Neurology in Aviation

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Abstract

Preparing an overview of neurology in aviation starts with a review of the Civil Aviation Safety Authority (CASA) guidelines. The CASA guidelines cover a range of neurological conditions such as: headaches; syncope and seizures; disequilibrium; degenerative diseases; and peripheral neuropathy. Trauma and post-traumatic amnesia are discussed, as is neurosurgical management. The role of routine neurophysiologic testing, such as electroencephalogy, is appraised and seizure receives further attention beyond the CASA rules. Other pathophysiologic factors are also examined to complete the overview and to serve as a basis upon which to evaluate aircrew, determine fitness to fly and offer support for ADF flying operations.

Introduction

When asked by RAAF Edinburgh to provide an overview of neurology in aviation for the aviation medical officer (AVMO) course and the AVMO refresher course, the magnitude of the task was more than evident.

The aim of the course is "... to prepare ADF medical officers and civilian health practitioners in order to provide aviation medical services to the ADF as AVMOs. This includes clinical management of aircrew, determination of fitness to fly and medical support to ADF flying operations ...". While it is accepted that aircrew in the ADF must achieve the accepted standards relevant to all aircrew, it is necessary to recognise that they may function within a much more hostile environment, as may occur in theatres of war or may be relevant to flying more sophisticated fighter planes, thereby necessitating additional considerations beyond those relevant to normal pilots.

Time allocation for the overview was 1½ hours, which really only permitted the broadest of overviews. Hence it was felt appropriate to offer a summary of the presentation to *Journal of Military and Veterans' Health* to capitalise on the research undertaken and to offer as comprehensive an overview as time and space would allow. The content of this paper does not specifically address many of the additional factors that are relevant to aviation within ADF operations, which may enforce more rigorous restrictions and expectations upon aircrew.

What follows is that overview of 'Neurology in Aviation'.

CASA Guidelines

It seemed appropriate to commence such an overview with a review of the Civil Aviation Safety Authority (CASA) Guidelines[1]. Topics covered in the Guidelines included: headache; blackouts; loss of consciousness and syncope; disequilibrium; seizures; head injuries; neurosurgery; cerebral infarcts; infections; dementia and degenerative diseases; extra-pyramidal diseases; demyelination; tumours and peripheral neuropathy[1]. This clearly reads like a textbook of neurology and to do it full justice would be well beyond the scope of an overview such as this. What follows will offer a succinct summary of the contents of the Guidelines.

CASA has adopted an approach to headache which favours a continuum of headache with tension-type headache at one end of the spectrum and migraine at the other. This is a concept favoured by the author[1,2]. What must be distinguished are primary headaches from secondary headaches, consequent to other causes, such as neuralgia, tumours or arteritis. A proper history defining quality of headaches, exacerbating and relieving factors, frequency, evolution, associated features, such as photophobia, phonophobia, visual symptoms, paraesthesia, severity and effectiveness of therapy are important deciding factors. It is important to distinguish migraine from transient ischaemic attack and also acknowledge the potential for migraine-induced stroke. CASA will consider each person on his/her merits and does not impose any blanket restriction due to diagnosis of headache[1].

It is recognised that terms such as 'blackout', 'loss of consciousness' and 'syncope' are open to interpretation in differentiating altered state of consciousness from vertigo, hysterical fugues, concussion, transient global amnesia or simple loss of vision. History is imperative and it is mandatory to try to differentiate neurological from cardiological causes. Again CASA assesses each case individually and advocates appropriate consultant involvement[1].

Disequilibrium may include benign paroxysmal positional vertigo (BPPV), acute peripheral vestibulopathy, Meniere's Disease and acute recurrent positional vestibulopathy (ARPV), alternative vertigo, momentary vertigo or non-functioning/hypo-functioning labyrinthitis, vestibular imbalance or multi-sensory dizziness. CASA maintains an individual response based on diagnosis and responsiveness to treatment. CASA also advises that treatment for disequilibrium may provoke drowsiness, which may itself be unacceptable for pilots[1].

When considering seizures, CASA has demonstrated flexibility stating "…tendency towards epileptic seizures is not an 'all or nothing' phenomenon. Most people, under certain conditions, may have a seizure if sleep deprived or withdrawing from alcohol or benzodiazepines, especially if in addition they are taking medications that decrease the seizure threshold…".[1]. CASA accepts 2% of the population will have a seizure and 30 – 40% of adults have a chance of recurrence after a single seizure[1]. Some research has suggested even higher prevalence figures for epilepsy, namely a tendency to recurrence of seizures, itself approaching 2%[3].

