Aviation Medicine

Function of the special senses in flight

I: Vision and spatial orientation

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*"Who needs instruments said he, with perfect eyesight like me?
My approach seems just right, he thought one black night,
And calmly flew into the sea." (Anon)*

The special senses are vital to safe flying; the visual, vestibular, and auditory modalities are particularly important, but even touch and smell play a part. This article is concerned with the way in which the senses operate in, and may be adversely affected by, the abnormal environment of flight.

Vision

Perfect eyesight is indispensable to pilots, but even with excellent vision flight imposes certain peculiarly visual limitations and problems.

In high speed flight (greater than 450 knots), particularly at very low level (altitudes below 500 ft (153 m)), the principal problem is extension of the total reaction time. For a man-machine complex this is conventionally divided into phases of perception (pick up, lock on, recognition), evaluation, decision, action, and response. Under perfect conditions it lasts between five and seven seconds—a time span that represents a distance travelled of over 3 km for two aircraft flying on a collision course at a combined speed of 1800 km an hour. Since the greatest distance at which any target might be expected to be seen—and only then as a point source without discernible detail—is about 11 km,¹ anything which extends the total reaction time will jeopardise the aircraft. Though many factors—including workload and fatigue—may prolong this period, it is the initial triggering of the "visual perception cascade" of pick up, lock on, and recognition that is especially important. This phase occupies about one second under ideal circumstances,² but visual factors which delay the cascade will prolong the total reaction time accordingly; these include poor atmospheric conditions (haze, fog, cloud), night flying, and the size and contrast of the target (small, camouflaged aircraft will be seen later than large, well lit or brightly coloured machines).

The dynamic visual field also has an effect. Targets approaching head on stimulate the retina less than those tracking tangentially across the visual field and so delay pick up. Similarly, peripheral targets are seen later than central ones because of

FIG 1—Blur zone: shaded area represents that part of the pilot's three dimensional peripheral visual field which is lost to him owing to speed of movement.

blurring of the peripheral visual fields (fig 1). This blur zone becomes more pronounced as speed increases.

High altitude flight—that is, at altitudes above 40 000 ft (12 192 m)—produces other visual problems, including solar glare.³ There is a slight increase in the intensity of light as altitude increases to 100 000 ft (30 480 m), and its distribution is so modified at altitude that most appears to come from below, where scattering of light by air molecules, moisture, and dust particles is greater and where clouds may create a bright visual floor. The sky above therefore appears darker at altitude, less light falls on the cockpit interior—particularly on the instrument panels—and the degree of contrast is increased so that retinal adaptation time is prolonged when the pilot looks from inside the cockpit to outside or vice versa. Colour discrimination is also affected by glare. Glare may be reduced by the wearing of sunglasses or by the attachment of a tinted visor to the helmets of military aircrew. High intensity cockpit instrument lighting,

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which reduces excessive contrast, has been fitted in some aircraft.

Visual function may be further impaired at altitude by the development of empty visual field myopia. In this condition there is no external detail on which the eye can focus—for example, in a cloudless sky at high altitude, or total darkness, or a uniformly overcast sky. The eye is unable to focus at infinity and instead remains in a steady state of activity focused 1-2 m away. The size of a target which is normally seen when the ability to focus at infinity is intact has to be doubled to be detected, thus increasing the duration of the visual cascade.⁴ Pilots are taught to minimise the risks associated with empty visual fields by periodically and deliberately focusing on an object known to be effectively at infinity such as the wing tip.

At night empty visual field myopia may be further complicated by the need to use off centre scanning techniques to ensure that dimly lit external targets are not missed by foveal scanning. Such off centre vision is effective only if the eye is fully adapted to the dark; about 30 minutes is needed for the rods to achieve maximum scotopic sensitivity.⁵ Historically, adaptation to the dark began on the ground with the use of red goggles and was maintained in the air by red cockpit lighting. This degree of adaptation is no longer considered necessary since night flight requires photopic function both for monitoring instruments and accomplishing most external visual tasks. Red lighting, which was the traditional solution to the apparently conflicting needs of external night vision and internal instrument vision, is therefore now felt to be inappropriate especially since it also impairs colour discrimination and reduces accommodative ability and speed. Dim white general lighting has none of these disadvantages and is to be preferred.⁶

Ocular hazards—such as windblast on ejection and birdstrikes—are important in military aviation. For these reasons military aircrew are usually provided with a clear polycarbonate visor, which is operated independently of the tinted visor and worn in the lowered position during low altitude flight and if possible before ejection.

