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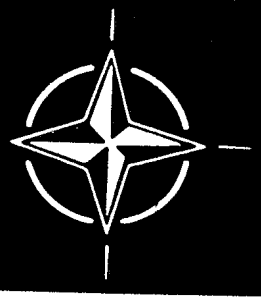

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POSTURAL FATIGUE AND THE BACKACHE OF HELICOPTER PILOTS

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Summary

A review of the literature on the back pain of helicopter pilots suggests that postural fatigue, rather than specific injury to the spine, may be the cause of much of the reported pain. Postural fatigue is defined here as fatigue in specific muscles whose continuous activity is required to maintain a working posture. Descriptions of the back pain of helicopter pilots are compared with those of the phenomenon of postural fatigue. It is significant that there is a strong association between the pilot's back pain and actual flight duty, in fact, pilots often blame their helicopters, rather than their own health, for their pain. Biomechanical aspects of the pilot's environment and of tasks within the cockpit are assessed as potential causes of postural fatigue. Both posture and vibration within the cockpit may be possible causes, since both conditions may impose continuous activity on muscles of the lower back. Postural fatigue is a temporary problem, but the causes of postural fatigue, such as sedentary work in awkward postures, are considered by many authors to be related to increased incidence of chronic back pain, back disease and related disability. Repeated exposure to postural fatigue may increase the likelihood of mechanical back injury by reducing the effectiveness of the protection given to the spine by its supporting muscles during tasks involving bending and lifting. Electromyography has been used to index postural fatigue in the laboratory, as well as in the civilian work environment. By objectively defining muscle activity and fatigue, electromyographic methods may allow the objective assessment of different ergonomic proposals to relieve the back pain in helicopter pilots.

The Back Pain of Helicopter Pilots

For about a quarter-century, the medical authorities of many armed services have described the phenomenon of pain in the lower back among helicopter aircrew [1]. The most comprehensive review of this problem is the chapter by Delahaye and his co-authors [2] in the book: "Physiology and Pathophysiology of Spinal Injuries in Aerospace Medicine." (I have used the English title of the translation by P. Howard.) These authors describe the phenomenon as follows:

> "Chronic lumbar pain is the most common complaint. The picture is of a low-grade, tiring, heavy ache localized in the lumbar region, or sometimes lower (lumbo-sacral pain). It extends laterally, often predominantly to one side, and may radiate to the buttocks, the iliac crests or, more rarely, the groin. This discomfort is brought on by flight, aggravated by lifting effort or by long car journeys, and relieved by lying down and by physiotherapy.
>
> At a higher level of intensity, this discomfort becomes a pain which makes flying very gruelling so that, despite the constraints upon the position of his limbs, the pilot seeks to change his posture. The pain increases in intensity during the last flight at the end of the day, and reaches a maximum when the pilot lands the aircraft. Although it persists during the evening, it tends to diminish, but reappears on standing. It disappears after a night's rest."

The severity and prevalence of the problem called "idiopathic low-back pain" is widely known. It ranks among the more common reasons for seeking medical help in the industrialized countries. Back disorders in general are an important cause of worker disability. Thus, the words "backache", "low-back pain", or the many synonyms for this condition, call to mind a chronic condition associated with considerable pain and costs.

The relationship between the problems of a helicopter pilot and the common phenomenon of idiopathic low-back pain is an important question. Is the problem of back pain in aircrew, which has been reported and discussed so frequently by military authorities, the same as the problem which costs the civilian population so much in medical treatment, lost time, and compensation?

The description of the helicopter pilot's complaint quoted above from Delahaye *et al.* [2] resembles the description given of idiopathic low-back pain given in

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text-books on the subject, such as that by Finneson [3]. However, there are some differences between the two phenomena which are worth mentioning. Shanahan [4], in a recent lecture, has observed that the incidence of back pain in the civilian population, although high for a disease, is much less than the reported incidence of back pain in surveys of helicopter aircrew, which sometimes reaches 100%. The other significant characteristic of the helicopter pilot back pain problem is its strong association with actual flight duty.

