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BACK PAIN AND DISCOMFORT RESULTING FROM EXPOSURE TO VIBRATION IN TRACKED ARMOURED VEHICLES*

by

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INTRODUCTION

That the ride of military vehicles can have pathalogical effects on the occupants has been recognized since charioteers rode with their knees bent to attenuate the shocks from the floor of their vehicles. More recently "tank back" was reported by medical officers during and immediately after the 1939-45 war, and similar effects ("jeep back") were noted for trucks and cars (Ref 1). Despite many references to the chronic effects of vibration and shock on humans, there are few data which relate the effects of exposure to the ride characteristics of the vehicle. This is reflected in the second draft of what are probably the most widely used guidelines for human exposure to vibration, ISO 2631 (Ref 2), which stated that "in view of the complex factors determining the human response to vibration, and in view of the paucity of quantitative data concerning man's perception of vibration and his reactions to it....(the guidelines have been prepared)...to give provisional guidance as to acceptable human exposure to vibration". The exposure limits of ISO 2631 are based on "approximately half the level considered to be the threshold of pain .... for healthy male subjects restrained to a vibrating seat".

From the earliest drafts, the standard also expressed the hope that it would lead to the "reporting and critical evaluation of new findings about the effects of vibration on man". That aim has been a consideration during the various surveys of vibration levels in military vehicles which have been undertaken at DCIEM during the past fifteen years. Thus when the Institute was asked by the Base Surgeon at Canadian Forces Base (CFB) Gagetown to investigate several instances of lower back trauma in tracked armoured-vehicle drivers, the opportunity was taken to study the interrelationship of

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vehicle ride, operator exposure and back pain (Ref 3).

The problem was evident in a pool of drivers attached to the Combat Arms School (CAS), who were required as part of the school curriculum to drive long hours in M113 armoured personnel carriers during training exercises. The Base Surgeon had noted that, within six months, two drivers from the CAS pool ("Pool drivers") had required surgery for lumbar disc herniation. Both men were under age 34, and subsequent investigation revealed that, among 28 CAS M113 drivers with possible back problems, ten had recurrent lower back pain to the extent that time was missed from work. Of the ten, one required surgery during the period of the investigation, and another six, who were free from congenital abnormalities of the spine, were found by X-ray examination to have changes such as degenerative disc disease.

INVESTIGATION OF THE PROBLEM

The actions of the Base Surgeon had, naturally, aroused the awareness of the Pool drivers to the risks associated with the ride characteristics of their vehicles. A three-aspects approach was therefore taken to the investigation. The first aspect was to review the medical history of the Pool drivers for the three years prior to the investigation, and to compare them with those of two other groups of drivers. One group, ("RCR drivers"), drove the same vehicle but for fewer average hours per week. The other group ("Centurion drivers"), drove a slower, heavier vehicle for a similar number of hours per week.

The three groups were roughly similar in size, (18 Pool, 24 RCR, 20 Centurion), and were matched for ages, heights and weights. The age distribution of the RCR drivers was, in fact, slightly skewed toward the left, implying a slightly younger population, but the three groups were not statistically different.

The second aspect of the study was to review the exposure history of the three groups of drivers. This was done using a modified version of the questionnaire developed by Fitzgerald and Crotty (Ref 4). The questionnaire was modified to cover aspects of the driving environment, including types of terrain, speed over different terrain and hours driving per day and per week.

The possible effect of poor posture as a contributory factor to back pain was of concern. However, equipment and techniques necessary to record the posture adopted by the driver in the confined space of an AFV were not available. Therefore, posture was investigated subjectively through questions related to the comfort of the seat, and the need for improvements to the seats of the two vehicles.

The third aspect of the study involved the recording and analysis of the ride characteristics of the M113 and the Centurion. Accelerations were measured in three orthogonal axes at the driver's buttocks, as each vehicle was driven at representative speeds over various types of road and terrain. A one-third octave-band analysis of the data was then compared with the Exposure Limit (EL), the Fatigue Decreased Proficiency Boundary (FDP), and the Reduced Comfort Boundary (RC) of ISO 2631.

Also used was a criterion for assessing human tolerance to [illegible]

factor acceleration (shock), taking into account the compressive load limitations of the spine. Payne (Ref 5) proposed a single degree-of-freedom lumped-parameter model to approximate the gross mechanical characteristics of the human spine. The model consists of a simple linear mass-spring system with damping that is proportional to velocity. As the system is excited by an acceleration-time history, it gives as an output a corresponding time history of the compressive deflection of the spring. A Dynamic Response Index (DRI), representing the peak value of the compressive deflection, is determined for each peak in the acceleration-time history.