Finally, visual mechanisms are of paramount relevance to orientation and disorientation.

Spatial orientation and disorientation

The organs of spatial orientation are the means by which position, attitude, and movement are determined in relation to fixed references. On the ground the references are gravity and the horizon, and it is in this 1 G environment that the perception of correct orientation develops, based on information from the eyes, inner ear, and proprioceptors. Once the pilot is airborne and subject to abnormal accelerative forces, however, the information supplied by these sensory modalities—particularly the vestibular apparatus and proprioceptors—may be interpreted incorrectly with potentially dangerous consequences. Correct spatial orientation is replaced by spatial disorientation in which the pilot's perception of his own position and often that of his aircraft is false.⁷ All aircrew experience disorientation at some stage during their careers, but it is only when control of the aircraft is based on false perceptions that accidents occur. Disorientation is a contributory factor in about 12% of all fatal airline accidents, in about 20% of military accidents, and probably even more in general aviation.⁸⁻⁹

MECHANISM OF ORIENTATION

If visual function is normal and external cues unambiguous vision provides reliable sensory information from which orientation may be perceived correctly. Similarly, the semicircular canals provide reliable information about angular accelerations of the head and may be regarded as angular accelerometers working as three matched pairs (fig 2). Sustained change in the angular velocity of the head greater than about

3° per second is detected by the canals in the plane of movement, and its magnitude and direction are signalled to the brain. Movement will be detected by the canals only for as long as there is a suprathreshold acceleration or deceleration. Once constant velocity is reached the signal will decay even though movement is continuing.⁷ The otolith organs, which lie within the utricles and saccules and are also bilateral, are linear accelerometers: the utricles lie in the horizontal plane, the saccules in the vertical (fig 2). The otoliths register accelerations greater than 0.1 m/sec², but again the signals decay when constant velocity is reached. Cerebral integration and interpretation of vestibular signals is achieved in conjunction with visual signals and reinforced by proprioceptive information to produce a complete and accurate assessment of body orientation.

FIG 2—Relation of the components of the vestibular apparatus to their axes of response and to the planes of aircraft movement.

The principal function of the vestibular apparatus is, however, the maintenance of body equilibrium by reflex motor control of muscle groups. The most important group in relation to orientation is the ocular musculature. Vestibular stabilisation of this muscle group is responsible for the maintenance of a static retinal image whenever the head is moved. Thus every response of the semicircular canals, however small, is matched by compensatory eye movements that are equal in magnitude but opposite in direction to the movement of the head. Such vestibulo-ocular reflexes are also present in response to inputs from the otoliths but are less precise.

Once a person is exposed by flight to patterns of angular and linear motion beyond the dynamic range of sense organs adapted for life on the ground, visual, vestibular, and proprioceptive signals—which are further complicated by the vestibulo-ocular reflexes and central mechanisms—may be totally erroneous and lead to false perceptions. These illusions may be classified by their system of origin but considerable overlap inevitably exists between them.

ILLUSIONS OF VISUAL ORIGIN

Pilots are taught to fly in accordance with regulations for either visual flight, used when meteorological conditions exceed certain laid down minima, or for instrument flight, used at all other times.¹⁰ When flying under visual flight rules any impairment of vision may very quickly lead to catastrophic disorientation since it will require immediate transition to instrument flight rules. During the time taken to recognise the need for transition and to accomplish it the risk of disorientation is greatly increased. Thus absent or inadequate visual cues—as when flying in cloud, fog, rain, dust, at night, or over featureless landscapes such as sand, grass, or water—are particularly hazardous. The situation is dangerously compounded if there is also any failure of, or lag time in, the instrument displays, since the pilot relies on these when his external visual field is absent or impaired. The visual problems are accentuated even further by vibration, turbulence, or glare. Occasionally, despite an apparently normal external visual scene, visual cues may be falsely interpreted, usually as a result of errors of expectancy. For example, a sloping cloudbank

may be assumed to be horizontal because most cloud tops are horizontal (fig 3).

Both visual impairment and expectancy errors are particularly relevant during approach and landing, a phase of flight in which five of the nine British airline accidents in 1980 occurred.¹¹ Height and distance have to be accurately judged in the final stages of landing by means of several monocular visual cues including the shape of the runway and its changing perspective, motion parallax, and retinal image size and movement. Any factor that interferes with or modifies these cues may lead to mistakes. Landing in fog, haze, rain, or at night may cause overestimation of height and distance, whereas landing in clear,

FIG 3—Error of expectancy: the sloping cloudbank is assumed to be horizontal. (After: Benson and Burchard⁷).

bright conditions may cause underestimation. The attempt by the pilot to attain the expected angle of approach of $2.5\text{--}3^\circ$ under such circumstances may lead to landing short of the runway if height and distance are overestimated and to landing long if they are underestimated. There is little time in this phase of flight to correct mistakes.

