SF: SKIN DIVING - Visual Acuity under Water

U. S. NAVAL SUBMARINE MEDICAL CENTER

Submarine Base, Groton, Conn.

REPORT NUMBER 581

VISUAL ACUITY UNDER WATER WITHOUT A FACE MASK

by

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and
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Bureau of Medicine and Surgery, Navy Department
Research Work Unit MF12.524.004-9014D.03

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NAVAL SUBMARINE MEDICAL CENTER REPORT NO. 581

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SUMMARY PAGE

THE PROBLEM

To measure the visual capability of persons submerged without a face mask.

FINDINGS

Visual acuity, measured under water without face masks, was exceedingly poor. Under the most ideal conditions, it was reduced to the level found for night vision; that is, the underwater target had to be 10 times as large as the target in air to be seen. Further losses result from decreasing light-level and reduced target contrast. The acuity of all individuals is much more nearly equal under water than it is in air. There is no correlation between acuity in air and that under water.

APPLICATION

These results indicate the expected range of acuity under water for men who find themselves without face masks. It must be kept in mind, however, that water-clarity must always be considered: water turbidity sets the limit beyond which no target—no matter how big—will be seen.

ADMINISTRATIVE INFORMATION

This investigation was conducted as a part of Bureau of Medicine and Surgery Research Work Unit MF12.524.004-9014D, Improvement of Vision and Orientation Underwater. The present report is No. 3 on that Work Unit. It was approved for publication on 19 May 1969 and designated as Submarine Medical Research Laboratory Report No. 581.

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ABSTRACT

Visual acuity was measured under water for subjects without face masks and was compared with their acuity in air. The loss of acuity was around 90 percent for the entire group, but there were marked differences for the various sub-groups. Emmetropes suffered the greatest loss in the water; they required targets more than 20 times as big as those they could see in air. Myopes suffered the least loss; they required an increase in target-size by a factor of only seven. There was no correlation between emmetropic acuity in air and in water.

Acuity was also measured at various luminances in air while the subjects wore negative lenses of various powers to induce the same type of out-of-focus vision found under water. High and low contrasts targets were used. Tables were drawn up giving the approximate target sizes which can be seen under water at various light levels and at the two levels of contrast.

VISUAL ACUITY UNDER WATER WITHOUT A FACE MASK

INTRODUCTION

Under optimum conditions, acuity under water is slightly better than it is in air.[1] Optimum conditions entail extremely clear water, a clean face mask, and short viewing distances. Much less attention has been paid to underwater acuity with sub-optimal conditions, and apparently none at all to the least desirable condition, that of being under water without a facemask. There may, however, be occasions when an individual, such as an escaping submariner or a downed pilot, will find himself in that predicament. His acuity will unquestionably be poorer without the mask, but there have apparently been no measurements taken under this condition and the amount by which his acuity will suffer is not certain.

It is well known that the lens of the eye accounts for only a small fraction of the refractive power of the eye; 60 per cent or more of the refraction of the light-rays is accomplished at the corneal-air interface. When the eye is immersed in water, this interface is lost—and with it most of the refractive power of the eye.

There are no data from which to predict the loss of acuity from a given loss of refractive power. While several tables have been published which give acuity as a function of changes in clinical refraction,[2] they have been tabulated for negative corrections; positive correction, however, is required underwater. Moreover, the magnitude of the correction—40-50 diopters—falls considerably beyond the range of values given.

For these reasons, two experiments were conducted: one in a pool in direct summer sunlight, and the other in air with the underwater distortions simulated.

EXPERIMENT I

METHOD

Acuity was measured with a series of photographically reproduced grating targets. The targets consisted of six black bars separated by five white bars of such a length as to form a square for the complete configuration. The bars were all of equal width for a given target and ranged from .014 to 1.16 inches. Those used in the underwater experiment were sealed in plastic. The targets were presented one at a time in haphazard order, and the subject reported their orientation—horizontal or vertical. The measure of acuity taken was the smallest target which was always correctly seen. The subjects were instructed not to guess.

The subject observed with his head in a chin-rest two feet below the water surface. He was permitted either to use a snorkel or to hold his breath. The targets were placed against a wall of the swimming pool, at an equal depth, in direct sunlight, ten feet from the subject.