Allen (Ref 6) has proposed a specification for human tolerance to repeated shocks, based on the DRI model and on the concept that structural fatigue or damage is cumulatively linear to the point of rupture (Miner's Rule). The implementation of the proposal provides a means of quantifying tentatively the occurrence and severity of shocks in an acceleration-time history, and is used by the Institute as an interim method for assessing cross-country vehicle ride quality.

In the proposal, Allen has specified exposure limits representing various degrees of discomfort as a function of the number of repeated shocks: Passenger Comfort (PC), Moderate Discomfort (MD), and Severe Discomfort (SD) (see Figure 1). In addition, a five per-cent back-injury criterion is specified, based on vertebrae breaking strength data from which the parameters of the DRI spinal-loading model were defined (DRI = 20 g corresponds to 50 per-cent probability of spinal injury (Ref 7)), and on the correlation of DRI to aircraft-ejection injury rates (Ref 8).

The DRI model and Allen's proposal for human tolerance to repeated vibration shocks were implemented at the Institute on an analogue and a digital computer, and used to analyze samples of the M113 and Centurion off-road (cross-country) Z-axis acceleration-time histories.

RESULTS

Medical Records

Chi squared analysis of the records showed that the three groups of drivers had not differed in their frequency of visits to the Medical Investigation Room (MIR) in the three years prior to the study. However, the Pool drivers reported significantly* more back pain complaints than the RCR drivers, or than the RCR and Centurion driver groups combined. Similarly the Pool drivers mentioned their vehicle as a causative factor in their complaints significantly more often than the other two driver groups.

Questionnaire Results

It was to be expected that the MIR records would not represent the total incidence of back pain in any of the driver groups. It appeared probable that some back pain was considered too minor to warrant a visit to the MIR, and was self-treated with massage, rest etc. The data from the questionnaire supported that assumption, indicating that more men in all three driver groups suffered from back pain than was shown by the MIR records.

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* Throughout the analysis significance is at the .05 level or better.

Eighty-nine per cent of Pool drivers, 46 per cent of RCR drivers, and 55 per cent of Centurion drivers reported suffering from backache or back pain.

Median Chi square tests showed no significant difference in the proportion of sufferers in each group having a prior accident involving the back. From that observation it is argued that prior injury involving the back is not the major causative factor of the higher incidence of back problems in the Pool group.

The questionnaire responses indicated that there were differences in the sports activities of the three groups. Significantly more RCR drivers participated in jogging and swimming than the other drivers; significantly more Centurion drivers played golf than drivers in the other two groups.

Median Chi square tests showed no significant difference between the driver groups in terms of prior experience driving their vehicles. Examination of the distribution of the questionnaire responses showed, however, that there was a trend to the RCR and Centurion drivers having had fewer years of armoured fighting vehicle (AFV) driving experience than did the Pool drivers. This agreed with expectations from the career progression pattern, since AFV drivers tended to be streamed into the CAS on the basis of experience. Pool drivers were found to be spread over all levels of experience, whereas the RCR drivers were skewed towards less experience, and the Centurion drivers more markedly so. Therefore, the type of driving and the cumulative effect of experience may be confounded.

The questionnaire results confirmed the selection of the two comparison groups. The amount of driving per week was found to be the same for Pool and Centurion drivers, with the RCR group driving significantly less. The number of hours per week driven across country was also the same for the Pool and Centurion drivers, and significantly less for the RCR drivers (see Table I), and the Pool and Centurion drivers drove significantly fewer hours per week on gravel roads than did the RCR drivers.