A further, purely visual, illusion is the apparent movement of a single static point source of light at night—the autokinetic illusion. The absence of other detail in the visual field, combined with small but normal involuntary eye and neck movements, leads to the impression of movement of the light across the field of vision, usually randomly but occasionally in a deliberate manner. The pilot may find himself taking potentially dangerous avoiding action on the assumption that the light is another aircraft.

ILLUSIONS OF VESTIBULAR ORIGIN

As with visual information, that reaching the vestibular apparatus may be either inadequate or erroneous. Movements in flight may be so slight as to be subthreshold. (The thresholds quoted above for angular and linear accelerations are laboratory findings but in flight they may be much higher because the pilot's attention is devoted to other aspects of flying.) Subthreshold phenomena are probably responsible for the most frequent form of disorientation, the so-called "leans."¹² In this condition (fig 4) the aircraft and its pilot adopt an abnormal attitude—for example, in roll—at a subthreshold rate. Once the pilot recognises the situation, by referring to his instruments, he will correct the attitude but at a suprathreshold rate. This movement, the first to be sensed by the semicircular canals, is interpreted by the brain as a movement in the opposite direction to the original, unsensed, change of attitude. Though the pilot knows from his instruments that he has corrected the flight path to straight and level he nevertheless feels that he is leaning to one side.

FIG 4—One mechanism by which the "leans" may be produced. (After: Benson and Burchard⁷).

Erroneous information is also common. For example, the semicircular canals may provide false information on recovery from a prolonged spin. During the spin the canals correctly indicate an angular acceleration, but once constant velocity is reached the signal decays only to recur and indicate rotation in the opposite direction when the spin is recovered. The pilot feels that he has actually entered a spin in the opposite direction and this somatogyral illusion may cause him to re-enter the original spin in an attempt to counter the apparent new one. The vestibulo-ocular reflex then stimulates a post-rotational nystagmus so that vision is impaired in parallel with the erroneous vestibular sensations. This visual component is called the oculogyral illusion.¹³ Fortunately, any sensory conflict is usually resolved quickly, but in extreme and rare cases the cycle may repeat itself until the pilot, who is usually inexperienced, crashes at the end of what has become a "graveyard" spin.¹⁴

The semicircular canals may also produce false sensations of movement when the head is rotated while the aircraft is turning. This phenomenon, the Coriolis effect, results from the introduction of a previously unstimulated pair of canals into the plane of movement. As a simple example, with the aircraft turning solely in yaw—a motion normally signalled by the horizontal canals—the head is rotated to the left and down to monitor an instrument. This manoeuvre brings the vertical canals into, and the horizontal canals out of, the plane of movement: there is acceleration of the first and deceleration of the last and the complex signals from the whole apparatus creates a bizarre vertigo in which the dominant illusory sensation is one of rotation in pitch.

Similar false sensations of angular movement may be precipitated by pressure changes transmitted from the middle ear cavity to the labyrinth via the round window. Such pressure changes are usually symmetrical, but if they should be unequal because of eustachian dysfunction then so called pressure or alternobaric vertigo may result.¹⁵ This uncommon condition is a further reason for the temporary grounding of aircrew with upper respiratory tract infections.

Linear accelerations are transduced by the otolith organs and proprioceptors and then interpreted by the brain. The brain does not, however, distinguish between imposed linear accelerations and acceleration due to gravity and regards their resultant perception as the true vertical. This perceptual limitation leads to

G = Acceleration due to gravity

FIG 5—Mechanisms by which pitch or somatogravic illusions may be produced. (After: Benson and Burchard⁷).

the somatogravic or pitch illusions (fig 5).⁷ Sustained forward acceleration ($+1\text{ Gx}$), as on take off, creates an inertial force which pushes the pilot back into his seat. When combined with gravity ($+1\text{ Gz}$) the resultant force is inclined backwards but is interpreted by the pilot's brain as the true vertical so that he feels that the aircraft is in a nose up attitude. The vestibulo-ocular reflex produces an oculogravic effect, which confirms the sensation of pitch by generating a visual field that is also pitching. The pilot's instinctive response is to correct the error by lowering the nose of the aircraft, an action that could obviously be disastrous. The opposite situation occurs during sustained decelerations—for example, when air brakes are applied. Thus at vital stages of flight the pitch illusions may have a catastrophic effect.

