SUMMARY OF PRESENTATION:

A REVIEW OF HIGH G RELATED ARM PAIN

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Introduction

This paper to explain the background and aetiology of arm pain, and place it into context when considering aircrew operating military agile aircraft. The predominant features of arm pain will be described, and consideration will be given to the underlying physiology of arm pain, based on the evidence currently available. The influence of aircraft operation and aircraft life support systems on arm pain will be explored, and finally some potential solutions to the problem will be offered.

Background

The RAF first encountered high G related arm pain in the 1970s. Forearm discomfort was reported by crews of the (then) newly introduced Hawk trainer aircraft, which at the time had a release to service of +8Gz. Flying instructors were most notably affected, and tended to place their arms on the aircraft canopy sills (above heart level) while their students were pulling high G. Arm pain has also been a regular feature for those riding the UK centrifuge at Farnborough. Although arm pain has often been encountered during development testing as part of the Eurofighter programme, it is not confined to such activities. Indeed, a large proportion of junior aircrew that attend high G training sessions using standard anti-G protection (at up to +8Gz) have also reported arm discomfort.

It has often been stated that arm pain is a 'centrifuge-only problem', but experience in the RAF CAM Hawk aircraft, operating at up to +9Gz has indicated that arm pain is also encountered in flight, given the appropriate acceleration envelope.

Features of Arm Pain

Pain is a very subjective sensation, by its very nature, and consequently there is considerable variation between individuals. Generally, arm pain is perceived as a dull, poorly localised pain in the forearm, elbow and wrist. It has been described as being similar to toothache, occurring deep within the arm. Arm pain is usually associated with the appearance of minor haemorrhages from ruptured capillaries in the overlying skin, termed 'G measles' or petechiae.

Tensing of the arm muscles under G has not been found to reduce arm pain in any way, and there is no simple measure aircrew can perform to alleviate their discomfort while flying the aircraft.

It has also been noticed that individuals can become 'sensitised' to arm pain – after the first exposure of a session, the threshold G level at which arm pain is noticed is reduced. This effect can take up to a week to wear off. There is also some anecdotal evidence that repeated exposure to arm pain may lead to some form of adaptation, such that the apparent severity of the pain is lessened.

Predisposing Factors

Arm pain is not usually experienced below +5Gz, and is unusual below +7Gz. It only occurs when the arms are positioned below heart level, usually on the stick and throttle. Arm pain is modified by the presence of G protective techniques, including positive pressure breathing, G straining and anti-G trousers, which will be discussed later.

Aetiology

The aetiology of high G related arm pain is poorly understood. Although bone pain, nerve pain, and joint pain have been suggested, the evidence available to date suggests that the pain originates in the vascular system of the arm, and is probably related to distension of vessels under increasing transmural pressure. The basis for this hypothesis is related to the increased vascular hydrostatic gradient that exists in the forearm under increased acceleration.

If vascular pressure in the forearm is measured during G exposure, a relationship can be demonstrated between pressure and perceived pain. In an experiment conducted on the Farnborough centrifuge, forearm venous pressure was measured via an indwelling catheter. Centrifuge subjects were exposed to a series of increasing acceleration profiles, and the magnitude of perceived arm pain recorded on a visual analogue scale. As the centrifuge G level was increased, forearm venous pressure also increased due to the hydrostatic gradient. A nearly linear relationship between venous pressure and pain was observed. Furthermore, there appeared to be a pain 'threshold' at a venous pressure of approximately 150mmHg.

This experiment demonstrated a relationship between pain, vascular pressure and acceleration through the hydrostatic gradient in the forearm. Further evidence supporting a vascular origin of arm pain is provided by the fact that arm pain is absent when the arms are elevated to heart level. In this position, the hydrostatic pressure gradient in the arms is removed, and vascular pressure does not rise above that generated by cardiac output.

One further observation strongly implicating the vascular system is the action of arterial occlusion. When inflatable cuffs were positioned on the upper arms of centrifuge subjects, and inflated to above arterial pressure, arm pain was removed.

In-Flight Experience

Measures of forearm vascular pressure have also been made in flight in the RAF CAM Hawk aircraft, with similar findings. Perceived pain levels were sometimes less than equivalent centrifuge exposures, possibly as a result of distraction by the flying task.

The acceleration profile performed in the aircraft also influences arm pain. Centrifuge profiles are typically sustained for 10-15 seconds at plateau acceleration, whereas in aircraft the time at peak G may be much shorter. Short exposures are anecdotally associated with less arm pain, and consequently the way aircrew fly and fight with the aircraft is important.

Arterial or Venous?

In the foregoing considerations, no distinction has been made between the arterial and venous components of the vascular system. At present, it is not clear whether the pain originates in arteries or veins. Veins are more compliant than arteries, by virtue of their thin-walled construction and paucity of vascular smooth muscle. Under conditions of high transmural pressure, vein walls undergo more distension than an equivalent artery, possibly triggering pain afferents via C fibres.

However, a recent ultrasound study has found changes in the brachial artery with exposure to arm pain induced by differential hypobaric exposure, possibly related to blood flow. This study also suggested that repeated exposure to arm pain caused habituation, such that perceived pain was reduced. Further work is required to define clearly the origin of arm pain.

Influence of Life Support Equipment

A recent study carried out at Farnborough has demonstrated that positive pressure breathing for G protection lowers the threshold at which arm pain appears, by approximately 1G. The effect of anti-G trouser coverage is, as yet, unknown. However, one might hypothesise that the increased support of venous return by full coverage trousers has a greater effect on arm pain than standard 5 bladder suits.

Consequences of Arm Pain

The most obvious consequence of arm pain is that the aircraft's operating envelope may be limited by the pilot. If it is painful to pull +9Gz, aircrew will be unwilling to do it. No long-term effects of arm pain have yet been recognised, but it is conceivable that changes in the forearm vasculature might occur, if regularly exposed to high pressures. Possible outcomes of such exposure might involve varicosities of arm veins, or damage to vascular endothelium although neither has yet been observed in relation to high G exposure.

Prevention of Arm Pain

It is already understood that if the hydrostatic gradient in the arms is removed, no arm pain occurs. Unfortunately, for most aircraft already in production, major changes in cockpit geometry are impractical. Likewise, although arterial occlusion may be effective, it is impractical. Recent studies in the US and UK have shown full arm counter-pressure, particularly in combination with hand counter-pressure, is effective. However, the additional bulk of flying clothing may be unacceptable to aircrew.

The Swedish Air Force has found success with a partial arm counter-pressure system, positioned on the upper arm, although the mechanism of action of this device is not clearly understood.

Alternatively, the G protective system could be changed by removing pressure breathing for G protection, with attendant increased risk in G Induced Loss of Consciousness. Other solutions to G protection, which apparently are not associated with arm pain, such as Libelle, are also under development.

Summary

In summary, high G related arm pain is a consequence of current aircraft performance, current cockpit geometry and to a lesser extent current anti-G protection. It is considered likely that preventative measures will need to be taken in some agile aircraft types.

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