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BACK PAIN IN HELICOPTER AIRCREW: A LITERATURE REVIEW

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Back Pain in Helicopter Aircrew: A Literature Review

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Back pain in helicopter aircrew has been reported by the armed services of many countries. The problem is compared to the similar phenomenon of back pain in civilian industrial groups, particularly drivers and the operators of heavy equipment. In both drivers and helicopter aircrew, posture and vibration exposure have been identified as causes of the back pain. The significance of these factors, and the mechanisms that relate them to the discomfort, and possible solutions are discussed.

BACK PAIN in helicopter aircrew has been reported by the medical authorities of armed services since the early 1960's and has been the subject of recent reviews (6,12,55). Delahaye and his colleagues have reviewed the subject in "Backache in Helicopter Pilots," Chapter 6 of *Physiology and Pathology of Spinal Injuries in Aviation Medicine* (12). At a recent NATO-AGARD Aerospace Medical Panel Specialists' Meeting on backache and back discomfort, several papers on this problem were presented.

The values for the incidence of back pain in helicopter aircrew that have been reported by various authors are generally high. Delahaye *et al.* (12) have tabulated data given by earlier authors, which indicate incidence rates of from 21% to 95%. It is not possible to verify in all cases how the data were obtained or how large a group was surveyed. Table I is a summary of the results given in five recent publications available to the author. Each of these describes surveys that were conducted by distributing questionnaires to samples of all members of an operational group. Most of the authors do not state whether there were any unanswered questionnaires or how the respondents may have been selected from the group they represent. Shanahan *et al.* (54) state that 1,100 questionnaires were distributed and 802 were returned.

A general picture of the back pain in helicopter aircrew is as follows: The back pain is most likely to appear in the pilot during a flight mission. A certain amount of time must be spent in the air before it appears. The time depends on the pilot, the helicopter, the type of mission, and the total flying hours in a day or even in the previous month. Typically, this time is between 2 and 4 h. In addition, according to Delahaye *et al.* (12), pilots must have a certain amount of flight experience, anywhere from 300 to 1500 h, before back pain is noticed. This latter observation has been contradicted by the results of Shanahan *et al.* (54), who note that over half of their respondents reported back pain before the first 100 h of flight. They attribute the discrepancy to a difference in experience between the populations of pilots studied.

The frequency and severity of low back pain probably depends on the type of helicopter, although there is no evidence from controlled studies from which to assess the differences. Delahaye *et al.* (12), Fitzgerald and Crotty (17), and Reader (46), report that certain helicopters are identified by pilots as being worse than

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TABLE I. REPORTED INCIDENCE OF BACK PAIN IN HELICOPTER AIRCREW.

Authors, Date (ref. #)	Number of answered questionnaires	Percent reporting discomfort or pain during flight	Percent reporting pain not relieved by rest or within 48 hours
Schulte-Wintrop & Knoche, 1978 (52)	145	40.0	15.8
Malik & Kapur, 1981 (37)	113	58.4	3.5
Singh, 1983 (57)	21	100.0	0.0
Shanahan *et al.*, 1986 (54)	802	72.8	10.6
Froom *et al.*, 1986 (19)	264	57.6	3.4

others for producing back pain, usually because of uncomfortable seating.

According to Delahaye *et al.* (12), the back pain is usually sensed in the lumbar region, and is a dull ache, associated with a tired feeling, although it can grow to an excruciating intensity if the pilot continues to fly. Some pilots may experience pain in the thoracic spine, and in the shoulders and neck as well.

In most sufferers, back pain is relieved by bed rest after the flight duty is over. Shanahan *et al.* (54) reported that, of a group of 802 U. S. Army helicopter aircrew, 72.8% suffered from back pain during and after flight, but only 10.6% reported that the pain lasted longer than 48 h after landing. They suggest that there may be two populations of back pain sufferers among helicopter aircrew, a small one that suffers chronic pain similar to idiopathic low-back pain, and a larger one that experiences temporary pain only during and immediately after flight.

Chronic back pain is one of mankind's most common and yet most mysterious ailments. Over 60% of the population in an industrialized country will admit to having suffered from back pain at one time (2), and it is among the most frequent causes of disability and lost production in the civilian workforce (20).

The phenomenon of "idiopathic low-back pain" is a major part of this problem and resembles some aspects of the helicopter pilot's pain. In particular, it is most commonly felt in the lumbar area and in many patients, is associated with a tired or weak feeling (15).

There are peculiar aspects to the helicopter pilot's problem, however. While pilots are ready to blame their flight duty for their discomfort, many other back pain sufferers may not associate any particular activity with the onset of their pain (55). The pain reported to civilian doctors is more likely to be a chronic pain, associated with a limitation of movement and interfering with work.

