole field. (But,

Form detection involves channels tuned to narrow ranges of spatial frequency and orientations. On the other hand, at the discrimination stage, ~~we find that~~ orientation information is freely available across spatial frequencies and spatial frequency information is freely available across orientations. Airborne and laboratory tests of vision correlated with low-level bombing accuracy and with success in air-to-air combat using telemetry-tracked A4 and F-14 jet aircraft. Either motion sensitivity or aspect recognition could explain pilots' ability to judge an adversary's change of heading.

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2a. OBJECTIVES

(1) Define the properties of visual channels that are likely to be important in aviation.

(2) Define the visual display features of a flight simulator that contribute to good transfer of training by stimulating the visual channels used in real flying.

(3) Find how visual channels for form, depth and motion operate when the eyes are moving and when the angle of convergence of the eyes is changing.

(4) Find the effect of eye movements upon visual judgments of the direction of self-motion.

(5) In particular, define how motion parallax distinguishes figure from ground.

(6) By using radar-tracked aircraft, find whether the correlations between flying performance and visual test results found using the ASPT flight simulator apply to aircraft performance.

(7) Design new tests for (a) selecting student pilots and (b) monitoring the visual abilities of experienced pilots so as to aid in-service retraining programs for maintaining an adequate level of performance. These tests will measure the sensitivities of the information-processing channels already identified in Objective #1 as likely to be important in practical flying.

(8) By following the progress of student pilots, identify visual tests that predict which student pilots who, having passed conventional visual tests, nevertheless will fail to acquire flying skills.

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Chief, Technical Information Division

2b. STATUS OF THE RESEARCH EFFORT

Spatial vision: extraction of figure from ground by motion

It is well known that some objects that cannot be seen in the absence of motion become visible when there is relative motion between the object and its background. A practical example is that grassy hillocks and ridges that cannot be seen from a hovering helicopter can become clearly visible when the helicopter is moving.

Figure 1 illustrates a laboratory version of such a target. These are photographs of a dot pattern on a CRT. A contains a camouflaged rectangle. In B and C the dots within this rectangle move and the rectangle becomes visible (the moving dots appear as streaks in the two exposures). The boundaries or edges of the rectangle are made visible (i.e. the camouflage is broken) by motion: in the absence of motion the rectangle is invisible. Compare this with a conventional target. A conventional target's boundaries are brightness steps. Clearly, these are two quite different types of object. One is defined by motion steps, the other by brightness steps.

We, and others, have previously explored target visibility produced by abruptly displacing part of a dot pattern (Regan & Spekreijse, 1970; Julesz, 1971; Braddick, 1974; Baker & Braddick, 1981). Providing that the abrupt displacement does not exceed about 20 min arc and take longer than 100 msec, the "short range" process operates so that the target's camouflage is broken and it becomes visible. However, these previous studies did not use continuous motion, and thus confounded the effects of dot displacement and stimulus duration. Our present study uses continuous velocity and explores the effect of velocity on target visibility, looking at temporal and spatial summation in fovea and periphery (Regan & Beverley, submitted).