Back pain in the civilian population is usually reported to medical professionals by patients who have suffered chronic pain for many days. Although there are some patients in which a rapid onset of pain is associated with a particular activity, such as bending or lifting, there are many patients who cannot remember the occasion of the onset of their pain [5].

In contrast, the helicopter pilot's back pain is closely associated with actual flight duty. Fitzgerald and Crotty [6], in a general survey of aircrew and groundcrew in the UK Royal Air Force, found that over half of the 300 pilots who experienced frequent in-flight backache never suffered from backache on the ground. In a previous AGARD conference, Schulte-Wintrop and Knoche of the Federal Republic of Germany reported on a survey of 145 helicopter aircrew that 40% complained of back pain during flight and 51% of back pain after flight. In only 39% of the cases, the back pain was described as a lasting one.

Shanahan [4] reported on a survey of 802 U. S. Army aviators which found that 72.8% experienced back pain while on flight duty, while only 14.5% had symptoms which persisted longer than 48 hours. Singh [7] reported that all of a group of 21 Chetak pilots in the Indian Air Force experienced back pain in flight, but this was relieved in all cases by rest.

There has not been a formal survey of Canadian helicopter pilots published recently, but informal reports indicate that there is also a strong association between back pain and actual flight duty in Canadian Forces pilots.

All these results suggest the conclusion proposed by Shanahan [4]: there are two groups of pilots who suffer from back pain, a majority who suffer a temporary pain which is felt only during and immediately after flight, and a minority who suffer from chronic pain, which resembles the problem known as idiopathic low-back pain in the civilian world.

Shanahan proposes that repeated exposures to the temporary pains of flight may lead to persistent pain in time. It is probably premature at this time to say that helicopter flight duty is a proven risk factor in chronic low back pain or the related disorders, such as herniated intervertebral disks or sciatica. However, the fact that similar activities in the civilian population, such as professional driving, are proven risk factors [8] suggests that this may well be the case.

The temporary pain associated with flight should not be ignored. Many authors, and some pilots, acknowledge that it may induce a pilot to modify his flight plans or distract him from his mission. It may be a more significant problem for the military use of helicopters at a future time when helicopters are required to play a greater role in military operations and longer and more arduous missions are undertaken.

It is also likely that, through understanding the temporary pain, better knowledge of the causes of the chronic pain may be obtained.

Given that the temporary back pain of helicopter pilots is a phenomenon and operational problem in itself, how can we most easily understand its causes and provide relief for the afflicted pilots? This essay proposes that the pain arises from postural fatigue. This hypothesis is not new; the concept of fatigue as the source of discomfort in helicopter pilots has been mentioned by other authors [5,7,9,10]. It deserves some examination in detail, both as a focus for future research and as a guide to those who are attempting to relieve the problem.

Postural Fatigue

"Postural fatigue" is the condition which arises when an awkward posture is maintained for a long time. Arndt [11] describes the phenomenon, as experienced by video display operators, as follows:

> "While the amount of effort required to maintain the various postures involved in (video display terminal) work depends on the position of the trunk, the limbs and the head, the maximum capacity of the musculoskeletal system is ordinarily not approached, even in the most extreme positions. However, such jobs often involve prolonged periods of constrained posture characterized by static loading of muscles. Under such conditions, blood circulation may be reduced, preventing the proper supply of nutrients to the muscles and removal of muscle activity by-products, leading to rapid fatigue and pain. If these conditions persist on a daily basis, the result may be chronic problems often including the joints and tendons."

A number of investigators have reported on the temporary discomfort caused by the maintenance of awkward postures, without describing the phenomenon as fatigue. The source of discomfort may be the sustained stress on joints, ligaments or tendons, which may create discomfort through interference with normal blood flow and nutrition of tissues [12].