The difference between the description of back pain in helicopter pilots and that of idiopathic low-back pain in the civilian population may be an indirect result of the difference in the ways that the phenomena have been studied. Epidemiologists, such as Kelsey and Hardy (33) or Gruber (24), have relied upon medical records of visits by patients to health professionals to identify those in civilian populations who suffer from back pain or related diseases. Thus they will only describe those patients whose pain has persisted to the point where medical treatment is sought. The surveys of helicopter pilots have attempted to cover a selection of all pilots, and would include individuals who have experienced temporary pain, but have not been driven to seek medical treatment. It is this latter group that has defined the characteristics of helicopter pilot back pain.

There may also be real differences between the phenomena. Although idiopathic low-back pain is common, it is not as common as the helicopter-induced pain appears to be (55). Although there are some groups, such as tractor drivers (43), who associate the development of chronic complaints with their work, most cases of back pain reported in the civilian population are either associated with a specific injury, or have taken so long to develop that their causes are obscure even to the patient (15).

The temporary form of helicopter pilot back pain is, thus, far more prevalent than is idiopathic back pain in either helicopter pilots or the general population. As pointed out by Shanahan *et al.* (54), it should be considered significant for two reasons: a) it distracts a pilot from his mission, and may cause missions to be shortened or refused; and b) there is the possibility that repeated exposures to the causes of temporary pain may produce chronic pain or disability.

Apart from the studies of Shanahan *et al.* (54) and Froom *et al.* (19) mentioned above, there have been no recent studies of the prevalence of chronic back pain and back disease in general among helicopter pilots. Delahaye *et al.* (12) report that 2 of a group of 12 helicopter test pilots required surgery for herniated lumbar intervertebral discs. Froom *et al.* (18) report that lumbar spondylolisthesis was significantly more prevalent among a group of helicopter pilots than among a group of non-flying cadets, and noted that the association between this condition and low back pain was significant. The relations between helicopter flight duty and chronic low back pain and back injury require further investigation.

Any review of the back pain of helicopter aircrew would not be complete without a discussion of the incidence and type of back pain encountered in other pilots, those engaged in professional driving or the operation of tractors or heavy construction machinery, activities similar in many ways to that of helicopter aircrew.

As mentioned above, back pain among tractor drivers was identified long ago as a special problem (43). Kelsey and Hardy (33) found that professional drivers were at increased risk of herniated lumbar intervertebral discs. Other investigators working for NIOSH investigated the medical records of heavy equipment operators (39,59,67), truck drivers (24) and bus drivers (23) to determine if they were more likely to suffer from back diseases. Their results were inconclusive, and one of the explanations given was that those who suffered from back pain were more likely to change to a different job, a conclusion verified by Backman and Jarvinen (3). The relationship between driving and back pain has been reviewed by Sandover (50) and by Troup (61,63).

As mentioned above, studies of the civilian population show that civilians are largely silent about back pains that are not prolonged or severe enough to drive patients to seek medical assistance. Some investigators have found evidence of temporary pain arising from driving. Hall (26) reported that 16 of a group of 17 test drivers for a consumer test organization suffered temporary pain after driving long distances in a car, although only 6 suffered from chronic low back pain. According to Hill *et al.* (28), 23 of a group of 62 drivers of tanks and armored personnel carriers stated in a questionnaire that they experienced low back pain while driving, but only 6 reported that the pain persisted for more than 24 h. Zerlett (67) reported that 75% of 352 operators of earth moving machines experienced back discomfort during work but only 59% experienced discomfort after the shift. These reports support the contention of Troup (63) that temporary back pain may be the most common form among professional drivers.

The Causes of Helicopter Pilot's Back Pain

The back pains of helicopter aircrew must be caused by some aspect of the environment in the cockpit or of their behavior. Other reviewers have mentioned: a) the seated posture of the pilot; b) the workload of the pilot; and c) the vibration transmitted by the seat. All these factors are common to the environment of helicopter aircrew, fixed-wing aircraft pilots, drivers, and heavy machinery operators. The degree to which each factor contributes to back pain in each case may be different.