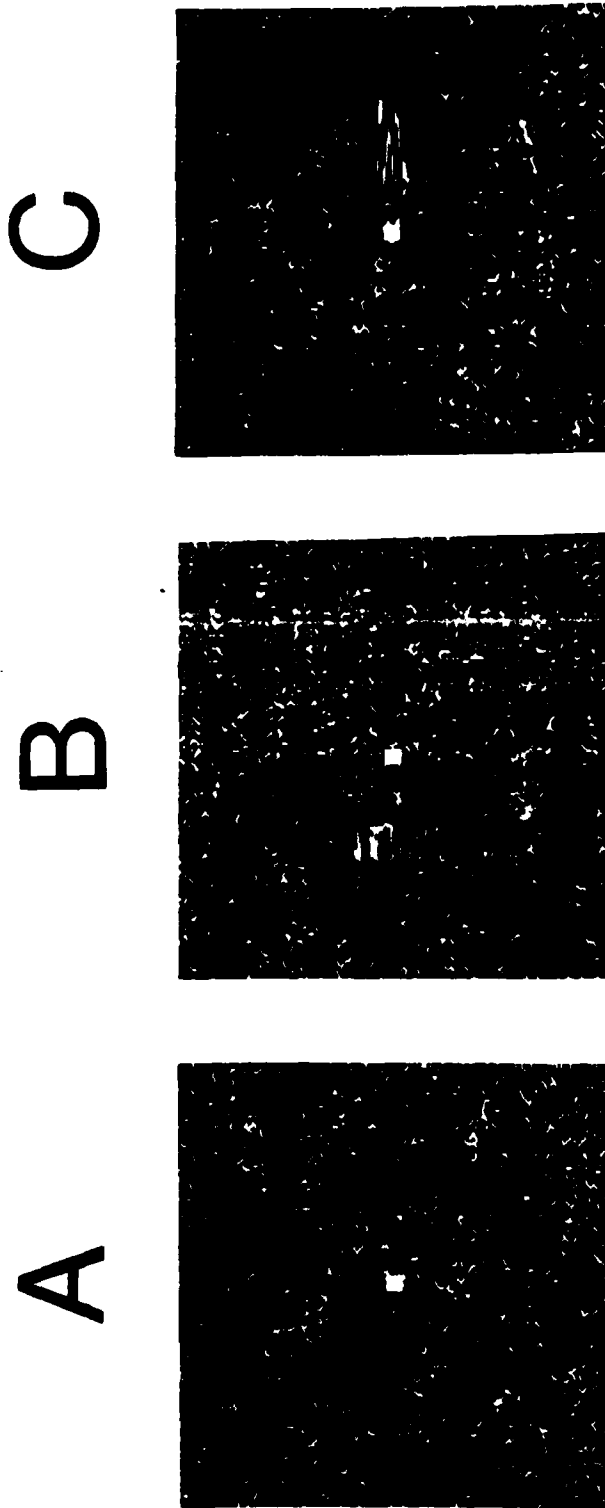


Figure 1 - Camouflaged target stimulus. A - The rectangular target is invisible in the absence of relative motion. B and C - The rectangular target's boundaries are defined by relative motion.

Figures 2 and 3 compare target parafoveal detection thresholds for: (a) a dot target whose edges are defined by motion contrast, and (b) a conventional target whose edges are defined by luminance contrast. Figure 2 shows how target detection thresholds depend on stimulus area. The lines are theoretical fits assuming that receptive fields have gaussian sensitivity profiles. Receptive field area is about 5 times larger for targets whose boundaries are defined by motion contrast, the areas for camouflaged targets being about 0.16 deg^2 in the parafovea.

Figure 3 shows how target detection threshold depends on presentation duration. The line in Figure 3B is a theoretical fit assuming a single stage exponential integration process. The time constant is 60 msec, consistent with classical data. The theoretical curve fitting the new data in Figure 3A assumes a two-stage exponential integration process. The first stage has the same time constant as the luminance integration stage of Figure 3B. The second stage has a time constant of 750 msec. Thus, temporal integration extends over about 12 times longer duration for a target whose edges are defined by motion contrast than for a target whose edges are defined by luminance contrast.

Figure 4 shows how target detection threshold is affected by blur for a dot target whose boundaries are defined by motion contrast. Motion thresholds are also shown on this figure. Ordinates plot thresholds, and abscissae plot the powers of lenses placed before the eye. Zero on the abscissa corresponds to a sharply focussed foveal image. Figure 4 shows that visual sensitivity was best for a sharply accommodated target, and that sensitivity fell off as blur increased. This finding held at all eccentricities tested (0 deg, 4 deg, 8 deg, 16 deg, 24 deg). In all subsequent measurements it was ensured that the eye was correctly refracted at each eccentricity tested.

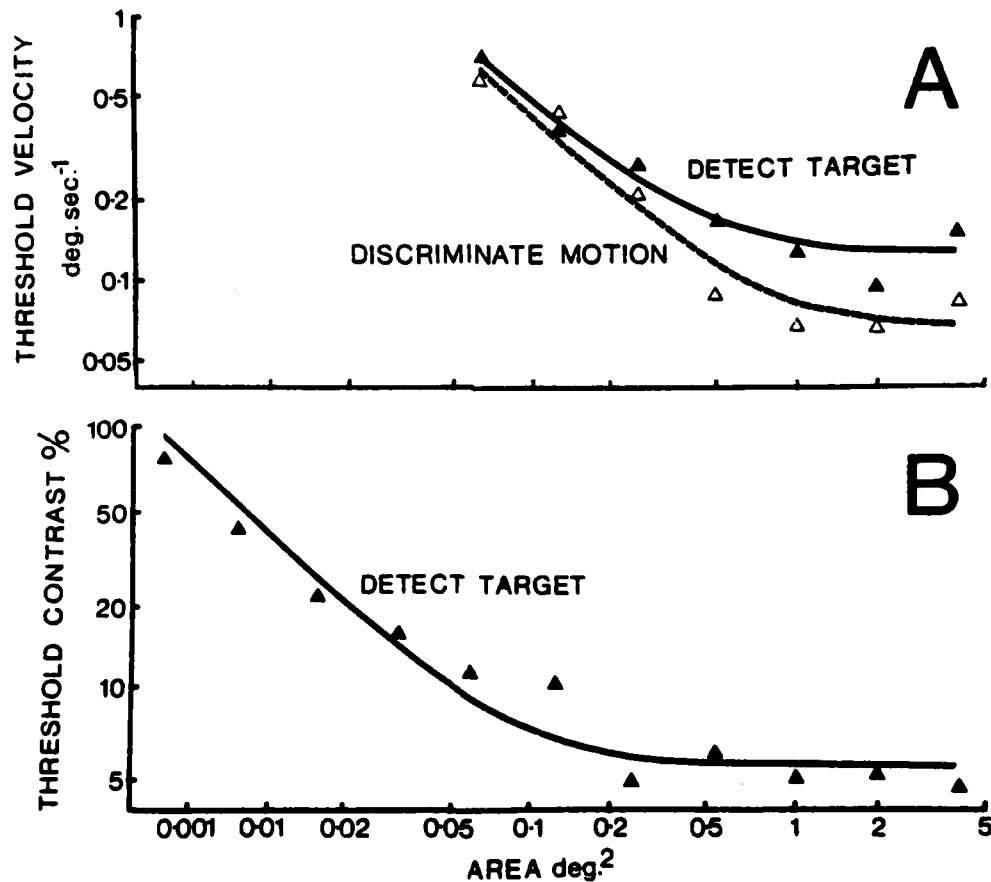


Figure 2 - Effects of target area. A is for camouflaged targets whose boundaries were defined by relative motion, and B is for conventional targets whose boundaries were defined by luminance contrast. The curves in A and B are theoretical fits assuming a gaussian sensitivity profile for summation fields. Spatial summation area is about 5 times larger for targets defined by relative motion (A) than for targets defined by luminance contrast (B). Targets were square and presented for 150 msec.

