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WHITEOUT - A BIBLIOGRAPHICAL SURVEY*

*Subtask under Psychophysiological Studies, USAMRL Project No. 6-95-20-001, Subtask, Basic Problems of Vision and Perception in Human Behavior.

RESEARCH AND DEVELOPMENT DIVISION
OFFICE OF THE SURGEON GENERAL
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by

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ABSTRACT

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INTRODUCTION

Interest in the Arctic and Antarctic in relation to the International Geophysical Year has brought to general attention a meteorological condition called, because of its visual appearance, "whiteout." It is stated to occur "...when the sky is overcast with low-lying stratus and the ground is covered with snow." The occurrence of whiteout represents a distinct hazard to both ground and air operations because functionally, with respect to the snow features of the environment, the individual is blind.

PHYSICAL FACTORS

The determining meteorological characteristic of whiteout is uniform, diffuse, shadowless illumination consequent to a diffusion stratum of airborne particles. The occurrence of whiteout is a function of local conditions, particularly of the presence or absence of an extended, diffusely reflective surface such as snow. When the diffusion stratum is in contact with the ground, a visibility problem is present in that the meteorological range is reduced. The necessary role of a diffusion stratum in the whiteout condition assures that illumination in the whiteout will be less by the luminous flux lost through absorption in the overcast.

PHYSIOLOGICAL FACTORS

Subjective impressions of increased illumination under whiteout conditions may arise from the veiling luminance within the eye consequent to the scattering of light entering the pupil from sources other than the object of regard. There is a possibility that this feature of the visual mechanism may significantly effect the visibility of an object under whiteout conditions.

It has been suggested that empty-field myopia, the accommodation rather than relaxation of the eye in the absence of stimuli to accommodation, is part of the whiteout phenomenon. Actually, present ground

operations procedures preclude the possibility in other than the exceptional instance. The exceptional instance might occur for an isolated individual afoot or for an aircraft pilot. Continued efforts "to see" in an empty visual field usually result in excessive tearing, a sense of eye strain and very probably, dissociation of the eyes.

PSYCHOLOGICAL FACTORS

The Arctic whiteout is for the aircraft pilot an instrument condition. Failure to recognize this or lack of the necessary flight instruments exposes the pilot to the possibility of vertigo. Similar phenomena are occasionally experienced during ground operations. The pitching and yawing of an over-snow vehicle exposes the operator and his passengers to tilted body positions which may result in loss of the gravitational vertical.

A most dangerous situation arises when an individual moves into a whiteout condition from an area of adequate visual reference and, realizing that he has lost contact, attempts to turn through 180 degrees to retrace his path. Knowledge of directional orientation is a judgmental process specific to the particular situation and environment. An individual attempting to follow a straight path without guide will veer - afoot from anthropometric and physiological causes, in a vehicle from mechanical causes.

The ground surface plays an important role in organizing the various cues to distance; and in its absence, as in the whiteout, the ability to judge distance is severely handicapped. Such cues as may be available are relatively unprecise, and mediate primarily the distance between objects rather than the distance from the observer to an object. Distance estimated can, nevertheless, be systematic with respect to the physical environment. In general, the judgment of the distance between objects will be less as a function of distance than the actual distance.

CONCLUSIONS

The phenomenon of "Arctic whiteout" has been placed in a context of research contributory to an understanding of its physical source and physiological and psychological effect. Present understanding suggests that problems arising from the phenomenon might be met by the use of directional illumination to restore to the natural environment the cues needed by the individual for his perceptual judgments, or by navigational aids which would provide the necessary information for specific tasks. The psychology of the situation seems to be limited to: 1) emotional

responses to an inability to see under photopic illumination; 2) maintenance of vertical and directional orientation; 3) interpretation of minimal cues to procure meaningful estimates of distance; and 4) the psychophysics of the display systems for such guidance devices as may be developed.