Immediately before the water measurements, the subject's acuity was measured at ten feet in air, again in the sunlight.

Twenty-four subjects were tested. Of these, 15 were emmetropes, 7 were rather severe myopes, and 2 were hyperopes. The ametropes were tested without their corrections both in air and in water.

In addition, 6 emmetropes, 1 myope, and 2 hyperopes were tested with the targets at a distance of 2 ft. 8 in. both in air and water.

RESULTS

Table I gives the acuity (reciprocal visual angle in minutes of arc) of the subjects in air and in water. The mean acuity of the emmetropes in air was 1.70; that of the myopes was only .71, and that of the hyperopes was 1.24. The acuity of every myope was very poor, and there was no overlap in the acuities of the myopes and emmetropes. The two hyperopes were intermediate.

In water, the situation was completely different. The mean acuity of the emmetropes was now .080, one-twentieth of the value in air. The mean acuity of the myopes and hyperopes, rather than remaining worse than that of the emmetropes, was now somewhat better. It is clear that the range of

Table I. Visual acuity in air and in water without face masks at 10 feet.

Emmetropes			Myopes			Hyperopes		
S	Air	Water	S	Air	Water	S	Air	Water
DW	2.06	.125	CG	.81	.090	JK	1.03	.090
SL	1.76	.060	JL	.80	.125	BB	1.45	.125
AM	1.76	.090	ET	.80	.092			
GB	1.45	.090	LZ	.60	.125			
MA	2.17	.090	HM	.51	.061			
WW	1.76	.061	CIG	.48	.065			
JD	1.45	.090	EL	.96	.125			
RS	1.92	.090						
CM	1.67	.045						
RG	1.92	.061						
JaD	1.76	.061						
MM	1.20	.100						
SD	1.76	.061						
HH	1.67	.090						
LC	1.20	.090						
M	1.70	.080	M	.71	.098	M	1.24	.107

acuities in water is the same for all three groups. That is, while the acuities of emmetropes, myopes, and hyperopes are quite different in air, they are comparable in the water.

It should also be noted that there is no correlation between the acuity of the emmetropes in air and in water; the rank order correlation between these two sets of acuities is —.003.

clear that the acuity of all subjects is about the same in the water.

These results enable us to make rough estimates of the sizes of objects which can be seen under water without face masks. The estimates are, of course, heavily dependent on water clarity. This controls the distance at which an object can be seen irrespective of size. It also affects target contrast, which is an important variable in acuity. For water

Table II. Visual acuity in air and in water without face masks at 2 ft. 8 in.

Emmetropes			Myopes			Hyperopes		
S	Air	Water	S	Air	Water	S	Air	Water
SL	1.76	.167	HM	.51	.162	JK	1.03	.180
NN	1.76	.186				AA	1.34	.137
LC	1.20	.127						
SD	1.76	.180						
DW	2.06	.180						
RG	1.92	.162						
M	1.74	.167	M	.51	.162	M	1.18	.158

Table II gives the results of the acuity measurements at a distance of 2′8″. The loss of acuity in water was much smaller, because water clarity is much less of a factor at the short distance. There is less degradation of target contrast, and so acuity is much better; it is now one-tenth that in air. Again it is

of moderate turbidity—the transmission of the water in the experimental pool was around .50/meter—Figure 1 shows the range of sizes of target detail which would be resolved at various distances by our subjects. At a distance of 10 ft., the subject with the worst acuity under water—an emmetrope with reasonably good acuity in air—would have required a Snellen chart letter almost as big as the largest letter on the Armed Forces Visual Acuity chart, while the subject with the best acuity would have required almost the second largest letter. The charts are designed to be used at 20 ft., of course, and in Snellen terms these subjects had acuities of 20/265 and 20/80.