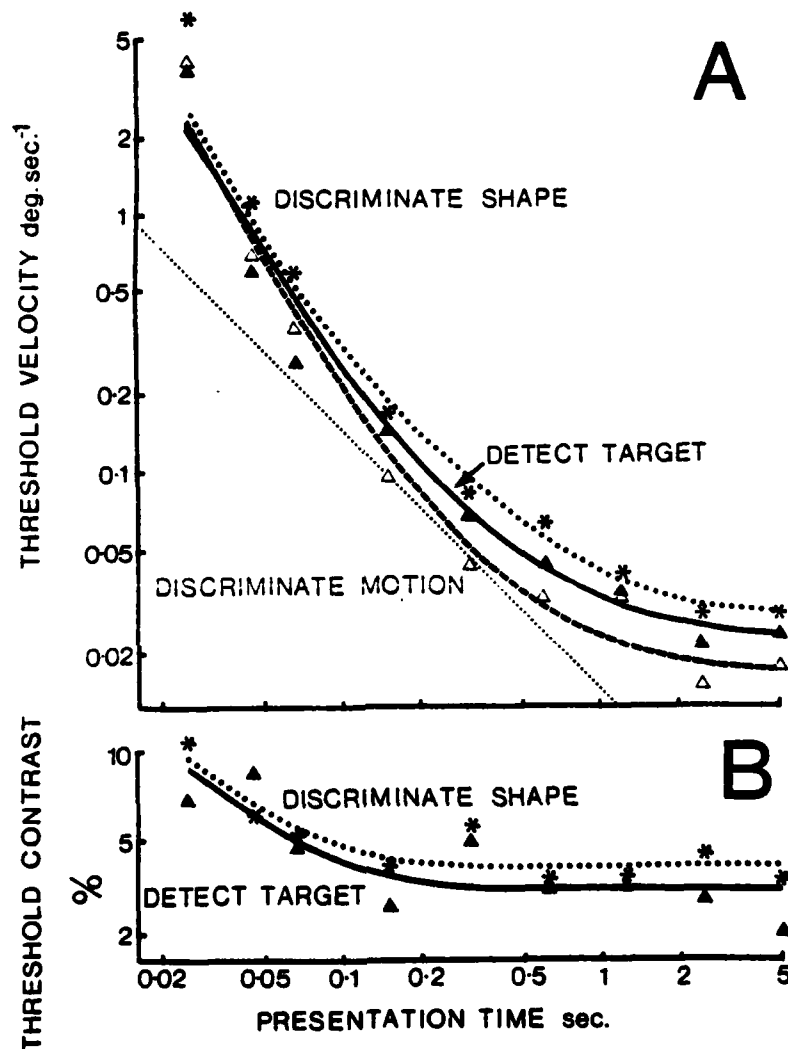


Figure 3 - Effect of presentation duration. A is for camouflaged targets whose boundaries were defined by relative motion, and B is for conventional targets whose boundaries were defined by luminance contrast. The dotted line in A plots a constant-displacement law, displacement being 1 min arc. The curves in B are theoretical fits assuming a single integration time constant τ_1 . The theoretical curves in A assume a two-stage temporal integration, the same time constant τ_1 being followed by a time constant τ_2 over 12 times larger. The rectangular targets were of constant shape ($K = 2.8$) and 1 deg² area.