The aeromedical certification considerations concerning epilepsy require specialist neurological opinion; consideration of provocateurs; unavoidable concomitants of aviation (such as strobe lights, propeller flicker, fatigue, recognising that photically-induced seizures occur in ≤ 15% of people with epilepsy[4], difficult to avoid provocateurs such as menstruation (in association with catamenial epilepsy[5] and avoidable or insignificant provoking factors in the context of aviation, such as alcohol excess and/or withdrawal and sleep[1]. Individuals with established epilepsy, defined by CASA as experiencing >1 unprovoked seizure, are considered unfit for aviation medical certification. Those "…who have experienced seizures but who are not diagnosed as epileptic may be deemed to meet the medical standard…"[1].

CASA identified some special circumstances which include: partial seizures; sleep (nocturnal) epilepsy; childhood seizures; and single epileptiform seizures and deals with each of these separately[1]. As the involvement of a neurologist is mandatory in these cases – further discussion is unnecessary within the context of this overview.

The two concerns identified by CASA as relevant to head trauma, re fitness for aviation related duties, are the possible neuropsychological consequences and potential for post-traumatic epilepsy (PTE). The neuropsychological consequences result from acceleration/deceleration forces causing "…focal damage…to orbital, frontal and anterior temporal areas of the brain. Diffuse white matter damage may be associated with the cortical damage …"[1]. CASA has identified potential deficits in executive functioning regarding reaction times; memory impairment; decreased endurance of higher intellectual function; mental decline and fatigue; impaired attention span; diminished propensity to initiate or sequence activities; decreased capacity for planning; or ambivalence to performance level. CASA has recognised the possibility of subtle deficits with retained intellectual quotient and mental status that necessitate special neurophysiological assessment. It is also acknowledged that there is potential for these deficits to improve with time[1].

Duration of post-traumatic amnesia (PTA) received special attention, with PTA <1 hour resulting in suspension from aviation-related duties for 1 month; PTA of (1) – 24 hours causing 3 months suspension; and PTA > 24 hours resulting in suspension for at least 1 year [1].

Childhood febrile convulsions and/or a family history of epilepsy doubles the risk associated with any other markers for PTE[1]. PTE within the first week after trauma carries a 25% risk of later epilepsy [1] while overt convulsive activity immediately on impact does not increase the risk, although post-immediate convulsions are classed as 'early PTE'. Intracerebral haemorrhage, especially cortical, is associated with 25 – 45% risk of PTE[1]. Proper evaluation is essential, including imaging – preferably with MRI, but after the first week (period of 'early PTE') the risk declines exponentially such that by 2 years it is 20% of initial risk, by 4 years it is 10% and CASA accepts a risk of 1% for PTE to allow recertification[1].

Those sequelae most commonly resulting in failed assessment include: "…epilepsy; intracerebral haematoma; persisting CSF fistula; primary open cerebral laceration and the presence of any significant persistent neurological deficit…"[1]. Guidelines for recertification, as set out within the CASA guidelines, are considerably more restrictive than appears to be the case when reviewing the above rules[1] and include:

1. PTA ≤ 30 mins without sequelae and normal neurological examination may return to full duties in 3 – 4 months if CT is normal.
2. PTA ½ - 24 hours with normal MRI and EEG are acceptable after 1 year unless there was early PTE, which dictates individual assessment.
3. PTA > 24 hours with all else normal are fit after 2 years but may require flight stimulator testing.
4. Head injuries with intracerebral bleeds or focal deficits without significant neuro-psychologically proven deficits at 5 – 7 years post-trauma may resume duties after 7 years. Those with neuropsychological deficits will be assessed individually and MRI is required to evaluate bleeding.
5. Anti-epileptic medications (AEM) may mask PTE, hence seizure-free period only starts after AEM use has ceased and if still deemed at risk of seizures (>1%) then the person remains unfit[1].

Neurosurgery assessment is based on underlying disease and its prognosis; neurological deficits; type of surgery performed; risk of post-surgery epilepsy; and location thereof. All cases start as "doubtful" thereby necessitating individual approach[1].

Cerebrovascular disease necessitates consultant involvement and specialist opinion, which is beyond the scope of this review [2], which is also the case for central nervous system (CNS) infection (recognising that CASA imposes at least 6 months exclusion for both meningitis and encephalitis[1]. Dementia attracts special attention[1] and where there is doubt or discrepancy between reported and observed function then functional assessment is required and comparison with earlier testing may be helpful. Where dementia is considered progressive, "..an immediate "fail" assessment is likely …"[1].

Extrapyramidal disease (Parkinsonism) and demyelination (multiple sclerosis) necessitate consultant involvement in management and thus are largely outside the scope of this overview. Parkinsonism does not necessitate immediate exclusion but may demand more frequent assessment to monitor disease progression with a minimum of annual review and possible restriction of licence to "as or with co-pilot"[1]. Cases of multiple sclerosis are individually assessed with regular neurological review[1]. Intracranial tumours and peripheral nerve disease also mandate specialist opinion with the at risk peripheral disease being dysautonomia, which may cause syncope and is incapacitating[1].