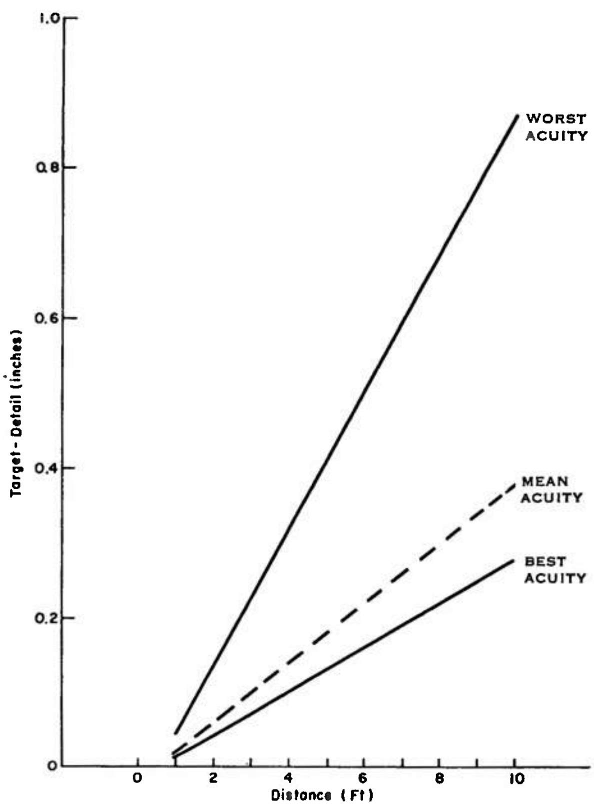

Fig. 1. The size of target-detail which can be discriminated at various distances by the subject with the best acuity under water, by the subject with the worst acuity, and on the average by all observers.

EXPERIMENT II

The first experiment was carried out just below the surface of the water in direct summer sunlight. The results, therefore, hold only for one light-level—the optimum level. It is, however, probably more important to know the range of acuities for lower light levels. More specifically, we must know the rate of change of acuity with changes in light level for underwater viewing.

The changes in acuity as a function of light level are well known for normal foveal vision.[3] We also have information on the acuity-luminance function for vision at various degrees in the periphery,[4] but there are very little data of this kind for various degrees of refractive error.[5] What little has been done has been confined to errors of rather modest magnitude compared to the degree involved under water.

For these reasons, a second experiment was carried out. Since it was impossible to control the light level in the experimental pool, the experiment was conducted in air, and the loss of the air-water interface was simulated with high power negative lenses. The acuity of the subjects was measured through a wide range of photopic light levels and through the total refractive range of 60 diopters using targets at two contrast levels.

METHOD

Acuity was again measured with a series of photographically reproduced high contrast grating targets. They were presented one at a time in random order; half of the presentations were horizontal and half were vertical and the subject reported their orientation. The percent of correct reports for each target was plotted on cumulative probability paper to establish the 50 percent threshold.

The subjects observed under four conditions of refraction: a control condition with no spherical correction, and 20, 40, 60-diopter negative lenses before their right eyes. The left eye was occluded.

Observations were made at four light levels, 0.3, 1.8, 20, and approximately 1800 ft-L. The highest light-level was direct winter sunlight through a bank of large windows.

Two contrast levels were studied, .81 and .27. The low contrast level was obtained by placing the targets directly behind a screen of frosted glass.

Observations were made at a distance of 10 ft, except at the lowest light level. Under this condition, it was sometimes necessary, with lenses of 40 or 60 diopters, to decrease the viewing distance to obtain a threshold. The shortest viewing distance was three feet.

The various combinations of refraction, contrast, and light level were given haphazardly; the controlling factors were the availability of subjects and the presence of a cloudless sky.

SUBJECTS

Three subjects observed, an emmetrope, a hyperope, and a myope. In contrast to the procedure in Expt. I, the ametropes wore their usual contact lens spectacle corrections in addition to the experimental lenses, so that their acuity would be comparable under the control condition.

RESULTS

The mean acuities for the three subjects under the various conditions are given in Table III. This shows the progressive drop in acuity resulting from reductions in light level, the reduction in target contrast, and the increases in lens power. When, for example, the subjects were wearing no experimental lenses, their mean acuity for the high contrast targets illuminated to 0.3 ft-L was .833; for the low contrast targets, it was .484. When they were wearing negative lenses of 20 diopters, their mean acuity for the high contrast targets at 0.3 ft-L was .087, and so

Table III. Mean acuity under the various conditions.

