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Back pain in Grand Prix drivers: a 'found' experiment

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The 'found' experiment uses a natural change in conditions to investigate the possible effects of those conditions. In this case, the natural change was reduction in stiffness of Grand Prix suspensions between 1982 and 1983. The effects of this change on back pain in drivers were investigated and it was found that both the incidence and severity of back pain decreased significantly. Of the various possible sources of back pain, only the ride changed over the same period. This suggests that mechanical shock and vibration are a significant cause of driving related back pain.

Keywords: Back pain, seating, racing drivers

Introduction

A number of papers have indicated a relatively high incidence of back pain amongst drivers (Kelsey and Hardy, 1975) and in particular amongst professional drivers of various vehicles including tractors (Desse, 1956; Haluzicky and Kubik, 1957; Rosegger and Rosegger, 1960; Dupuis and Christ, 1972; Kohl, 1975), trucks (Fishbein and Salter, 1940; Raymond, 1956; Mungo and Guarina, 1957; Cremona, 1972; Gruber, 1976; Frymoyer *et al*, 1979), taxis (Cavigneaux and Laffont, 1969), aircraft (Sliosberg, 1962; Fitzgerald and Crotty, 1972; Schulte-Wintrop and Knoche, 1978) and in earth moving vehicles (Milby and Spear, 1974; Spear *et al*, 1976a, 1976b; Kohne *et al*, 1982).

Although vibration is a marked component of the driver's environment in these types of vehicle, one could postulate a variety of possible causes of back pain. Troup (1978) has pointed out that dynamic spinal loading and poor posture are two important factors. In the case of tractor drivers in particular, the vibration magnitude is usually very high (that is, without an anti-vibration seat) and the task (e g, ploughing) often requires that the spine is twisted about its vertical axis. In a laboratory study, including a two-hour exposure to a simulation of the vibration conditions of a helicopter, Shanahan and Reading (1984) found that vibration was not related to back pain although posture was. (However, this related to immediate effects rather than chronic effects.)

As regards posture, all recommendations for good seating relate to the static situation – which may have requirements different from the dynamic situation. The task of the operator also has a significant influence on seat design and posture.

The effects of shock and vibration on people have been investigated over a number of years. In extreme conditions, such as aircraft ejection, the spinal stresses can lead to direct vertebral fracture (Henzel *et al*, 1968), but little is understood of the effects of long-term exposure to vibration. It is well known that when man is exposed to vibration along the spinal axis, many responses are frequency dependent with maxima at 4 to 5 Hz. This was first recognised in biodynamic responses (e g, Muller, 1939, and demonstrated by many since and reviewed in Sandover, 1982), but also applies to various pain responses (Magid *et al*, 1960) and to degradation in task performance (Lewis and Griffin, 1978). This is recognised in the relevant International Standard 2631 (ISO 1974) which suggests a weighting function with maximum sensitivity between 4 and 8 Hz.

One might expect epidemiological data to settle arguments on back pain in vehicle drivers and the relevance of posture and dynamic loading. There are, however, numerous problems. As well as the usual difficulties of definition and diagnosis of spinal disorders, age effects and the need for prospective investigation with standardised data gathering and matching controls, both vibration and posture are difficult to assess and change with vehicle and external conditions.

The way forward probably depends on a slow process of integration of epidemiological research, laboratory research and field observations. This paper describes a small 'found' experiment that throws some light on this complex situation.

The 'found' experiment

One of us (KB) has regular contact with motor racing drivers and in 1982 met frequent anecdotal reference to increasing back and neck pain amongst Formula 1 (F1) Grand Prix drivers which coincided with the higher levels of aerodynamic downforce and increased suspension stiffness since 1979. Undoubtedly, the 1982 F1 cars, with little or no suspension movement beyond the flexing of the tyres, were uncomfortable machines to drive. The driver was exposed to heavy vibration and shocks as the car encountered irregularities in the track surface as well as the effects of acceleration, deceleration and cornering.