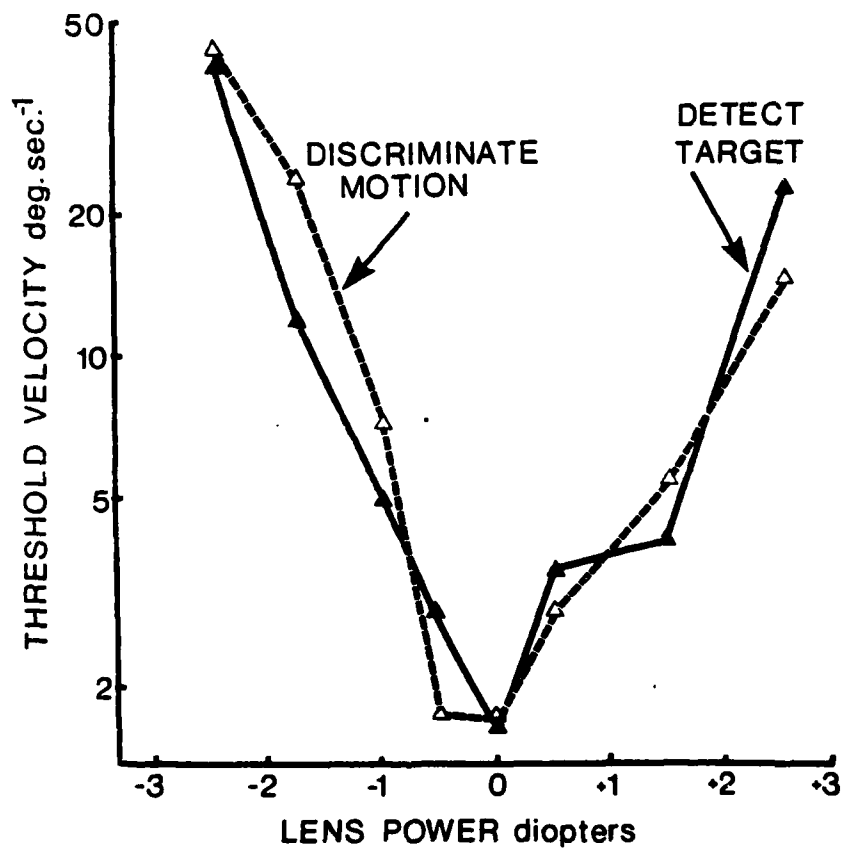


Figure 4 - Refractive error elevates thresholds for camouflaged dot targets. Data shown are for 16 deg eccentricity. Zero lens power means correct refraction for foveal vision. Target area was 1 deg² and presentation duration was 150 msec.

Figure 5 shows how thresholds varied as a function of eccentricity for different target areas. Log threshold was linearly proportional to eccentricity between 0 deg and 32 deg eccentricity at least. The slope of the plot depended on target area, sensitivity to larger targets being less affected by eccentricity. Receptive field sizes were estimated from the Figure 5 data. First the data were replotted as threshold versus stimulus area for different eccentricities. In fitting the theoretical curves in Figure 6 we assumed that the receptive fields for target detection had gaussian sensitivity profiles. The data points fit this assumption fairly well. Summation field diameters calculated on this basis are plotted in Figure 7. Field size for target detection is roughly linear with eccentricity on log-linear paper. Field size for motion discrimination is roughly constant at 1 deg - 2 deg over a broad range of eccentricities between 3 deg and 24 deg. This is very different from the situation for acuity where field size scales linearly with eccentricity.

Spatial vision where boundaries are defined by hue differences

The boundary of an object may be defined by luminance contrast alone or by motion contrast alone as in the study reported above. It may also be defined by chromatic contrast alone. It is known that boundaries defined by chromatic contrast can disappear when the retinal image is stabilized by voluntary fixation (McCree, 1960a,b) or by using stabilization apparatus (Clowes, 1962). Thus, temporal changes are necessary for such boundaries to be visible. In a joint study carried out at Dalhousie University, Dr. C. A. Burbeck and I investigated what temporal changes are adequate to restore boundary visibility.

The stimulus was a 2 deg x 2 deg area divided vertically into two halves. The left side was set at some reference wavelength. The 2 deg x 2 deg area was surrounded by an unstabilized dotted region to assist accommodation and

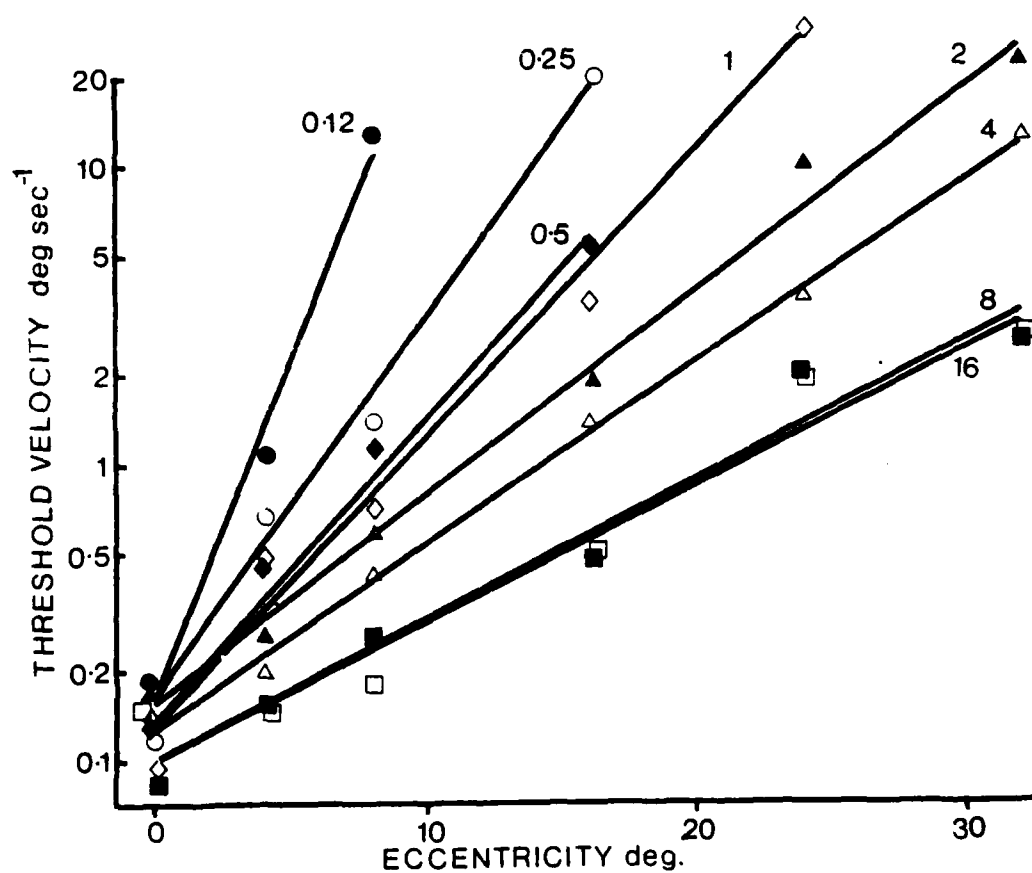


Figure 5 - Log detection threshold for camouflaged dot targets is proportional to eccentricity. The effect of eccentricity is less for larger targets.