Posture and Back Pain

The posture of a helicopter pilot has been described by many reviewers as being both tightly constrained by the seat and controls and unhealthy (12,37). Pilots flying light helicopters and those working in close quarters (which constitutes a large part of helicopter missions) must have continuous, precise control of the cyclic control stick directly in front of the seat, the collective control at the left side, and two pedals. The cyclic stick requires the most precise control, and pilots are instructed to rest the right elbow on the thigh in order to isolate the right hand from gross body motions and vibration, and to obtain more precise control of the stick through fine movements at the wrist. This posture cannot usually be achieved without a forward bending of the spine, called the "helicopter hunch" by pilots. In some helicopters, the collective lever cannot be reached with the left hand without some twisting or lateral bending of the spine as well. The operation of the pedals by the feet prevents the pilot from using them to assist in shifting his seat position while in control of the aircraft. The pilot may be further constrained in some helicopters by badly-designed and unadjustable seats, restraints, cockpit clearances, and survival gear which must be worn in flight.

The mechanics of the seated posture have been studied for many years, and certain results can be applied to the helicopter pilot's situation. Nachemson and Morris (42) measured directly the pressure in the intervertebral disc of humans, and found that it increased when a standing person sat down, and increased still further when he leaned forward while sitting. Although it has never been investigated, it would be expected that the "helicopter hunch" of pilots would cause a high pressure in the intervertebral disc.

The reason for the relationship between posture and mechanical pressure on the intervertebral disc is the geometry of the ligaments and muscles that support the spine. Most of the muscles and ligaments that stabilize the spine act through the articular processes of the vertebrae, which are all positioned dorsally with respect to the discs (40). Thus, the forces required to stabilize the spine are increased when the spine is bent forward. Since the muscles are close to the spine itself, any torque they exert on the vertebrae in resisting flexion is accompanied by a compressive force.

The muscular activity itself can cause temporary pain through the mechanism of fatigue. This mechanism has been discussed by the author in another paper (5), and has been explored by Pope *et al.* (44). Pain usually limits the duration for which a sustained isometric tension in skeletal muscle can be maintained (8). The pain is relieved, albeit slowly, by rest. Although some authors (11,29,64) have tried to investigate the activity of the lumbar *erector spinae* muscles in patients with back pain using surface and wire electromyography, their results have been inconclusive. Since the muscles themselves are complex, the relationship between activity and force is dependent on posture (22), and the activity is generally a small fraction of the maximum voluntary activity.

It is possible that there are other mechanisms whereby sustained compressive forces on the spine lead to temporary pain. Nachemson (41) has argued that the lumbar intervertebral disc is the most likely cause of chronic idiopathic low-back pain. He associates the pain with ruptures of the posterior part of the *annulus fibrosis*, which allow the disc to distend the surrounding ligaments and to cause painful compression of the nerve roots in the spinal canal. The compressive forces caused by the posture of the helicopter pilot may exacerbate these symptoms in individuals who have previous trauma.

The delayed onset of the pain may be the result of "creep," the slow deformation of the intervertebral disc in response to a continued applied load noted by Kazarian (31) in cadavers and by Eklund and Corlett (14) and others (62) in the living human. The change in height of the intervertebral discs may cause the articular facets to carry more of the compressive force on the spine (31), and this may be an additional source of pain in certain individuals.

The evidence for the relationship between driving and chronic back pain comes from epidemiology, and many authors who have reviewed it find that, although it is suggestive, it is frustratingly limited (51,63). Three possible mechanisms for the relationship are:

a. In the seated position, the spine is near an extreme position of its range of motion, thus the ligaments and the *annulus fibrosus* may be more prone to injury from externally-applied forces or sudden motions.
b. The spinal muscles, fatigued by the stress of

constrained posture, are less able to protect the spine against the effects of loading in activities conducted outside the driver's or pilot's seat, such as lifting, carrying or sports.

c. Repeated or persistent loading of joints in the living human may cause or exacerbate inflammation or degeneration of the affected joints. The observations of Westgaard and Aaras (66), and of Kadefors and his colleagues (27), that workers exposed to awkward postures that constrain the arms and shoulders are more prone to develop chronic disorders of the musculo-skeletal system, support this hypothesis. Sandover (49,50) has proposed that dynamic loading of the intervertebral disc by compressive or torsional stresses generated by awkward posture and vibration may cause it to degenerate, either by creating microfractures of the vertebral endplate, which may impair the nutrition of the disc tissue, or by generating microscopic tears of the *annulus fibrosus.*

It is possible that all three mechanisms may contribute to the reported relationships between poor posture and chronic back pain. The only practical method of investigating these hypotheses is the use of careful, controlled, prospective epidemiological studies. However, these studies may involve more control over the lives of the subjects than is practically possible.

Vibration and Back Pain

The role that vibration plays in the development of back pain in drivers and pilots appears to be developing into an area of controversy. On the one hand, investigators in France, (e.g., Quandieu and Pellieux (45), and in other countries (1,25) are systematically studying the effects of vibration on the spine. Sandover (49) has proposed a mechanism whereby vibration could accelerate degenerative changes in the intervertebral disc.