	Luminance in ft-L							
	0.3		1.8		20		1800	
Diopters	High	Low	High	Low	High	Low	High	Low
0	.833	.484	1.262	.794	1.701	1.389	1.916	1.667
20	.087	.037	.128	.061	.191	.113	.232	.164
40	.036	.014	.060	.026	.085	.055	.093	.069
60	.018	.006	.027	.015	.051	.030	.071	.048

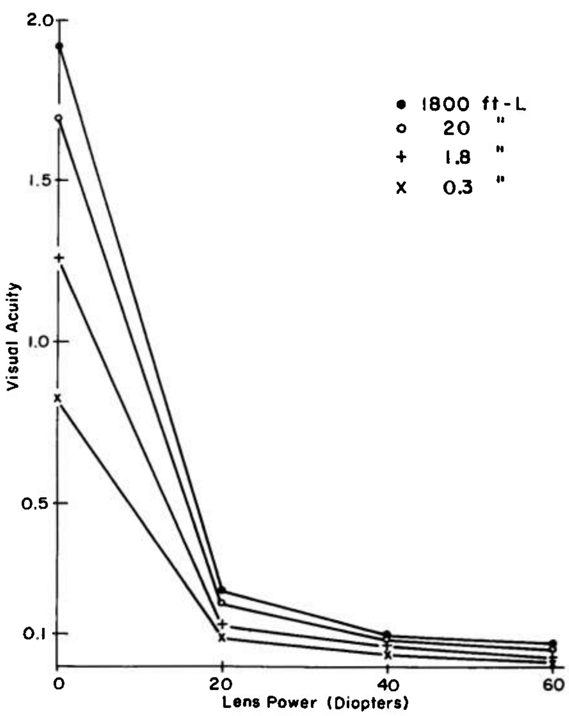

Fig. 2. Visual acuity for high contrast targets while wearing lenses of various powers at light-levels.

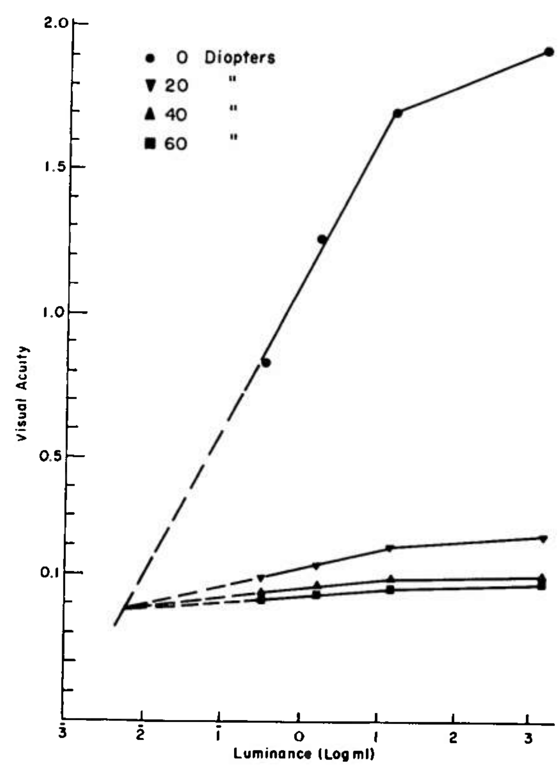

Fig. 3. The data of Fig. 2 replotted to show visual acuity as a function of light-level while wearing lenses of various powers.

on. These results for the high contrast targets are plotted in Fig. 2 to show the decrease in acuity with increased lens power at each luminance level.

The same data are replotted in Fig. 3 to show the increase in acuity with increasing luminance for each lens power; the increase in acuity grows progressively less as lens power increases. With lenses of 60 diopters, there is little increase in acuity with an increase in luminance over a range of 4 log units. Put another way, as lens power increases, reductions in luminance produce less of a drop in acuity.

It is clear that at all daylight levels of luminance, acuity is drastically reduced by the lenses. The curve is negatively accelerating; most of the acuity loss occurs by 20 diopters, and further increases in lens power result in much smaller decreases in acuity. And as the luminance is reduced, the effect of a given lens is also reduced. In other words, the higher the initial acuity, the more degradation of acuity is possible, and the more occurs.