ILLUSIONS OF CEREBRAL ORIGIN

Correct sensory information may be misinterpreted by the brain—for example, causing errors of expectancy—but coning of attention (fascination), high or low arousal states, and other environmental stresses such as hypoxia and hyperthermia also affect the central nervous system. The break off phenomenon is, however, a purely central cause of disorientation in which the victim is subject to bizarre sensations of dissociation. This usually occurs when the sensorium is relatively unoccupied and unstimulated, as in straight and level flight at high altitude. Aircrew must be made aware of the possibility of such dissociative sensations under these circumstances lest they believe them to have a psychiatric basis.

Spatial disorientation must be regarded as an extension of normal physiology, which implies that it cannot be entirely prevented. The risks, however, may be minimised if the predisposing factors are known. Operational aircrew must be taught to recognise those environments (night, fog, cloud), phases (landing, take off, high altitude), and manoeuvres (spins, head movements, etc) which may lead to disorientation and to be particularly alert at these times. They must also learn to reject bodily sensations as unreliable. Within the aircraft itself clear, adequate, unambiguous, and reliable instrumentation should be suitably located to avoid unnecessary head movement.

The aircrew must be fit to fly and have no acute or chronic sensory disorder. The deleterious effects of hypoxia, heat, exercise, fatigue, cigarettes, drugs, and alcohol must be emphasised during training. Training itself and experience are invaluable assets, though even highly experienced aircrew are not immune.¹⁶

Next week's article covers further aspects of sensory disturbance due to flight.

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Are any tests advisable to screen people who wish to do marathon runs?

This question was initiated by a suggestion that all potential marathon runners should have a biochemical screen.¹ No doubt it could also be suggested that they should all have a cardiac risk factor assessment, maximal cardiac stress test, 24 hour monitored electrocardiography during training, and assessment of the risks of their becoming hypothermic or hyperthermic in adverse weather conditions. Most of the results from such mass screening of runners would be uninterpretable in terms of minor abnormalities and what risks they might predict. The costs (18 000 runners in the London Marathon) would be enormous for a minute "pay off" in finding any severe abnormalities that had remained asymptomatic. The London Marathon medical advice sheet suggests a gradual build up in training and warns runners that if they cannot run 15 miles fairly easily by one month before the marathon they should not take part. This is the only practical screen for such large numbers. If a runner has a high coronary risk or has any symptoms suggestive of coronary artery disease then he should certainly be screened further, but to submit thousands of joggers to biochemical screening on the basis of a few fatalities, whose causes are not fully understood, would be difficult to justify and would carry the implication that what is for the vast majority a pleasurable and beneficial form of recreation is much more dangerous than in fact it is. Not only could this be unhelpful, it could also be counter productive because biochemical screening performed after a prolonged training run might show abnormalities in completely normal subjects. If an older person wants to run a marathon a cardiac risk factor assessment is certainly justified but most runners are in their 20s and 30s and would not

willingly come to their doctor for investigation. (Any symptoms should of course be appropriately investigated.)—DAN S TUNSTALL PEDOE, medical director London Marathon.

¹ Whiting PM, Maughan PJ, Miller JDB, Leiper JB. Popular marathons: forecasting casualties. *Br Med J* 1983;286:395.

Is there any evidence that dieting by people in their 50s and 60s increases the likelihood of coronary thrombosis?

Obesity alone is not a strong risk factor for coronary artery disease but probably does assume greater importance when associated with other factors such as hypertension and hyperlipidaemia. What the questioner suggests sounds plausible but is, I am sure, rather rare. Hard evidence is difficult to obtain, but I am unaware of any study suggesting that dieting by people in their 50s and 60s increases the likelihood of coronary thrombosis. In the recently well publicised multiple risk factor intervention trial a "nutrition intervention programme" was prescribed. The main aim was control of serum cholesterol concentration, but weight reduction was sought in men whose weight was 115% or greater of desirable weight.¹ There was no report of harmful effects being observed. It must be admitted, however, that when multiple risk factors are treated at the same time it is theoretically possible that the harmful effect of treating one risk factor may be counterbalanced by the beneficial effects of treating another.—K O FOX, consultant cardiologist, London.

¹ Multiple Risk Factor Intervention Trial Research Group. Multiple risk factor intervention trial. Risk factor changes and mortality results. *JAMA* 1982;248: 1465-77.