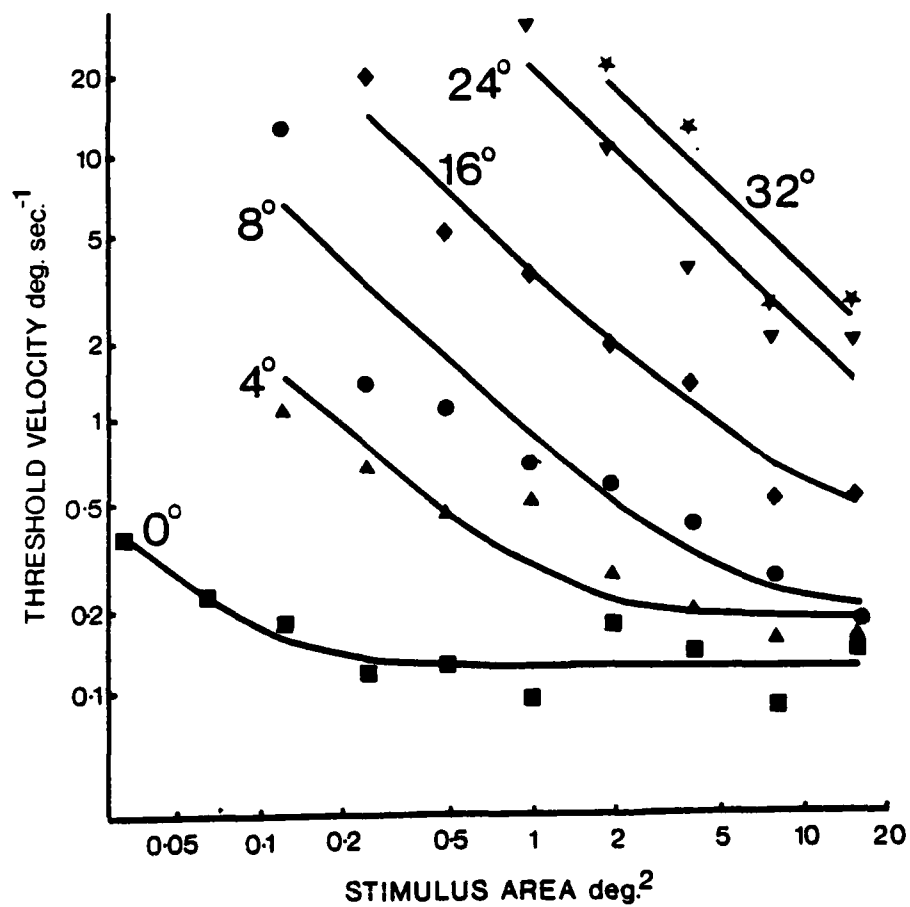


Figure 6 - Spatial summation for camouflaged dot targets can be modelled with a gaussian receptive field profile. The theoretical curves have been fitted to the target detection thresholds of Figure 5.

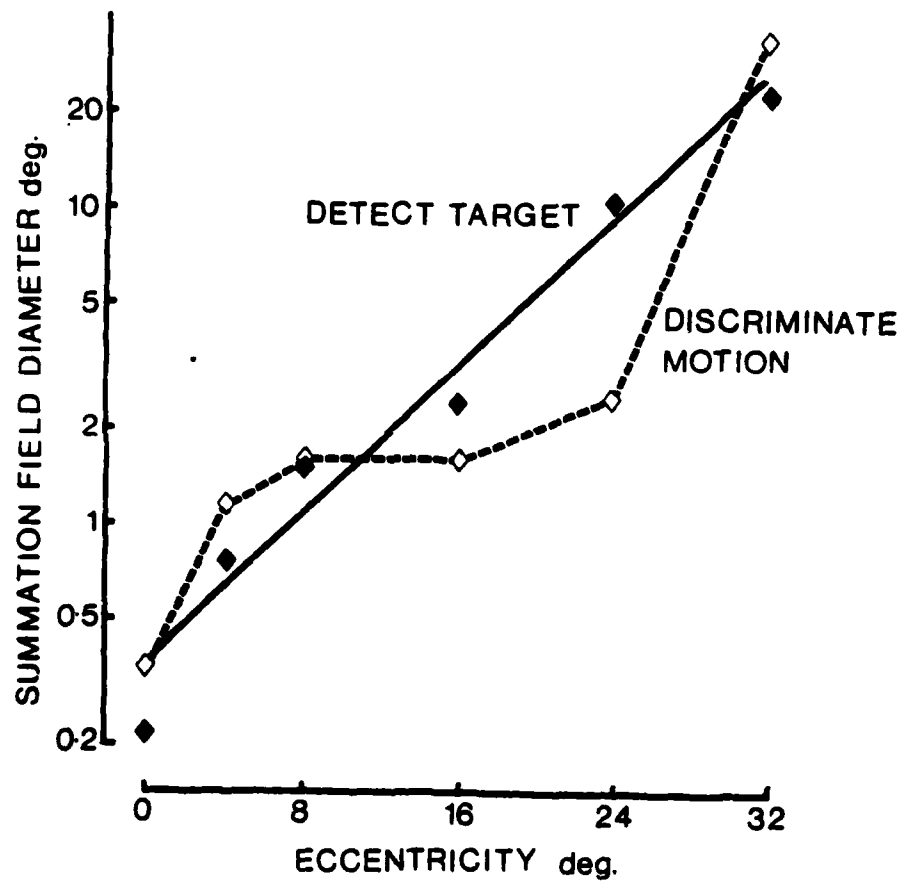


Figure 7 - Summation field diameters obtained from Figure 6 plotted versus eccentricity for the detection of camouflaged targets (continuous line) and for motion discrimination (broken line).