It was decided in 1982 to interview the Grand Prix drivers and a control population to compare the incidence of spinal complaints and also to examine the seating arrangements in F1 cars. Fortuitously, at the end of the 1982 session, the rules governing the construction of F1 cars were changed to reduce the amount of aerodynamic downforce, resulting in a reduction of suspension stiffness. This presented the opportunity to perform repeat interviews in 1983 to determine any changes in spinal symptoms in the F1 drivers that might arise as a result

Materials and methods

A questionnaire was designed to discover the frequency and severity of spinal symptoms in F1 drivers. This was administered orally to a random sample of the 30 or so regular drivers (the precise number varies with accidents, retirements, etc). The questions were concerned with site of pain and time of occurrence. 'Severity' was marked on a simple numeric scale from 0 to 5. Eight drivers were interviewed in June 1982 and again in July 1983. They were also asked, on the second occasion, to recall their symptoms during the 1982 season. Another seven drivers were interviewed in 1983 concerning their current and previous symptoms. Two drivers retired at the end of the 1982 season which meant that the sample size for 1982 was 15 drivers and for 1983 was 13 drivers. At the time of the 1982 interviews a similar questionnaire was administered to a sample of 24 non-racing drivers selected from spectators at a Grand Prix race and matched for age, sex and approximate body weight.

The seats used by the F1 drivers were examined during both 1982 and 1983 seasons. A visual inspection of the cockpits was made in respect of seat location and construction including the provision of lumbar, thigh and lateral support, together with the drivers' use of additional padding. Backrest angles were measured in situ with an inclinometer.

The pathological state of the F1 drivers' spines was determined by reference to their medical consultant.

Unfortunately, the dynamic environment had to be investigated retrospectively. Discussions were held with car designers and team managers in 1983 concerning the effect of rule changes on the construction and behaviour of the cars. In order to obtain an objective comparison of shock and vibration levels in 1982 and 1983, we decided to measure the acceleration characteristics at the driver's seat. Ideally, this would require similar vehicles with the same driver, race track and speeds. In this extremely expensive sport we have had to settle for any opportunities available.

The acceleration was measured in the vertical and fore-aft axes at the lowest part of the driver's seat – usually the vehicle floor in effect. Two Vibrometer SA105 accelerometers were mounted in a 185 mm diameter polymer disc that moulded to the shape of the seat and buttocks The signals were amplified and recorded on a TEAC R-61 instrumentation tape recorder. Space in an F1 car is extremely limited and the amplifiers, tape recorder and power supply were housed together in a box that could be fitted quickly on the outside.

Results

Questionnaire

The incidence of lumbar and cervical symptoms occurring in 15 F1 drivers and 24 other drivers as controls in 1982 is illustrated in Table 1

These symptoms were those which were specifically related to driving, being present during, or for some hours or days after, a race or car journey. All but one of the F1 drivers had low back symptoms compared with a quarter of the controls, whilst two thirds of the F1 drivers had cervical symptoms compared with 13% of the controls. Almost two thirds of the controls were without driving related symptoms but none of the F1 drivers claimed this. This difference in symptoms was found to be highly significant ($\chi^2 = 12{\cdot}71$, $p < 0{\cdot}001$)

The incidence of symptoms in the 13 drivers interviewed in 1983 was lower than in the previous year (Table 2). Lumbar symptoms were claimed by eight drivers (62%), cervical symptoms by seven (54%) and no symptoms by two (15%)

The difference in incidence between 1982 and 1983 was not statistically significant (lumbar $p = 0{\cdot}1$, cervical $p = 0{\cdot}7$ Fisher's Exact Test). The subjective rating of symptom severity from the numeric scales had a mean of 3·88 during 1982 but this dropped to 2·08 in 1983 (Table 3).

The difference between these means is highly significant ($p < 0{\cdot}001$). All the drivers mentioned the jarring from their suspensionless cars during 1982 but indicated that this was less severe after the rule changes for 1983.

The incidence of congenital spinal body anomalies and degenerative disorders in F1 drivers is apparently not increased over that found in the general population (Watkins, 1983).

Table 1: Incidence of back and neck pain in 15 F1 drivers and 24 other drivers, 1982

	Lumbar pain		Cervical pain		No pain	
	No	%	No	%	No	%
F1 (N = 15)	14	(93)	10	(67)	0	(0)
Others (N = 24)	6	(25)	3	(13)	15	(62)

Table 2: Analysis of the incidence of symptoms in F1 drivers between 1982 and 1983

	Lumbar		Cervical	
	1982	1983	1982	1983
No symptoms	1	5	5	6
Symptoms	14	8	10	7

Table 3: Comparison of F1 drivers' subjective assessment of the degree of symptom severity between 1982 and 1983