Postural fatigue appears to be distinct from the muscle fatigue induced by strong contractions in that:

a. the muscles involved are active at levels which are a small fraction of the maximum voluntary contraction force;

b. the evidence of fatigue is muscle pain, rather than the diminution of force (which is the criterion given by Edwards [13], among others); and

c. the fatigue takes a much longer time to occur than is usually the case in studies of sustained contractions.

Muscle fatigue is a complex phenomenon, in which different causes (force, duration, duty cycle, blood flow, muscle type and motivation) play a part, and many different effects (reduction in maximum force, pain, stiffness) are produced. Physiologists have studied the relationship between the causes and effects of this phenomenon extensively for many years. A CIBA foundation symposium [13] provides a summary of recent research. Most studies have examined the effect of relatively brief, nearly maximal contractions or exercises on the performance of individual muscles.

One phenomenon of relevance to the study of postural fatigue is the "low-frequency fatigue" described by Jones [14] and by Edwards [15]. This is induced after a long series of ischaemic contractions and persists for several hours, as a reduction in the force response to nerve stimulation at frequencies less than that required for the production of the maximum tetanic force. The cause of the slow recovery is believed to be damage to the internal tubule system of the muscle. The association between this fatigue and pain is not described by these authors.

Other authors attribute the temporary pain associated with sustained contractions to the accumulation of lactic acid or other products of muscle metabolism. The relationship between the pain associated with fatigue and impairment of blood flow has been mentioned by several authors [16-18]. The impairment of blood flow appears to be as significant a factor in the development of pain as the actual exertion of the muscles. This impairment can arise either from external pressure or the internal pressure developed in an active muscle [19,20].

The development of fatigue in sustained muscular contractions and the process of recovery have been studied by Monod and his colleagues (as reviewed by Monod [21]) and by Rohmert [22,23]. The application of their findings to postural studies has been discussed by Corlett [24] and by Corlett and Manenica [25]. There is some disagreement about the effect of contractions which are a small fraction (less than 10%) of the maximum voluntary contraction (MVC). Whereas Monod and Rohmert suggest that there is a "critical force", about 15% of the MVC, below which an exertion can be held for an indefinite time, Corlett states that the "critical force" is no more that 8% of the MVC, and suggests a definition of "indefinite" which "restricts it to about 30 minutes" [24]. This disagreement probably arises from the behaviour of different muscle groups, as well as the difficulty in measuring the effect of a small contraction held over a long period of time. Corlett's observations apply more specifically to the muscles of the lower back.

The Use of Electromyography in Determining Postural Fatigue

Electromyography has become a method of choice for investigation of the effects of awkward postures and the development of postural fatigue. Earlier investigators used the simple amplitude of the electromyographic (EMG) signal to estimate the level of activity in the back muscles [26-30]. This is valuable for estimating the force produced by a muscle group, and, indirectly, the stress on associated joints and ligaments. It has been used this way in studies of biomechanical models of the spine by Nachemson [31], and by Andersson and his colleagues [32-38]. The relationship between the EMG signal amplitude and muscle force is not an exactly linear one in all cases, as noted by Grieve and Pheasant [39]. However, if the posture of the subject and the length of the muscle under study are controlled, the EMG signal is a good relative index of muscular force.

It has been known for some time that there are changes in the electromyogram which are associated with muscle fatigue: (see the review by Lindstrom and Petersen [40]) and, in the last fifteen years, the computer analysis of electromyograms has allowed the routine application of techniques which use this phenomenon. The principal change in the EMG signal is a shift in the frequency spectrum towards lower frequencies [40-43]. This can be measured as a shift in the mean power frequency, as described by Lindstrom et al., [44,45] or as a shift in the median power frequency as described by de Luca and others [46-48].