On the other hand, Shanahan and Reading (53) and, more recently, Pope *et al.* (44), have demonstrated that helicopter vibration does not increase the rate of development or the severity of the back pain induced by a simulated helicopter cockpit and task.

In addition, Reader (46) has noted that the results of British surveys show that the aircraft which are most likely to cause back pains in their aircrew are those which have poor seating arrangements, rather than those which vibrate the most. These observations may lead one to reject vibration as a contributory factor in the genesis of back pain, particularly the temporary pain of helicopter aircrew.

This rejection should be qualified in two ways. First, there are studies that suggest that the incidence of chronic back pain and injury may be increased by exposure to severe vibration, or repeated shocks. Thus, Zerlett (67) has shown that radiographic evidence of morphological changes in the spine occurs at a younger age among operators of heavy earth-moving equipment than among others. Hill *et al.* (28) reported that the drivers of wheeled, armored personnel-carriers appear to be more vulnerable to back pain and injury than those who drive tanks. The armored personnel-carriers produce far more severe vibrations than the tanks (4).

We also have the interesting results, published by Froom and his collaborators (19), that fighter pilots suffer more frequently from chronic back pain and back injury than helicopter aircrew. Perhaps the severe loads on the spine imposed by high-speed maneuvers or buffeting in fighter aircraft exceed a threshold for the development of permanent injury in the pilots. The helicopter vibration is more persistent, but less likely to be severe (30) or accompanied by shocks. If a threshold for spinal injury from external load exists, it is likely to be a function of posture.

The other aspect of vibration that may be related to back pain in helicopter aircrew is that vibration may indirectly affect both the posture of the pilot and the physical and mental workload of the task of flying. The subjects in the experiments of Shanahan and Pope and their colleagues (mentioned above) took a posture like that of a helicopter pilot because they were told to, not because it represented a natural adaptation to their environment or their task. Similarly, the task which they were instructed to perform with the cyclic control was the operation of a video game, the controls of which are remarkably coarse. It would be interesting to see what the results of their tests would be if: a) the tasks were more like the precision movements required to control an unstable helicopter; and b) the subjects, in either the vibrating or static environment, were free to choose the posture that most suited them for the task. Perhaps the vibrating environment would then be more uncomfortable. Vibration makes many manual control tasks more difficult (35), both through direct interference with motor activity, and through interference with kinesthesia (21). This enforces the helicopter pilots' practice of resting the elbow on the thigh in order to precisely control the cyclic lever. Vibration of the head affects vision, and this may discourage the use of a back rest, since it may increase the transmission of vibration to the head (47). Thus, the reduction of vibration in helicopters is a worthwhile objective, apart from its purely mechanical effects, and efforts to reduce the transmission of vibration to the seat may be of some value.

On the other hand, the problem of back pain is more likely to be solved by changes in the posture and in the task of the pilot.

Workload and Back Pain

The task of controlling a helicopter in flight has already been mentioned because of its effect on the posture of the pilot, and the effect of cockpit vibration on this task. The workload itself may be a major factor in creating back pain through the mechanisms of tension and muscular fatigue.

The helicopter is inherently more difficult to fly than fixed-wing aircraft because of its dynamic instability (58). Helicopter missions and training often require hovering flight in close quarters where critical control is essential for survival. It is not surprising that helicopter flying is regarded as particularly stressful and fatiguing.

Lundervold (36) noted the increased electromyographic activity in the back muscles of typists who were concentrating on their work. Electromyographic activity

in the trapezius muscle increases so predictably with workload that it has been used in studies of the workload of helicopter aircrew (34). This muscular activity may contribute to back pain through the development of fatigue or sensations of tension.

Solutions to the Problem of Back Pain in Aircrew

Solutions to the problem of helicopter pilot back pain might be classified in two ways—those which involve the pilot and those which involve the aircraft. Both should be considered, although there are practical limitations to each. The pilot population may be made less prone to back pain through selection during recruitment for predisposition to back pain, as is done in France (13).

The majority of armed forces that use helicopters may agree on the potential causes for back pain among their aircrew, but must work with their existing fleets (which may have a long service life), since back pain does not appear to be sufficient cause for replacing them. The Indian Air Force has replaced the seats of a fleet of Chetak helicopters with new ones incorporating a more vertical seat back and head rest (57). In other helicopters, the replacement of the seat may be impractical because of cockpit space limitations or cost.