Causes for pilot disqualification

In the past the most common cause for pilot disqualification was cardiological, which accounted for more than double that of neurology (0.59/1,000 pilot years cf 0.26/1,000 pilot years for neurological causes, 0.20/1,000 pilot years for psychiatric disorders)[6]. More recent data to emerge from Norway [7], with comprehensive data ascertainment incorporating 48, 229 pilot years, identified 275 who were permanently disqualified. The most common cause for such disqualification was neurological, bypassing cardiological and hence emphasising the need for the current review.

The rate of disqualifications due to cardiological disease declined after 1997, most likely because of improved 'evidence-based' approach to regulation, which reflects the significant advances in treatment and follow-up. Pilots with coronary bypass surgery may now return to unrestricted flying duties. The majority of those disqualified because of neurological disorders were disqualified due to CNS disorders often based on abnormal findings using neuropsychological tests[7].

Neurophysiological Tests

There are those who advocate use of routine electroencephalography (EEG) to screen prospective pilots even if they are asymptomatic[8]. Others challenge this approach[9]. The USAF stopped use of routine EEG screening in 1978, the USN stopped in 1981 and NASA stopped in 1995[9].

Various studies have cast doubt on the predictive value of EEGs [10-14]. When testing 28,658 student naval aviation personnel, 31 had potentially diagnostic epileptic EEGs, of whom 1 had a seizure, compared with 4 who had a seizure from the 28,627 with normal studies. This confirms both false positives and negatives, raising concerns as to cost effectiveness[11]. A prospective six-year study of EEGs in military pilots cast further doubt on its cost effectiveness[14].

Seizures, Epilepsy and Flying

US standards for commercial pilots diagnosed with epilepsy determines that they are automatically excluded from commercial flying. A private pilot may be recertified depending on certain circumstances with individual case assessment. The US may allow general aviation if the pilot has had a single seizure, was subsequently seizure free for 10 years and off all AEM[15].

The fact that a patient has a single seizure does not automatically generate a diagnosis of epilepsy. Moniago & Griswold[16] reported the case of a seizure occurring consequent to normobaric hypoxic training in association with sleep deprivation and failure of re-oxygenation (namely failure to adequately absorb oxygen) with application of 100% oxygen (oxygen paradox). The student, a day later, had normal neurological examination with two normal EEGs and a normal MRI of the brain.

Analysis of this case highlighted various factors related to seizures and capacity to return to flying[16]. These included: "…likelihood of incapacitation during flight; the severity of such an episode; the crew member's function in the aircraft; and the demands of the aviator's particular type/model of aircraft". A practitioner of aviation medicine must weigh severity and risk in determining an aviator's fitness for return to duties involving flight (16 at 488).

In the case described, the patient was an electronic countermeasures officer within a multi-seat aircraft rather than its pilot[16]. Based on full analysis, the case was deemed a provoked seizure based upon physiologic compromise with a low recurrence risk allowing the officer to resume full duties[16].

Pathophysiological Factors

Clinical neurology is usually practised in a normal environment (at one atmosphere of pressure) in circumstances of 21% oxygen and 78% nitrogen[17]. As demonstrated in the above-cited case[16] other environments have the capacity for toxic complications.

Aviation conditions can alter the normal environment due to hypoxia (gas at decreased pressure - also referred to as hypoxic or hyperbaric hypoxia), acceleration (affecting the vestibular apparatus) and volume effects from changes in ambient pressure that can be either gradual or rapid with the latter causing decompression.

The CNS is vulnerable to reduced oxygenation from a number of potential causes. These include: histotoxicity, hyperaemia hypoxia, stagnation or “stagnant hypoxia” or hypoxia with deficient alveoli oxygenation. Each of these terms warrants definition. Histotoxicity occurs when cells cannot use delivered oxygen due to dysfunction of the cytochrome oxidase system as may occur with cyanide exposure. Hyperaemia hypoxia relates to decreased capacity of red cells to carry oxygen as may occur with anaemia or carbon monoxide poisoning. Stagnation, or “stagnant hypoxia” occurs with inadequate blood flow as may occur with deceleration forces. Hypoxia with deficient alveoli oxygenation and ventilation/perfusion mismatch may occur with altitude which causes decreased pressure and air density.

Hypoxia may produce tunnel or blurred vision, fatigue, drowsiness and headache[17]. It may also produce confusion, altered behaviour, inco-ordination and loss of consciousness and even seizures[16]. A pilot may not recognise the effects of hypoxia, but if aware, then supplemental oxygen is required especially if above 10,000 feet altitude. If this is not possible then descent below 10,000 feet may be required.