TABLE I

NUMBER OF HOURS PER WEEK DRIVING CROSS COUNTRY

	Groups		
	Pool Drivers	RCR Drivers	Centurion Drivers
Less Than 10 Hours	2	13	1
Between 10 and 30 Hours	8	3	6
Between 30 and 50 Hours	6	0	9
Greater Than 50 Hours	2	0	2
No Reply	0	8	2

Factor Analysis

From the analysis of the MIR records and the questionnaire data, several differences were noted between the Pool drivers and the two other groups, any of which could have been a contributory cause of the higher incidence of back pain experienced by the Pool drivers. The following differences were considered for further analysis:-

i. driver age
ii. driver physique (weight/height ratio)
iii. years of driving experience
iv. hours driven per week
v. total hours/week on all terrain-(road, gravel, cross-country)
vi. driving speed over terrain (roads, gravel, cross-country)
vii. mass of the vehicle

These variables, plus the presence or absence of back pain were subjected to factor analysis. Four factors were used, and a minimum loading of 0.3 was required on each factor. Variables included in the same factors as presence of back pain were considered to be the major contributors to that condition. Two factors were found to include back pain. The variables associated with back pain were high total hours driven per week, long hours on all three types of terrain, and a high personal weight to height ratio.

Variables which grouped together in a third factor were no back pain, heavy vehicle weight, slow driving speeds and long hours cross-country. Those factors were interpreted as representing the Centurion drivers' environment. Other variables which grouped together were older drivers, more AVF driving experience and slow driving speeds across country. No significance was attached to this factor, but it could be interpreted as indicating either that older drivers learn to drive more slowly, or that they are less tolerant of shock than younger drivers.

Ride Data

The acceleration levels measured on the driver's seat in the two vehicles indicated that Z-axis levels in the M113 were considerably higher for off-road conditions than for paved- or gravel-road conditions. In the much slower and heavier Centurion, Z-axis levels did not differ significantly between road and cross-country conditions, and were less intense than those in the M113 (Ref 9).

For cross-country conditions in the M113 (20 kph) and in the Centurion tank (12 kph), the Z-axis FDP boundary was exceeded in the vehicles (at the driver's seat) after one hour and eight hours respectively, and the EL boundary after four hours and 24 hours respectively (Table II) (Ref 9). In the M113 ride sample, crest factors as high as 13 were encountered. When the crest factors exceed six, the effects of the motion upon health, fatigue and comfort may be underestimated by the ISO 2631 criteria (Ref 2). In the Centurion Tank, crest factors were less than six.

TABLE II

M113 AND CENTURION TANK CROSS-COUNTRY Z-AXIS VIBRATION EXPOSURE LIMITS, AT THE DRIVER'S SEAT, USING ISO 2631 AND ALLEN'S DRI-TOLERANCE CRITERIA

Vehicle/Speed	Acceleration Crest Factor	ISO 2631 RC	FD	P	EL	DRI/ALLEN PC	MD	SD
M113 APC 20 kph	13	<1 min	1hr		4hr	4 min	4hr	--
Centurion Tank 12 kph	--	1hr	8hr		24hr	--	--	--

The results of the DRI-Allen computer analysis are summarized in Table II, and indicate that the PC and MD boundaries would be exceeded in the M113 after four minutes and four hours respectively. During the 3-minute sample, 12 shocks exceeding 1 Gz were observed, producing values of DRI ranging from 1.01 to 2.79, with a mean value of 1.65 and a standard deviation of 0.56 (Ref 10).

Note that the effect of gravity-bias acceleration was suppressed at the output of the analogue computer (DRI model) in accordance with standard practice (Ref 11), and that the digital-computer program did not accumulate DRI values (DRI< 1.0) for accelerations less than 1 Gz. It is not until the spinal compressive-spring force completely counteracts the weight-force vector that the vertebral column becomes the primary weight-bearing element. Hence, accelerations less than 1 Gz are not significant in the spinal-loading model.

No values of DRI were generated for the Centurion Tank. This is because the tank cross-country data did not contain acceleration shocks exceeding 1 Gz.

DISCUSSION

The major limitation to the study was the small sample size and their limited distribution across the variables. The sample size, however, was dictated by the number of Pool drivers. The effect of such a small sample on the statistical analysis is an obvious weakness. Therefore, the results of the study must be considered as indications of trend, rather than robust cause-effect relationships.

Other reservations must be expressed about some of the data. Upon identifying back trauma among the Pool drivers, the Base Surgeon had instituted a limitation in driving hours, so that it was not possible to validate the questionnaire returns for the hours driven in different terrain. Some members of the Pool and Centurion groups indicated that they were driving between 50 and 70 hours a week. It is questionable whether those AFVs would be continually driven for more than ten hours a day on a routine basis, and it is possible that the total hours include time at rest, or in a hide. It has been noted during other exercises that the drivers of such vehicles take any opportunity to move them, so that, although they are nominally "at rest", they are actually often moving about the "rest" area. When at rest the vehicle engines are left running. The drivers would therefore be exposed to the vibration from that source, if not from actually driving. Overall, then, the details of the vibration stress on drivers reporting long hours per week are not clear. Since the time exposure limits of ISO 2631 are logarithmically related to acceleration, however, they become increasingly imprecise for exposures greater than four hours, and the questionnaire data were therefore judged to be adequate for the study.