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WHITEOUT - A BIBLIOGRAPHICAL SURVEY

I. INTRODUCTION

Interest in the Arctic and Antarctic in relation to the International Geophysical Year has brought to general attention a meteorological condition called, because of its visual appearance, "whiteout" (1; 2; 3; 4; 5, p. 72). The nature and import of the condition are well documented in the observations of those who have experienced the phenomenon. It is stated to occur ". . . when the sky is overcast with low-lying stratus and the ground is covered with snow. At such times in twilight conditions, the horizon disappears completely and the greyish-white snow blends with the grey clouds into a uniform background lacking shadows, detail, and perspective" (6, p. 26). "It occurs when clouds are so thick and uniform that light reflected by the snow is about the same intensity as that from the sky. No object casts a shadow, the surface of the snow merges into the sky, and no horizon, ground, or sky features can be recognized." (7, p. 81). "There is an overall 'greyness' to the surroundings which is most marked when the sky is overcast with dense clouds. The resultant loss of shadows causes an individual to lose his sense of depth perception. Thus a step forward may result in pitching down a 'deep hollow' of a few inches or stumbling and falling, due to an equally 'insurmountable' hill of like magnitude. What appears to be level ground may in truth be a small hill or hollow." (8, p. 9). Thus, whiteout as a physical phenomenon is characterized by these authors as resulting from the combination of the elements of overcast and snow cover.

A more recent publication mentions the complicating factor of precipitation (9). Gerdel and Diamond (10) include precipitation or airborne particles as one of the physical sources of the phenomenon and classify five major meteorological conditions which ". . . have been reported as whiteout. They are:

1. Overcast whiteout, caused by a continuous cloud cover.
2. Water-fog whiteout, produced by supercooled water droplets in the air.
3. Ice-fog whiteout, produced by ice crystals suspended in the air.
4. Blowing snow whiteout, produced by wind-driven, wind-eroded snow.
5. Precipitation whiteout, produced by falling snow."

The occurrence of whiteout represents a distinct hazard to both ground and air operations (1, 3, 4, 8, 9). The available illumination

establishes the expectancy of sight though, in the absence of discernible ground forms, the individual is at much the same disadvantage as if he were in total darkness (11, p. 60)! Functionally, with respect to the snow features of the environment, the individual is blind.

The purpose of the present paper is to delineate the physical, physiological, and psychological features of whiteout and to index references to research areas significant to the several factors. The bibliography is selective rather than exhaustive.

II. PHYSICAL FACTORS

A. Diffuse Illumination

The failure of the visual function in whiteout is due to the lack of differential brightnesses and image contours on the retina of the observer. The meteorological characteristic of whiteout which gives rise to this uniformity of stimulation is diffuse, shadowless illumination (5, p. 440). Diffuse, shadowless illumination occurs in the natural environment in the presence of airborne particles (water droplets, ice crystals, or snow) of such character, density, and depth as to scatter uniformly the incident directional illumination. Shadowless illumination occurs in the temperate climate as well as in the Arctic. Its occurrence is appreciated by the photographer since pictures taken under such conditions are flat, lacking in contrast (12, plate 1 facing p. 54, and p. 144). The occurrence of whiteout conditions consequent to a particular overcast will be a function of local conditions, particularly of the presence or absence of an extended, diffusely reflective surface such as snow (9, p. 954; 1).

The effect of shadowless illumination upon the conduct of operations in the Arctic as distinct from its effect upon the conduct of operations in temperate climates is due to the preponderance of ground forms which have little or no inherent contrast from their background. Snow forms under directional illumination are differentiated from their background principally by shadow. In the absence of this shadow, the snow forms become invisible (13). The surfaces they generate become indefinite or nonexistent and operations which are predicted upon knowledge of these surfaces become extremely hazardous, if not impossible.

The effects of shadowless illumination are not restricted to objects of low or no inherent contrast. The ability to perceive the three-dimensional form and orientation of objects of inherent though uniform contrast, such as oil drums, huts, vehicles, etc., is dependent upon

shadow (12, p. 311). In the absence of shadow or color to differentiate the roofs, barrel ends, fenders, etc., the perspective relations of the outlining borders become the determiner of the perceived orientation of the objects with the consequent likelihood of illusory perceptions.

B. Meteorological Range

A visibility problem is present when the diffusion stratum is in contact with the ground (9, p. 958; 10). The airborne particles in the line of sight obstruct and scatter the light emanating or reflected from an object and by reflection, superimpose the background luminance upon that of the object, i.e., the airborne particles act to reduce the meteorological range (11, pp. 61, 64, and 103). The effect of this veiling luminance is to reduce the apparent contrast of objects and, thus, to reduce their visibility (14, 15, 16). The belief that airborne particles act to reduce the contrast more strongly at the edges, the "edge effect," than at the middle of an object and that the overall appearance of the object becomes dappled, the "ground-glass effect," is not supported by research (11, p. 78; 17, p. 142; 18, p. 186-7; 15; 16).