fixation. The target was viewed through an SRI image deflector mounted on a double Purkinje eye tracker. The image was stabilized, then the subject altered the wavelength difference between the two halves of the field, adjusting the luminance of the variable half-field so that a luminance match was maintained between the two halves of the field. The subject then set the wavelength difference between the two halves of the field for which a boundary was just visible. Figure 8 shows that the effect of stabilization on boundary visibility was least in the yellow part of the spectrum, but in the blue and red a much greater wavelength difference was required to create a visible edge after stabilization than before stabilization.

Several different types of temporal modulation were then introduced. First the luminance of the whole target was flickered at 0.5 Hz and 25% modulation depth. This almost completely restored visual sensitivity to the boundary. Next the luminance of the target was left constant and the whole target was oscillated on the retina either with a 0.5 Hz, sinusoidal waveform of ± 0.3 deg amplitude or with a noise waveform. Again, this almost completely restored sensitivity to the boundary. Finally, the outer edges of the target were left stabilized while the vertical central boundary was oscillated from side to side at 0.5 Hz. This modulation substantially restored boundary visibility also.

We conclude that visual sensitivity to boundaries defined by chromatic contrast alone is much reduced when temporal changes are removed, except when the two wavelengths are on opposite sides of yellow. Visual sensitivity can be substantially restored by several different kinds of temporal modulation including luminance flicker and image motion. We suggest that luminance flicker may restore boundary visibility by disturbing the equality between the

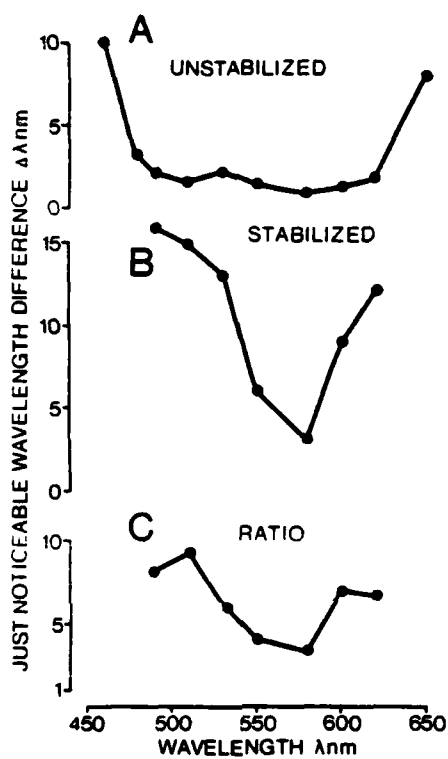


Figure 8 - Wavelength difference across boundary required to just see boundary in normal vision (A) and stabilized vision (B). C plots ratio between A and B curves, showing that visibility of boundary is least affected in the yellow part of the spectrum.

stimulus luminance and the local level of retinal adaptation. This suggestion is based on the idea that image fading occurs because the local state of adaptation rises until it cancels the effect of the stimulus (Wright, 1957; Burbeck & Kelly, 1982). In everyday vision, eye movements maintain boundary visibility. In this natural situation retinal image movements are correlated with eye movements. Our results indicate that a correlation between retinal image motion and eye motion is not necessary for the maintenance of boundary visibility.

"Channeling" concepts

Basic idea:- At the detection stage the brain splits up visual information into separate packages by means of functional subunits. For example, there are subunits for motion in depth, position in depth, frontal plane motion and spatial frequency. A later stage in the brain responds to the relative activities of different subunits - this explains very acute visual discriminations, e.g. between slightly different colors or slightly differently-sized objects.

Implications:- (a) Specific tests of specific subunits may predict practical performance in different tasks. For example, visual tracking of changing-size stimuli predicts low-level flying performance in real aircraft (Kruk & Regan, 1983; Kruk, Regan, Beverley & Longridge, 1981, 1983). (b) Losing a particular functional unit causes a predictable and specific visual loss.

These several ideas are not new. I have recently reviewed the concept of channeling as it applies to vision as a whole (Regan, 1982).

Independence of orientation and spatial frequency

The basis of the "channeling" approach is the idea that the visual system

processes some visual dimensions approximately independently. (Note that these psychophysically-independent dimensions need not necessarily be physically independent.) In an experimental study (Burbeck & Regan, 1983, in press), Dr. C. A. Burbeck and I applied this idea to the processing of spatial form.

It is widely accepted that the human visual system analyzes spatial form information by means of subunits (channels), each of which is sensitive to a restricted range of spatial frequencies and orientations. Many studies have attempted to find whether different spatial frequencies are processed independently, while others have attempted to find whether different orientations are processed independently. However, a fundamental question has not been addressed. Do orientation and spatial frequency constitute independent psychophysical dimensions?