Driver No	1982 (N = 8)	Difference	1983 (N = 13)
1	3·5	0·5	3
2	3·5	1·5	2
3	4·5	1·5	3
4	4·5	1·5	3
5	3·5	1·5	2
6	3·5	0·5	3
7	4·5	3·5	1
8	3·5	1·5	2
9	—		2
10	—		3
11	—		1
12	—		1
13	—		1
		n = 8	
	$\bar{x}$ 3·88	$\bar{x}$ 1·5	$\bar{x}$ 2·08
	SD 0·52	SD 0·926	SD 0·86
SE of difference = 0·34		t = 5·31	$p < 0.001$

Seats

An examination was made of 10 F1 seats in 1982, of which nine were of glass fibre or carbon fibre construction. The method of making these is to mould a 'primary seat' around the driver (sitting in the cockpit) using a fairly rapid setting plastic foam. The actual seat is then moulded from the 'primary seat'. Theoretically this should provide a seat which accurately conforms to the shape of the driver but the extra foam padding used by some of the drivers (50% in this sample) suggests this is not altogether satisfactory. An example is illustrated in Fig. 1.

Some F1 seats are used in the semi-rigid foam format and both types are mounted directly on the floor of the

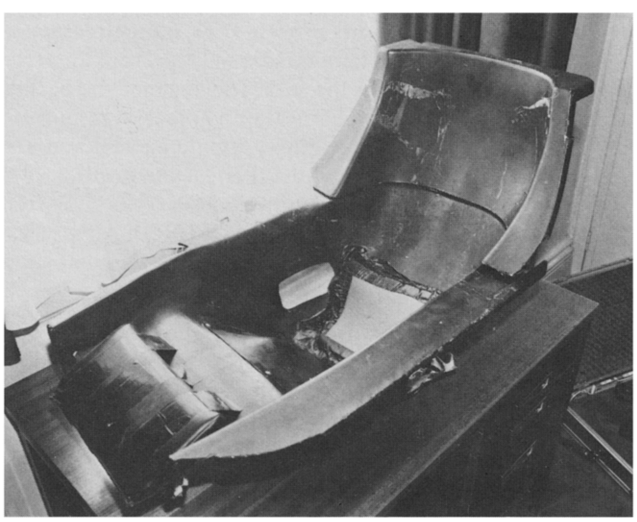

Fig. 1 A typical F1 glass-fibre seat showing lateral and knee support, lack of lordosis and driver-added padding

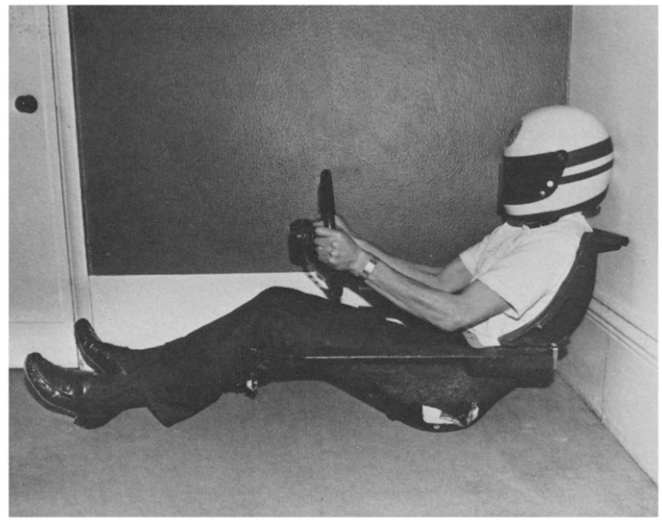

Fig. 2 Driver in-situ in the seat showing angles of backrest, neck, arms and legs

monocoque (chassis), the fixing being rigid without any springing or shock absorbency. The mean backrest angle of the seats studied was 118 degrees (range 100–130 degrees) and only 10% had a shape which would maintain lumbar lordosis. Most drivers adopt a driving position of flexed knees and arms (Fig. 2).

The construction of seats in 1983 was largely unchanged from the previous season, although, in an effort to save weight, some drivers had dispensed with the seat pan and simply sat on the floor of the monocoque whilst retaining the moulded backrest.

Cars

The rule changes at the end of 1982 resulted in a reduction in suspension stiffness for the 1983 season of approximately 50% (Murray, 1983). As well as reducing the jarring of the car over uneven track surfaces, this increased suspension movement reduced lateral cornering accelerations by some 25%. Pedal pressures and steering forces remained unaltered.

Acceleration at the seat

Unfortunately we have, so far, only been able to obtain access to a 1983 Grand Prix car. This, too, was limited to one car with one driver on one track. However, the results were very informative.