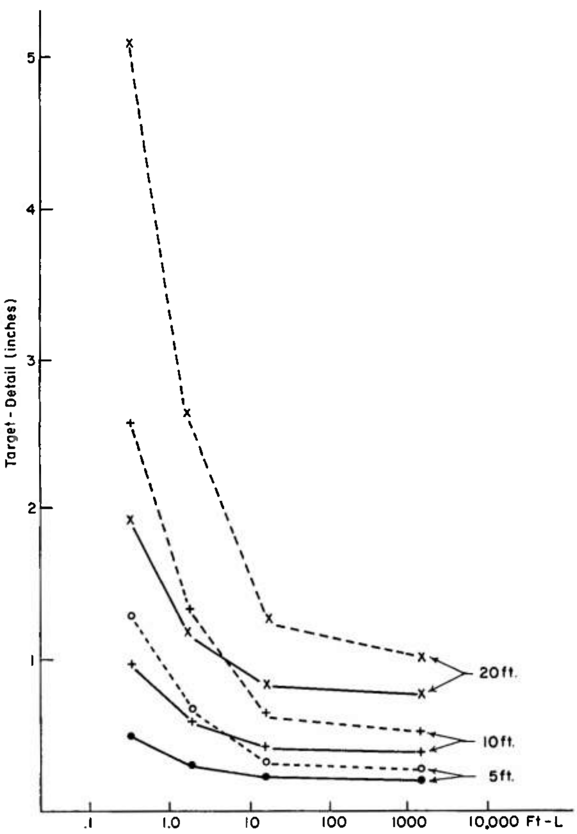

Fig. 4. The average size of target-detail which can be seen at various distances and light levels using high (solid line) and low (broken line) contrast targets.

DISCUSSION

It appears, first of all, that the simulation of the state of vision under water was successfully accomplished. It can be seen in Table III that the mean acuity levels for the high contrast targets at the highest light level were .093 for the 40 diopter lens and .071 for the 60 diopter lens, bracketing the mean value of .080 obtained under water.

The present results clearly show that for a given lens power there is a greater reduction in acuity as luminance is increased; at the lower light levels, all the acuity values tend to converge. This means that if the light level is low enough, it makes little difference whether a man is wearing a face mask or not. The reason is that acuity under water without a face mask is so poor that it is little better than normal acuity at night. Furthermore, underwater acuity is, for practical purposes, essentially invariant with changes in light level. Thus, lowering the amount of illumination does not reduce underwater acuity without a mask by an appreciable amount, but it does degrade normal acuitv until the two are about the same.

Although the loss of focus does not change acuity very much at nighttime levels of illumination, with the range of daylight illumination, the loss of focus degrades acuity markedly, more so as light level increases.

We can now expand upon Fig. 1 and show the approximate size of target which can be discriminated under water at various distances and light levels. Figure 4 shows the smallest size of target detail which our observers could see on the average with both high and low contrast targets. Target size must be increased as the light level is decreased, and more increase is necessary with low contrast targets. The amount of increase, however, is small compared to that which would be necessary for vision which is in focus.

It must be kept in mind that these values are for target-detail and not for full size of targets. Thus, for letters, these values would refer to stroke-widths. If it were necessary to read an "EXIT" sign at a distance of 10 feet, each bar on a high contrast "E" would have to measure one inch at a light level of 0.3 ft-L. Since there are three horizontal strokes, the E would have to be about 5 inches high. For a low contrast sign, at a distance of 20 feet the E would have to be about 25 inches high before it could be read.

These results have interesting implications for Navy visual acuity standards for divers. These are now rather stringent. One reason for this apparently has been the desire to maximize acuity in the event a diver lost his facemask. Our results indicate that this need not be a consideration, since acuity underwater is essentially the same for everyone, regardless of their acuity in air. This indicates that men with poor acuity can serve as divers as long as their acuities can be corrected to an acceptable level with spectacles built into the facemask.

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13. ABSTRACT

Visual acuity was measured under water for subjects without face masks and was compared with their acuity in air. The loss of acuity was around 90 percent for the entire group, but there were marked differences for the various sub-groups. Emmetropes suffered the greatest loss in the water; they required targets more than 20 times as big as those they could see in air. Myopes suffered the least loss; they required an increase in target-size by a factor of only seven. There was no correlation between emmetropic acuity in air and in water.

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14. KEY WORDS	LINK A		LINK B		LINK C	
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Underwater vision						
Out-of-focus vision						
Acuity-luminance function						