C. Illumination

Comment has been made in the literature that light levels are increased during whiteout conditions (9, p. 957). In this regard, a distinction must be made between apparent brightness, luminance, and total luminous flux. There can be little question that the total luminous flux present during a whiteout is less than that which would be present in the absence of the whiteout by an amount equal to that absorbed in the overcast. The average luminance of the field of view is a different matter. Under directional illumination, the scene is populated with shadows and highlights. Luminance levels exist from maxima in the direction of the sun to minima in the shadows away from the sun. An observer viewing objects of interest will sample this range and may seek relief from the glare spots by directing his gaze to the shadows.

Under whiteout conditions, the range of luminance that would be available under directional illumination is eliminated. The lower portion of the range disappears with the shadows. The upper portion of the range is lost in the absorption of the overcast. The resultant uniform luminance of the whiteout will vary from the average luminance which would be present with directional illumination as a function of the shadow under directional illumination and the absorptive characteristics of the overcast. In any case, relief from the luminance of the field of

view is not available to an observer by the expedient of directing his gaze since it is uniform in all directions.

III. PHYSIOLOGICAL FACTORS

A. Retinal Illumination

The sensitivity of the eye for a particular brightness difference present in the physical environment is a function of the overall illumination of the retina. The elements of the eye scatter the light entering the pupil and illuminate areas of the retina in addition fo that portion upon which the light is imaged (19; 20, p. 295-8; 21; 22). This veiling luminance within the eye and the resulting adaptation and neural interaction reduces the apparent sensitivity of the retina (23, 24, 25). Thus, scattered light within the eye from portions of the visual field quite remote from the object may modify the retinal sensitivity such that an object just visible under directional illumination can not be seen under diffuse, uniform illumination. Variables significant to the task of seeing objects both brighter than and darker than a uniform background have been documented by Blackwell (26).

B. Empty-field Myopia

It has been suggested that empty-field myopia, the accommodation rather than relaxation of the eye in the absence of stimuli to accommodation, is part of the whiteout phenomenon (27, p. 139; 28; 29; 30). Its presence would, through the defocusing of the retinal image of distant objects, disperse over the retina the light energy which should form perceptable contours. Logically, the conditions necessary for the occurrence of empty-field myopia should be present in the Arctic. Horizon to horizon expanses of snow under diffuse illumination should provide a "Ganzfeld" (31) condition, the uniform, undifferentiated, photopic stimulation necessary for its occurrence.

Actually, present ground operations procedures preclude the possibility in other than the exceptional instance. The visual field is generally populated with supra-threshold objects, oil barrels, over-snow vehicles, huts, etc., at distances intermediate to and greater than twenty feet. To the degree that such objects are adequate to stimulate accomodative adjustment, loss of visibility of objects at greater distances must be attributed to other causes.

The exceptional instance would be that in which objects at intermediate distances are not present. This might occur for an isolated

individual afoot or for an aircraft pilot. Continued efforts "to see" in such an empty visual field usually result in excessive tearing, a sense of eye strain and very probably, dissociation of the eyes. In any case, should empty-field myopia occur as a consequence of whiteout, it would be a compounding factor in a situation which already requires special operating procedures (5, p. 335).

C. Entoptic Phenomena

The absence of perceptible contours in the retinal stimulation under whiteout conditions permits certain minor defects of the eye, if present, to become apparent. Most obvious of these defects are the "mouches volantes" referred to by Helmholtz (32, p. 7), the opacities in the vitreous humor which appear as dark shadows that move with the shifting of the gaze. A moving scintillation is also apparent with high-brightness levels. This last is similar in appearance, but different in origin, to the twinkle of airborne ice crystals. Like the minor defects of the eye, this phenomenon can be observed by gazing into a bright, cloudless sky.