Acceleration causing “G” forces, especially +Gz (eyeballs-down), may produce reduced vision and loss of consciousness (G-LOC) due to decreased retinal and brain perfusion consequent to blood pooling in the lower limbs[17]. This hydrostatic effect has particular relevance and is most important in military aviation with the blood pooling being a later phenomenon.

The sequence is impaired peripheral vision (with $PaO2$ <50 mmHg) to loss of central vision and blackout (with $PaO2 \leq 20$). With loss of consciousness, 70% will experience myoclonus (as occurred in the case report[16]. The EEG shows slowing with delta activity rather than epileptiform discharges[17].

Air emboli may result with 5% air emboli entering cardiac vessels and 95% travelling to cerebral vessels. Hyperbaric recompression and IV fluid therapy is indicated, as for decompression illness[17]. This is an issue for rapid decompression from high altitude (typically 25 k plus).

Conclusion

Full evaluation of neurology in aviation demands a detailed overview of most of neurology, which is both impracticable and largely impossible within this brief review. The salient features of the CASA Guidelines have been provided in support of the fact that neurological diagnoses present the most common cause for disqualification of pilots and aircrew. Routine neurophysiologic testing of asymptomatic flight candidates is non-cost-effective with both false positives and false negatives. Such tests should be limited to specific cases in which the clinical picture warrants further appropriate investigations. Seizures per se need not exclude flying duties, depending upon the diagnosis of epilepsy, the type of epilepsy and provocation. As with so many neurological diagnoses, the involvement of a consultant neurologist is a mandatory part of the patient evaluation. Just as hypoxia may result in a seizure, so too will neurology in aviation demand an understanding of the effects of pressure changes on neurological function.

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References

1. Civil Aviation Safety Authority *Designated Aviation Medical Examiner's Handbook* - 2 Medical Aspects – 2.5 Neurology – Approved by Assistant Director Aviation Safety Standards – Version 3.0, Dec 2003, Australian Govt, Canberra pp 2.5 (1 – 26)
2. Beran R G "Headache" *Medical Observer* 2008; May: 31 – 33
3. Beran R G, Hall L, Michelazzi J "An accurate assessment of the prevalence ratio of epilepsy adequately adjusted by influencing factors" *Neuroepidemiology* 1985; 4:71-81
4. Erba G "Preventing seizures from "Pocket Monsters" – A way to control reflex epilepsy" *Neurology* 2001, 57 (10): 1747 - 1748
5. Quigg M, Smithson S D, Fowler K M, Sursal T, Herzog A G, "NIH Progesterone Trial Study Group Laterality and Location Influence Catamenial Seizure Expression in Women with Partial Epilepsy" *Neurology* 2009; 73 (3): 223 – 227
6. McCrary B F, van Syoc D L "Permanent flying disqualification of USAF pilots and navigators (1995 – 1999)" *Aviat Space Environ Med* 2002; 73: 1117 - 21
7. Arva P, Wagstaff A S "Medical disqualification of 275 commercial pilots: Changing patterns over 20 years" *Aviat Space Environ Med* 2004; 75: 791 - 4
8. Hendrickson I J M, Elderson A "The use of EEG in aircrew selection" *Aviat Space Environ Med* 2001; 72: 1025 - 33
9. Clark J B, Riley T L "Screening EEG in aircrew selection: Clinical aerospace neurology perspective" *Aviat Space Environ Med* 2001; 72: 1034 - 6
10. King W H, Liske E"Electroencephalogram and aerospace safety" *Aerosp Med* 1974; 44: 90 - 1
11. Le Tourneau D J, Merren M D "Experience with electroencephalography in student naval aviation personnel 1961 – 1971: A preliminary report" *Aerosp Med* 1973; 44: 1302 – 4
12. Robin J J, Tolan G D, Arnold J W "Ten year experience with abnormal EEGs in asymptomatic adult males" *Aviat Space Environ Med* 1978; 49: 732 – 6
13. Everett W D, Akhovai M S "Follow of 14 abnormal electroencephalograms in asymptomatic US Airforce Academy Cadets" *Aviat Space Environ Med* 1982; 53: 277 - 80
14. Everett W D, Jenkins S W "The aerospace screening electroencephalogram: An analysis of benefits and costs in the US Air Force" *Aviat Space Environ Med* 1982; 53: 495 - 501
15. Drazkowski J F"Driving and flying with epilepsy" *Current Neurol. Neurosc Reports* 2007; 7: 329 – 34
16. Moniaga N C, Griswold C A "Loss of consciousness and seizure during normobaric hypoxic training" *Aviat Space Environ Med* 2009; 80: 485 - 488
17. Jaffee M S "The neurology of aviation, underwater and space environments " *Neurol Clin* 2005; 23: 541 – 52