A reason given for the change in the EMG spectrum is a change in the conduction velocity of action potentials in the muscle fibres; this is likely to be the consequence of changes in the membrane or internal tubule system caused by the accumulation of metabolites [49,50]. The changes in the EMG signal precede the development of pain in some muscles [41].

There are now many examples of the use of electromyography to demonstrate the fatigue caused by sustaining awkward postures. Andersson et al. [18] demonstrated the increased EMG activity in the back muscles of automotive assembly workers. Herberts and Kadefors [12] used the EMG technique to study the shoulder pains of welders in the shipbuilding trade; they have to hold their arms above their shoulders while performing welding tasks. More recent studies show that this posture leads to rapid fatigue [51], and increased intramuscular pressure in certain muscles of the shoulder. [52] Malmqvist et al. [53] has shown the same phenomenon in certain building trades, and Magunsson et al. [54] have shown it among butchers.

Postural Fatigue in the Helicopter Pilot

Delahaye and his colleagues [2] identify two potential causes of back pain in helicopter pilots: the posture of the pilot in the cock-pit and the vibration of the helicopter. Most investigators agree on the importance of one or the other of these causes. Whether posture or vibration alone can be considered as the major cause is not yet answered, and the relative importance of these causes will be an important topic for discussion at this meeting.

Three important aspects of the posture of a helicopter pilot appear to be principal factors in the genesis of low-back pain. They are:

a. the "helicopter hunch", the forward-leaning posture required in order to place the right elbow on the thigh for precise positioning of the cyclic control stick;

b. a twisting or bending of the trunk in order to reach the collective lever (this may be unnecessary for some pilots in some helicopters); and

c. the fact that all four limbs are engaged in the control task, permitting no change of the posture during the period when the pilot is in actual control of the aircraft.

Other factors identified as contributing to discomfort and pain are, the requirement to extend the neck for normal forward viewing while holding the "hunched" posture, stresses from backpacks or seat restraint systems on the upper back, thermal stresses (particularly, exposure to cold drafts [7,55]) and the natural tension created by involvement in a difficult task.

Individual seat and control designs can aggravate the postural stress. In particular, seats without adequate lumbar support and cockpits without adequate head clearance [56] can prevent the pilot from assuming a relaxed posture even when control is passed over to the co-pilot.

It is important to note that each of the above-named postural causes of discomfort is associated with increased activity in major muscle groups in the trunk.

The increase in muscular activity in the erector spinae muscles of a person who leans forward while sitting is well documented [32,37]. Similarly, the maintenance of a twisted or leaning posture has been shown to require extra muscular activity in the lower back [28,57].

The fact that the pilot cannot easily change his position while he is in control of the aircraft implies that the stress on postural muscles is often maintained for longer periods than is desirable. The pressure caused by muscular action and the pressure on the back and buttocks from the seat impair blood flow and accelerate the development of fatigue.

Troup [58] has noted that the psoas muscle which originates in the lumbar spine, is used by truck drivers every time they lift a foot from a pedal. Thus, continuous activity of the feet on the pedals may require continuous activity of the psoas muscle, and consequent fatigue. Helicopter pilots should be at least as vulnerable to this effect as truck drivers.

The development of muscle fatigue in the back muscles will be accelerated if the pilot is exposed to a high workload. Activity of back muscles increases during concentration at work [59] and has, in itself, been used as a measure of workload-induced stress [60].

Whole-body vibration has been understood to be a source of discomfort for many years. The vibration of helicopter cockpits has been identified by some authors, including Delahaye and his colleagues [2], as a significant factor in the genesis of pilot back pain. The International Organization for Standardization Guide for the

evaluation of human exposure to vibration (ISO-2631) [61] includes a "fatigue-decreased proficiency" boundary to tolerable vibration limits. The "fatigue-decreased proficiency" boundary was considered by those drafting the guide to be the intensity of vibration above which the preservation of working efficiency would be threatened [61]. Although this limit is the subject of some controversy, there is some evidence that muscular fatigue increases with vibration exposure [62].