Another concern is whether the incidence of back pain reported by the Pool drivers differs significantly from that reported in the general population of drivers or people with vibration-induced injury. The use of two comparison groups did not, in itself, guarantee that the Pool drivers would be compared to a "normal" population. Unfortunately, no data have been found which indicate the "normal" incidence of back pain in the Canadian Forces. The data from the three groups were therefore compared with data from the

British Army (Ref 12) and with Canadian farmers (Ref 13), tractor drivers (Ref 14) and interstate bus drivers (Ref 15). Based on the findings of those studies, it appeared that the control groups did have a higher incidence of back pain than "normal". If this is the case, then the comparisons between the groups may underestimate the effects of common factors such as age, driving experience and driving posture.

The relationship of driving posture and vehicle-ride effects on back trauma is of major interest to this symposium. Although posture was recognized as an important factor in the consideration of causes of back pain, and although questions on the design of the seat were included in the survey, it was not possible to treat posture systematically. Some M113 drivers indicated in their questionnaire responses that they used their back rests. It was found, however, that it was not possible to drive either the M113 or the Centurion with the back in contact with the back rest without adopting a very uncomfortable posture. Lap belts were provided in the M113, but if used they held the driver's buttocks in place, forcing him to lean forward to reach the controls. The relative position of the driver's hatch and the seat in both vehicles also made it difficult to sit upright. The resulting forward hunched posture almost certainly resulted in flattening of the lumbar lordosis and compression of the lumbar discs at their forward edge, which would exacerbate any stress on the spinal column.

Given the findings of Fitzgerald (Ref 16) that proper restraints, back support and torso-thigh angle were of importance to the reduction of the incidence of back pain among aviators, it seemed reasonable to conclude that the poor posture of both the M113 and the Centurion seats contributed to the drivers' complaints. If poor posture was the only factor contributing to the incidence of back pain, however, then no difference would be expected between the two M113 driver groups. That was not the case; whereas 80 per-cent of RCR drivers and 88 per-cent of Pool drivers reported the M113 seat very uncomfortable, only 42 per-cent of RCR drivers reported back pain, compared with 89 per-cent of Pool drivers. That poor posture does induce back pain was evident by the responses of the Centurion drivers, 55 per-cent of whom suffered from back pain.

As noted from the factor analysis, the ride characteristics of the two vehicles do imply that there would be differences in the frequency of back pain. The results of the ride analysis based on ISO 2631 indicate that the Exposure Limit is not exceeded in the Centurion in any speed/terrain condition, whereas that limit is exceeded after four hours in the M113 when travelling cross-country at speeds of more than 20 kph. Given the differences in hours driven cross-country, this could explain the differences in reports of back pain between the Pool and RCR drivers.

As noted at the outset, one of the prime aims of the study was the reporting and critical evaluation of new findings about the effects of vibration on man. That high levels of vibration, coupled with long hours of exposure result in a high incidence of back pain cannot be called a new finding. The fact that the exposure levels predicted by ISO 2631 do appear to have some relationship to the observed incidence of back pain is of interest. While a significant amount of effort has been put into validating the Reduced Comfort and the Fatigue Decreased Proficiency limits of the standard, there have been few studies of the Exposure Limits, which are, in fact, often the most critical aspects of military operations.

The validation of Allen's proposal for human tolerance to repeated shocks is not the purpose of this paper. The assumptions made by Allen are that (1) discomfort is caused by the dynamic compression peak loads in the spinal column, (2) these loads can be quantified by the DRI, and (3) damage is a linear function of accumulated loads. The first assumption is disputable in that discomfort is subjective and often due to non-specific stress; the second because spinal-column stiffness is not independent of load level. Data are required to determine whether the variable stiffness of the spinal column causes significant discrepancies in subjective responses to a given DRI value. The third assumption also requires validation, or a demonstration of non-linear effects.

A question also exists concerning the significance of input accelerations that generate values of DRI less than 1 g in evaluating ride quality (17). Although such values were not used in the cumulative PC and MD limits shown in Table II, their effects upon soft-body tissue may be an important factor in ride-discomfort analysis.