Using equipment developed at Dalhousie University, we measured spatial frequency discrimination between gratings that were aligned (a) parallel and (b) at right angles. Figure 8 shows that spatial frequency discrimination was the same in cases (a) and (b). This held for gratings of spatial frequencies 2, 5 and 12 cycles/deg. We also measured orientation discrimination between vertical gratings that were (c) of the same spatial frequencies, and (d) of very different spatial frequencies. We found that orientation discrimination (75% correct) was the same (0.3-0.5 deg) in cases (c) and (d). This result held for gratings of 5 vs 5, 2 vs 2 and 5 vs 2; 5 vs 5, 8 vs 8 and 5 vs 8 cycles/deg.

We concluded that, at the discrimination stage, spatial frequency information is freely available across orientations, and orientation information is freely available across spatial frequencies. Orientation and spatial frequency constitute independent dimensions at the discrimination

stage. The situation seems to be quite different at the discrimination and detection stages, since at the detection stage spatial form information is packaged into many restricted cells in the spatial frequency-orientation plane.

Correlation between visual test results and flying performance in telemetry-tracked aircraft

This study at Yuma has now been completed. It was partially described in the Final Report for Grant AFOSR 78-3711.

Table 1 shows correlations between flying performance and the results of both laboratory and airborne visual tests. Flying performance was measured in air-to-air combat between A4 and F-14 aircraft. Laboratory visual tests comprised a manual tracking task of frontal plane motion (T11), a manual tracking task of motion in depth (TA1), and a suprathreshold velocity discrimination task in which subjects viewed a radially-expanding flow pattern and were required to judge which of two rates of flow was the faster (FF). The airborne visual tests were carried out between two A4 aircraft flying towards each other from a range of about 25 miles. One was designated as attacker. In order to record visual acquisition distance the attacking aircraft was instructed to fire a simulated missile on first sighting the target aircraft. The target was instructed to turn sharply to left or right immediately on hearing the audible firing tone from the attacker aircraft. This turn was typically about 70 deg bank and 3G acceleration. The attacker was further instructed to call the direction immediately on being able to discriminate the direction of the target's turn. The attacker's ability to detect the direction of the target's turn was measured in two ways: first as the angular displacement of the target aircraft between the start of the target's turn and the attacker's correct call, and second as the distance between aircraft at the

Table 1

Correlations Between	Non-smoking aircraft (N=6)		Smoking aircraft (N=8)	
	r	p	r	p
<u>Acquisition range</u>				
kills/engagement	0.80	0.03	0.69	0.01
died/engagement	-0.85	0.02	NS	-
win/loss ratio	-0.74	0.05	NS	-
direction detect range	0.79	0.03	0.96	0.001
flow pattern threshold	-0.60	0.10	-0.61	0.02
<u>Direction detection range</u>				
died/shot at	-0.77	0.04	NS	-
died/engagement	-0.88	0.01	NS	-
win/loss ratio	0.79	0.03	NS	-
kills/shot	NS	-	0.65	0.04
angular deflection	-0.91	0.006	NS	-
<u>Angular deflection</u>				
shots/engagement	-0.83	0.02	NS	-
shot at/engagement	0.78	0.03	0.77	0.01
died/engagement	0.69	0.06	0.79	0.009
win/loss	-0.85	0.02	NS	0.08
TI1	NS	-	-0.71	0.02
TA1	0.80	0.03	NS	-
FF15	NS	-	-0.66	0.04
		p	POOLED	r
<u>Shots/engagement</u>				
TA1		-0.67		0.01
TP1		-0.67		0.01

instant that the attacker gave his correct call.

Our new findings concern the correlation between flying performance and these last two measures. The correlation between the two measures was close. They both correlated with combat success as measured by the win/loss ratio (i.e. number of hits on opponents versus number of hits received). Judging a leftward or rightward turn could involve the following two factors: (a) Visual sensitivity to aspect, since the target aircraft assumed leftward or rightward bank when changing heading; (b) visual sensitivity to frontal plane motion. The angular deflection measure was intended to bring out sensitivity to frontal plane motion. On the other hand, the importance of aspect has been emphasized by Kennedy et al. (1982). In order to find whether sensitivity to aspect alone could explain our findings we carried out a laboratory experiment using a stationary three-dimensional model A4 aircraft whose aspect was varied by setting it at the angles of bank for a left or right turn. Subjects judged left and right bank at different viewing distance, and we plotted the percent correct judgments on probability paper (Figure 9). Subjects' discrimination of bank angle did not fall to 75% correct until the angular size of the model aircraft fell to 3.3 min arc (subject KB) or 3.8 min arc (subject RP) wingtip to wingtip. This corresponded to a viewing distance of 8226 meters (subject KB) or 7130 meters (subject RP) for a real A4 aircraft. Our Figure 9 data suggest that, providing the target aircraft's contrast is about 60% at 7300 m distance or a little less, pilots could judge a change of heading merely by detecting the angle of bank. The broken lines in Figure 9 show that reducing target contrast from 60% to 30% is equivalent to a scaling factor.