Several authors have studied the response of the back muscles to vertical whole-body vibration, and have shown that there is activity in these muscles which is in step with the applied vibration at lower frequencies [63-65]. This activity could be the response of the stretch reflex to changes in body geometry caused by the different response of the pelvis and upper torso to the applied forces. Recent results from Bluthner et al. [66] suggest that this response may not be effective in attenuating vibration. In any case, the activity must contribute to fatigue.

In addition to the direct response to vibration, there is also the possibility that the human subject may use his muscles to stiffen his torso against the effects of vertical vibration. Griffin [67] explored this phenomenon, and found that a subject would naturally adjust his position and muscle tone in order to shift the resonant frequency of the body away from the frequency of the applied vibration. Vibration may also discourage the use of a seat back as a support for the body, since, as Rowlands [68] discovered, the seat back can affect the transmission of vibration to the head. These separate observations suggest that vibration exposure (and possibly exposure to the vibration of helicopters) increases the activity in the muscles of the back. Whether this is sufficient to cause fatigue, has not yet been answered in the literature.

All of this evidence indicates that the pilot of a helicopter is likely to show continuous activity in the muscles of his back as a consequence of the various stresses induced by the task and the cockpit environment. This activity will be sustained at least for the time that he is in control of the aircraft, and may persist for the duration of a flight. It will be accompanied by impairment of circulation from the external pressure of the seat and restraints, and possibly by local cooling of the muscle by cold drafts. All this should lead to a painful ischaemic fatigue, from which the muscles would, as Jones [14] noted, take hours to recover. Whether this is the cause of the helicopter pilot's back pain is now a matter of speculation. There is clearly an opportunity to study the posture and behaviour of the helicopter pilot with the same methods that have been applied to industrial workers who suffer from postural fatigue as a result of their workplace.

Postural Fatigue and Chronic Back Pain

Many authors have noted the epidemiological connections between occupations which demand awkward postures and chronic backache [8,58,69-74]. In the case of vehicle drivers and pilots, the effects of awkward posture are often complicated by the effects of vehicle vibration, which, as described above, may contribute to fatigue.

There are various hypotheses concerning the role of vibration and posture in the genesis of chronic back pain. The effects of mechanical loads have been reviewed by Sandover [75,76], who suggests that the stresses on the intervertebral discs and end-plates may cause local fatigue (in the engineering sense of the word) or impair the nutrition of the discs through the end-plates. In addition, the intervertebral disc loses height when exposed to compressive stress [77], particularly when vibration is superimposed on it. The bending postures which increase the muscular activity of the erector spinae muscles also increase the pressures in the intervertebral discs by proportionate amounts, so that the possibility of impaired nutrition or fatigue failure is increased. It is possible that these are the causes of the changes which are felt as chronic backache, however, it is difficult to test this hypothesis experimentally.

On the other hand, some investigators have suggested that there is a component of chronic back pain which is related to muscle function and muscle fatigue. Floyd and Silver [26], in their early electromyographic studies noted that patients with back pain showed no reduction in EMG activity in the lumbar erector spinae muscles during extreme forward bends, but healthy subjects did. De Vries [78], Troup and Chapman [79], and Jayasinghe [80] have sought evidence of increased fatiguability in the erector spinae muscle of patients with back pain. Suzuki and Endo [81] have found that patients with lowback pain are weaker in tests of maximal lumbar flexion and extension force than controls. However, this may be the consequence of a reflex response to back pain rather than a cause of the pain.

Another occupational risk factor for back pain and related diseases is heavy physical work [82-84]. Lifting, pushing and pulling often impose the largest stresses on the muscles as well as the intervertebral disks and these activities are often associated with sudden attacks of low back pain. It is possible that drivers and others who are exposed to postural fatigue of the back muscles may become more vulnerable to severe injury from lifting because of the weakening effect of their fatigue, which may last for several hours after the fatiguing posture is relieved.