IV. PSYCHOLOGICAL FACTORS

A. Perception of the Vertical

The Arctic whiteout is for the aircraft pilot an instrument condition (3, 7, 9). Failure to recognize this or lack of the necessary flight instruments exposes the pilot to the possibility of vertigo (33). Similar phenomena are occasionally experienced during ground operations. In a whiteout, with inadequate or misleading visual stimulation, the individual is dependent upon his kinesthetic and gravitational senses for his spacial frame of reference. The pitching and yawing of an over-snow vehicle exposes the operator and his passengers to tilted body positions which may result in a loss of the gravitational vertical (33, p. 28; 34; 35; 36). The inability to appropriately evaluate a grade or incline under such circumstances is a common experience (3). A man on foot without the necessary visual stimulation is unable to anticipate the needed postural compensation for small irregularities in his path and may stumble and fall (8).

B. Directional Orientation

A most dangerous situation arises when an individual moves into a whiteout condition from an area of adequate visual reference and, realizing that he has lost contact, attempts to turn through 180 degrees

to retrace his path. For an airplane pilot, successful execution of such a maneuver necessitates in addition to knowledge of direction, knowledge of aircraft attitude and relative altitude. For an individual on the ground, knowledge of direction and of possible lateral displacement of path is necessary.

Knowledge of directional orientation is a judgmental process dependent upon a multiplicity of cues. It is specific to the particular situation and the presence of reference stimulation in the environment, visible landmarks, a steady wind, or a localizable sound. In the absence of such reference stimulation, the individual has no primary sense from which to formulate such a judgment.

It is well known that an individual attempting to follow a straight path without guide will veer (37, 38). A comparable situation is present with vehicles since, the drive mechanisms, as a function of internal frictions and irregularities of traction, cannot be depended upon to pull straight. The effort to maintain one's direction through knowledge of relative direction by retaining in memory a previous orientation involves the rotational sense. As in "blind man's bluff," the rate of rotation, angular acceleration, angular deceleration, and the time relations between these several phases of the movement effects the individual's ability to properly account for the rotation experienced (39).

C. Distance Estimation

Knowledge of the distance from the observer to an object and of the depth relations between objects visible in the field of view is a derived perception. Such judgments are inferred from cues available in the environment. The ground surface plays an important role in organizing the various cues and in its absence, as in the whiteout, the ability to judge distance is severely handicapped (40; 41; 5, p. 48). Under these circumstances, judgments of distance are based upon such cues as atmospheric haze, the size of familiar objects, retinal disparity, blurredness of the retinal image, proprioceptive knowledge of the convergence of the eyes, etc. Such cues are relatively unprecise and, laboratory evaluation has indicated that they mediate primarily the distance between objects rather than the distance of objects from the observer (42, 43). Knowledge of distance from the observer to the object is apparently a function of the presence of intervening objects and ground surface texture (40).

The relation of the distance perceived to the physical distance between the objects is not one to one. The perceived distance between

objects is a function of the directional arrangement, number, and perceived size of the objects (41, 44, 45, 46, 47). Distance estimates can, nevertheless, be systematic with respect to the physical environment. In general, the relation of perceived space to physical space is such that the judgment of the distance between objects will be less than the actual distance between the objects, and, as a function of the distance to the objects, the error of underestimation will increase (48, 49, 50, 51).

V. CONCLUSIONS

The phenomenon of "Arctic whiteout" has been placed in a context of research contributory to an understanding of its physical source and physiological and psychological effect. Present understanding suggests that problems arising from the phenomenon might be met by the use of directional illumination to restore to the natural environment the cues needed by the individual for his perceptual judgments, or by navigational aids which would provide the necessary information for specific tasks. The psychology of the situation seems to be limited to: 1) emotional responses to an inability to see under photopic illumination; 2) maintenance of vertical and directional orientation; 3) interpretation of minimal cues to procure meaningful estimates of distance; and 4) the psychophysics of the display systems for such guidance devices as may be developed.

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The polar phenomenon of whiteout is described through the medium of quotations from persons who have experienced the phenomenon. The meteorological conditions indicated to produce the phenomenon are noted and the mechanism of their operation discussed in terms of research findings available in the literature. Topics considered are: diffuse illumination, meteorological range, illumination levels, retinal illumination, empty-field myopia, entoptic phenomena, perception of the vertical, directional orientation, and distance estimation.

UNCLASSIFIED

1. Psychology
2. Vision
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