One uncertainty about our laboratory study is that visual conditions in the air and in the laboratory were, unavoidably, quite different. We tried to

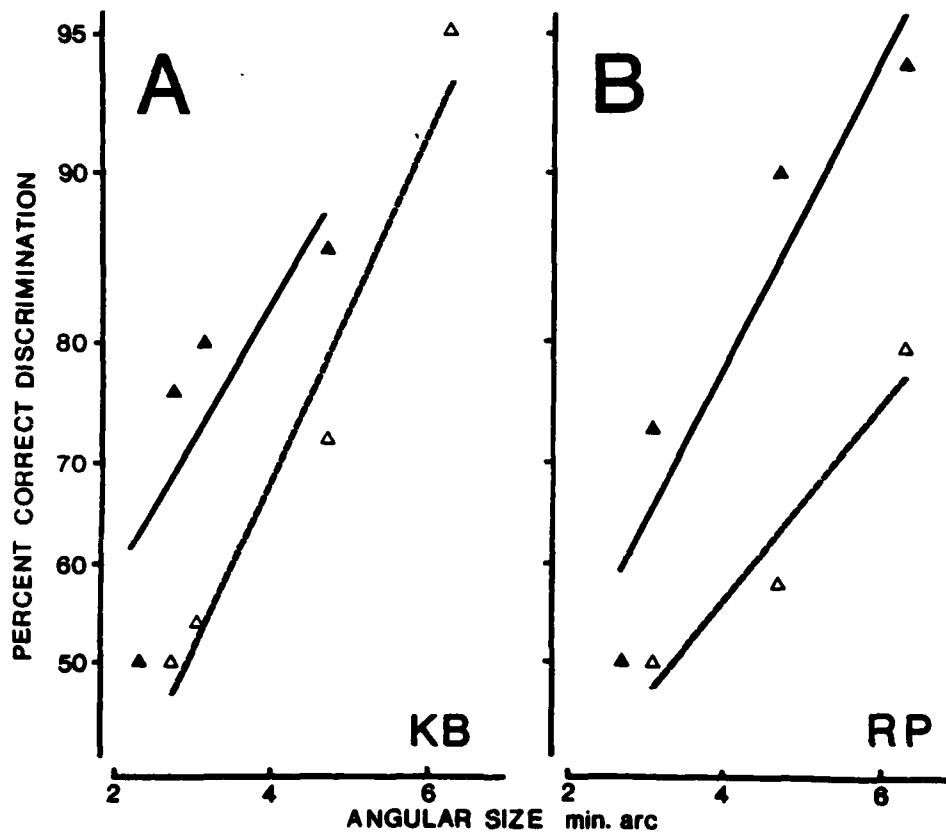


Figure 9 - Ordinates plot on a probability axis percent correct discriminations between leftward and rightward angles of bank of a model A4 aircraft. The angular sizes of the aircraft are plotted as abscissae. A and B show data for two subjects. Continuous lines are for an aircraft of 60% contrast, broken lines for 30% contrast.

compare airborne distances with our laboratory data by normalizing relative to visual acquisition distance. Therefore, we measured visual acquisition distance in the laboratory. For the 30% contrast model, detection was 25% above chance (75% correct) when the model's angular size was 2 min arc (both subjects), i.e. at a little less than twice the range at which change of direction could be detected. For a contrast of 60%, detection was 25% above chance when the angular size was about 1.8 min arc (subject RP) and 1.4 min arc (subject KB). This comparison, however, is likely to favor the laboratory data because of the lag while pilots made a motor response and because of the pilots' initial uncertainty as to the location of the adversary aircraft. Because laboratory subjects knew the model's location, because we used a 75% detection criterion (pilots would likely use a higher-certainty criterion), and because there was no atmospheric haze, laboratory acquisition distances are likely to be spuriously large. However, the roughly 1.6:1 to 1.9:1 ratio between the two laboratory measures compares with the roughly 1.6:1 ratio between mean visual acquisition distance for real aircraft and mean distance at which change in heading was detected. This suggests that aspect alone could account for discriminating change in heading in our airborne visual tests.

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2d. PROFESSIONAL PERSONNEL

D. Regan, Ph.D., D.Sc., Professor of Ophthalmology

K. I. Beverley, Ph.D., Assistant Professor

R. Kruk, Ph.D. (graduate student)

Joint research was carried out with C. A. Burbeck, Ph.D., Stanford Research Institute, Menlo Park, California

Advanced degrees awarded

R. Kruk, Ph.D. (Psychology), Dalhousie University, June 1983. Thesis title: "Visual factors in flying performance"

2e. INTERACTIONS

Papers presented at meetings, conferences, seminars, etc

Regan, D. New thoughts on evoked potentials. Invited address, Second International Evoked Potentials Symposium, Cleveland, October 1982.

Beverley, K. I. & Regan, D. Visibility and shape discrimination of camouflaged targets. Association for Research in Vision and Ophthalmology (ARVO), Sarasota, May 1983.

Burbeck, C. A. & Regan, D. Temporal factors in color discrimination. ARVO, Sarasota, May 1983.

Regan, D. Spatial frequency mechanisms in human vision: VEP evidence. ARVO, Sarasota, May 1983.

Regan, D. Paper on single units and psychophysics. AFOSR meeting, Sarasota, May 1983.

Seminars: SRI International, NASA/Ames Research Center, Smith-Kettlewell Institute, Rutgers University, University of Utah, U.S. Navy (Orlando), University of Manitoba, University of Calgary, University of Western Australia, Australian National University, University of Melbourne, Australia National Vision Research Institute

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