Conclusions

It may never be possible to completely understand the mechanisms whereby the postural constraints and vibration of the helicopter cockpit can induce either the temporary back pain associated with actual flight duty, or chronic back pain in the helicopter pilot. It appears inevitable that forces transmitted through the body will be shared by muscles as well as ligaments and joints. Therefore, all of these organs will show the effects of chronic exposure to stress. Similarly, the activity of postural muscles, whatever causes it, will impose additional stresses on tendons and joints.

The intent of this article was to focus attention on muscle fatigue as a cause of helicopter pilot back pain. The most prevalent form of back pain among helicopter aircrew is a temporary pain which is brought about by actual flight duty and relieved by rest afterwards. This resembles, at least in its time course, the effects of muscular fatigue. There is indirect evidence that the back muscles of an active helicopter pilot must be more active than normal and that they may also suffer from impaired circulation. Thus, it is possible that flight duty can bring on this localized fatigue.

This argument does require further research, if it is to be supported or refuted. Quantitative studies of the posture and activities of pilots in flight should be made in order to determine how much activity is produced in the muscles of the lower back and how much fatigue is produced by this activity. It is possible to do this using electromyography, and Pope and his colleagues [65,85] have approached this in their studies on vibration. The pressure within the muscles and the effective blood flow might also be measured.

How does the concept of postural fatigue affect those involved in designing helicopters and planning the use of helicopters in combat and other military operations? There is now an intense research and development effort directed towards making helicopters (and other aircraft) easier to fly in complex operational situations. Stability-augmentation systems eliminate much of the work required for simple attitude control. The workload can be further reduced by improved controls and displays. Ergonomists have defined better criteria for the positions of the cyclic and collective controls [86].

A more radical approach to helicopter controls is being pursued by authorities in the United States and Canada, where multi-axis side-arm control designs are being flight tested in experimental helicopters [87-89]. Preliminary studies of these controls indicate that the associated arm rest, and the improved back posture, lead to a great reduction in the back pain induced by actual flight (J. M. Morgan, personal communication).

At the same time, helicopter vibration reduction has been an important goal in new aircraft designs [90,91]. Vibration-attenuating seats and cushions are also being developed, in order to improve the comfort of those pilots who must contend with the current helicopters of our armed services [92,93].

In addition, new seat designs, or modifications to existing seats, are being proposed for many helicopters in order to improve the lumbar support offered by the seat and the comfort of the seat pan [7,94].

The cumulative effect of these improvements may be that the incidence of back pain associated with helicopter flight duty may be reduced, or that the permissible flight duty periods may be extended. However, design engineers, who have to work with the constrants of crashworthiness, restraint for the pilot, reduction in weight and other limitations, may be tempted to choose a single "ideal" posture for the pilot of a future helicopter, and suit their designs to this one position. In doing this they may fail to allow any changes in posture during flight, whether or not the aircrew member is in actual control of the aircraft.

Studies of postural fatigue and seated posture have emphasised the importance of regular changes in the seated posture during the time that an individual is seated [95,96]. It is not unrealistic to state that even the most comfortable seat may become a "torture-chamber" if one is forced to occupy it in a fixed position for an extended period. Pressure, whether from surfaces external to the body or from active muscles, must be relieved periodically, or the impairment of blood flow will lead to fatigue and pain.

One can see the potential for postural fatigue in proposals for "heads-up" displays or visual pointing systems for weapons control which demand a fixed eye-point for the pilot. Similarly, those who propose that the improved controls and seating of future helicopters will permit them to be flown by a single pilot [97], will have to consider the likelihood of postural fatigue, even in the most advanced cockpit.

However, if it is indeed true that the pain of muscle fatigue is a limiting factor in helicopter operations, there is the hope that a quantitative understanding of the process of fatigue and the need of muscles for rest will lead to prescriptions for work schedules which will make the maximum effective use of a helicopter pilot's abilities.

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