Although it is tempting to compare the four-hour Exposure Limit predicted by ISO 2631 with the four-hour Moderate Discomfort limit predicted by DRI-Allen, such comparisons are not justified. Allen (Ref 6) has cautioned against such comparisons, first because of the preliminary nature of the repeated-shock proposal, and secondly because of uncertainties regarding the time-dependency assumptions in ISO 2631. For the purpose of this study, suffice it to say that the cross-country ride qualities of the M113 are shown to be significantly more severe than those of the Centurion when evaluated by either ISO 2631 or Allen's proposal for human tolerance to repeated shock using the DRI spinal model.

On the basis of the evidence it seems not unreasonable to conclude that the high incidence of back pain observed in the Pool driver group was the result of poor posture and exposure to intense levels of vibration and shock for periods exceeding the exposure limits recommended by ISO 2631, and that the incidence of back pain among RCR and Centurion drivers was related to poor driving posture.

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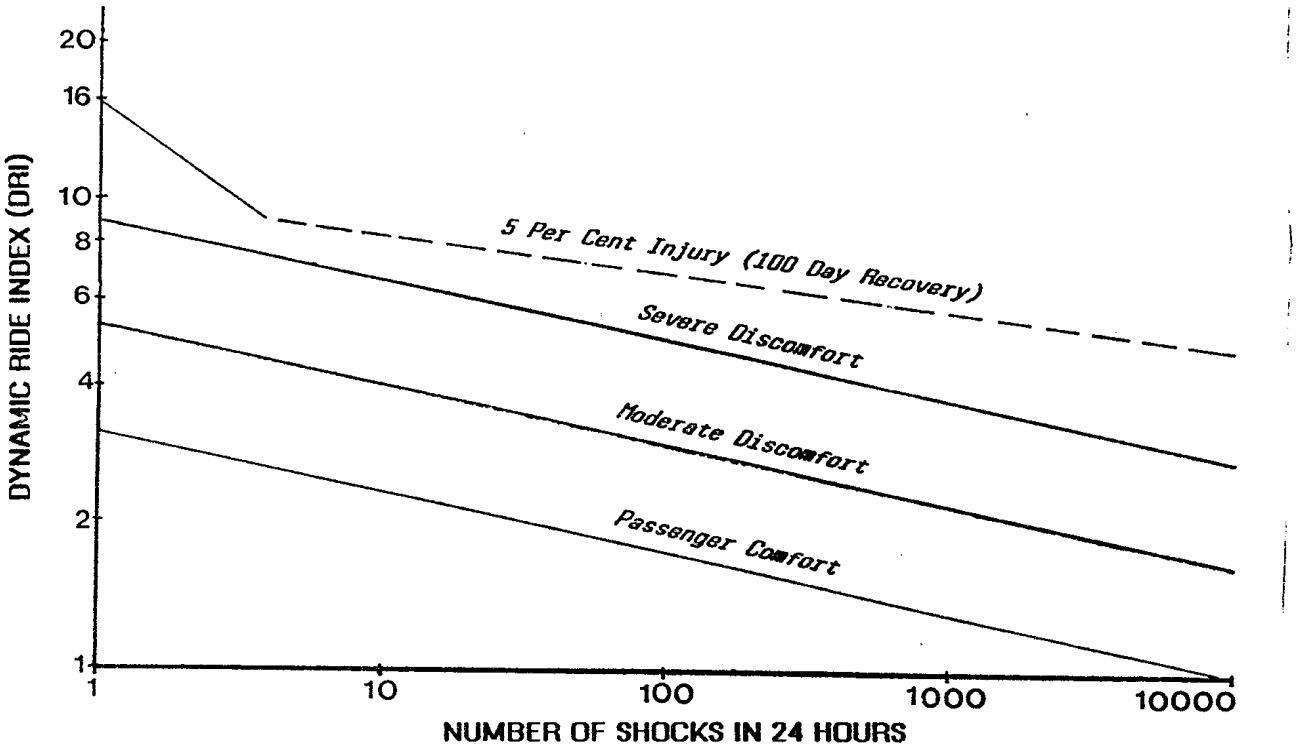

FIGURE 1. Suggested exposure limits representing various degrees of discomfort and a five per cent back-injury criterion, as a function of Dynamic Ride Index (DRI) and number of repeated shocks per day (After Allen (Ref 6)).

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