Some armed forces have supplied special lumbar supports or lumbar support pads to individual crewmembers. Notable among these devices is the individually-moulded back support designed at the British Royal Air Force Institute of Aviation Medicine (IAM) (16,48). Because these supports are individually moulded to the pilot's back, their use has been restricted to those aircrew who have reported back pain to their medical officers. These crewmen, in turn, have been referred to the laboratory that prepares the supports. The IAM support is not part of the helicopter seat back; rather it is worn by the pilot, who attaches it by means of a strip of webbing around his waist. Because of this, it could have limitations. It does not contribute to the support of the upper torso by the seat back. Its primary effect is to enforce some lumbar lordosis, perhaps by encouraging the pilot to rotate his pelvis or thorax into a more accommodating position. Reader (46) reports that 65% of those using the pads reported reduction of the pain, and 32% report a complete cure. The pads are also being used by the Canadian Forces. Even though no fundamental change occurs in the pilot's posture, the support is surprisingly successful.

Other armed forces have provided lumbar supports that are installed over the seat back cushion. A feature that many have in common is adjustability, either in height from the seat pan, or protrusion from the seat back, or both. Steele-Perkins (60) mentions that the provision of a fixed lumbar support in Lynx helicopters did not please all the users equally. Vyrnwy-Jones and Braithwaite (65) mention an inflatable lumbar support supplied to Gazelle aircrew in the British armed services; such lumbar supports are included in seat back pads that have been tested by the Canadian Forces. An inflatable support can easily be adjusted to suit different back contours.

Other modifications to existing seats that may improve comfort include adjustment of the seat pan angle, changing the spool-out point of the shoulder straps of the restraint system, and improving the worst aspects of some seat- or back-mounted survival gear. All these may reduce the incidence of back pain and provide relief for some individuals, but many helicopters prevent effective changes through a lack of cockpit space. The basic problem, that of the posture required for flight, is not really addressed.

It is hoped that, when new helicopters are designed, the factors that contribute to back pain may be abolished entirely, and the problem would be solved as a by-product of efforts directed towards making the helicopter easier to fly. These efforts would not only include modifications to the cockpit, but modifications to the controls, including computer-assisted controls, that would reduce the workload required for flight. Stability-augmentation systems have already been incorporated into operational helicopters, but modifications of the control geometry, such as side-arm controllers, that would change the posture of the pilot are still in the development stage (56). Although the primary purpose of the modified controls is to simplify the task of flying, the relief of back pain has been noted by the few test pilots who have compared them with the normal controls (J.M. Morgan, National Aeronautical Establishment, Ottawa, Canada, personal communication).

New control configurations should allow designers greater freedom in selecting the posture of the pilot. The "ideal" seating posture for the lumbar spine has been the subject of some discussion. The general principles catalogued by Corlett (9) dictate that the thigh-trunk angle should be as close as possible to the "normal" value of 135° described by Keegan (32). However, obtaining this angle by reclining the back would make forward vision difficult, and the alternative, obtaining the position by extending the legs, as advocated by Mandal (38), would require excessive cockpit height, and would possibly create circulatory problems similar to those consequent to standing in a restricted space. The requirements of vision may dictate a smaller angle between the thighs and trunk, between 95° and 110°. New controls and reduced vibration should allow the pilot to make effective use of a back rest to support his upper body, and this should relieve some of the stress on the lumbar spine.

Even if the ideal seating position cannot be achieved, it is to be hoped that some of the worst mistakes in the human engineering of our present helicopters, such as the Canadian Forces Kiowa (10) or the British Gazelle (65), are not repeated.

It is possible that future mistakes may undo some of the advantages of new helicopters. It does seem important that the pilot be able to adjust his seated position regularly, since even the most comfortable position places pressures on the body that must be relieved. The fidgeting of readers who would appear to be comfortably seated is evidence of this (7). It is not unreasonable to demand that aircrew be allowed to fidget to some extent; most do when the co-pilot takes control. It would be a mistake to have specialized

displays, control systems or restraints that demand a fixed posture in the cockpit, even if that posture is optimized by adjustments for the individual pilot.

Conclusions

The differences among individual helicopters in the prevalence of back pain induced in the pilots, and the success of some modifications suggests that a significant reduction of pilot back pain in future helicopter designs is possible through the application of ergonomic principles in the design of the cockpit and controls. The reduction of vibration and the augmentation of aircraft stability will assist this.

At the same time, there is a requirement for basic research that will contribute to the international effort towards a long-term solution to the back discomfort problem. The object of such research should be an understanding of the underlying causes of back pain that would allow the determination of the potential for back pain in a particular cockpit environment before aircrew are exposed to it.

Studies of biomechanical stresses on the spine, using biomechanical models or measurements of muscular activity, appear to be the most promising source of solutions to the problem of back pain in helicopter aircrew.

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