As one might expect, the vibration at a seat pan that was fixed to the vehicle chassis was severe. However, by observing the engine noise and vibration at the same time, we were able to show that much of the vibration was noise-related. This high-frequency component would tend to be damped out by body-tissues before reaching skeletal parts.

ISO 2631 allows the use of third-octave analysis or a frequency weighting function. The vibration data were frequency weighted with a filter satisfying ISO 2631 and the rms value was obtained with a time-constant of approximately 30 s. The frequency characteristics of the unweighted data were obtained with a Hewlett Packard 3582A Frequency Analyser. The ISO weighted acceleration value obtained was 2·0 m/s^2 rms. This compares with a typical value of 1·0 m/s^2 rms for a truck and an actual value of 0·4 m/s^2 rms for a saloon car. According to ISO 2631, a weighted acceleration of 2·0 m/s^2 rms is the 'exposure limit' if the daily exposure is 1½ h The acceleration spectrum is shown in Fig. 3. The measurement and analysis method were applied to a saloon car during motorway driving and these data are included for comparison.

Discussion

The authors are aware of a number of limitations of this small study.

The number of subjects would normally be considered too small for a questionnaire-based investigation and no attempt was made to investigate hobbies and other activities likely to relate to back problems, although we are aware of no evidence to suppose that F1 drivers are any more at risk from these aspects than an age/sex matched sample of the general population. Also, not all F1 drivers are fluent in English, so that the questionnaire had to be administered orally and under the hectic working conditions of the pit area during practice, though it should be stressed that the drivers are of necessity highly skilled 'subjective-reporters' under these circumstances. However, the sample covered about half the F1 driver population and the statistical analysis showed quite clearly that F1 drivers have a relatively high incidence of lumbar and cervical pain (this is supported by a previous communication –Burton, 1983) and that both incidence and subjective severity dropped from 1982 to 1983

The vibration measurements were limited to one car and acoustic vibrations led to measurement problems. (In later trials the vibration signal was low-pass filtered before recording in order to increase the dynamic range. Also, the acoustic vibration was capitalised on by mounting an accelerometer on the bodywork and using it as an effective microphone for a very high noise environment.)

However, the essence of a 'found' experiment is to make use of a natural change in conditions and to avoid the problems of the designed experiment where changes in condition are imposed and possibly artificial Limited data and poor experimental control are usually the price to be paid for the 'found' experiment

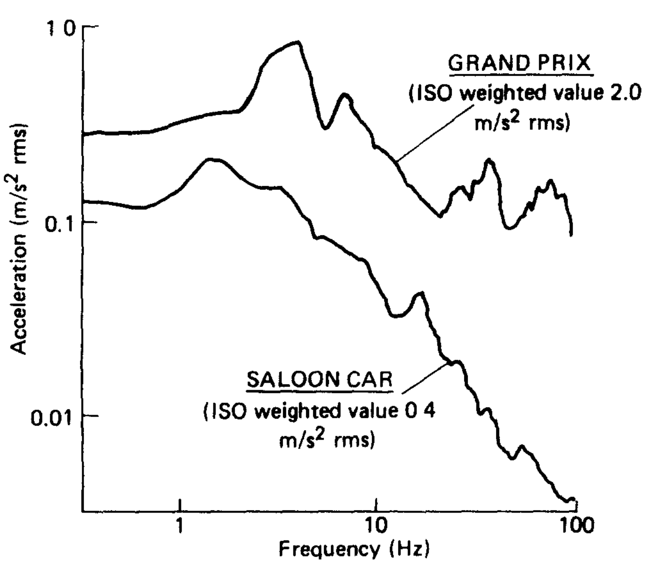

Fig. 3 Acceleration spectrum for 1983 Grand Prix car compared with a normal saloon car

We have shown that the vibration levels in a Grand Prix car are high The search for a 1982 car is continuing and, though we have not produced comparative vibration data, the change in car design would certainly result in decreased vibration in 1983 and we have anecdotal evidence from drivers that the ride of the 1982 cars was much worse than for the 1983 cars. Apart from this, there were no obvious differences in the drivers' conditions between 1982 and 1983 The seats and driver posture were similar, the driver population was similar and the race-tracks were the same. The study has therefore demonstrated a marked decrease in spinal symptoms and severity from 1982 to 1983, associated with a decrease in ride severity but no other marked changes. This does not deny that poor posture, psychological stress or other aspects of the F1 drivers' job may lead to back disorders. However, it does indicate quite clearly that the dynamic conditions (shock and/or vibration) have a definite influence on the frequency and severity of spinal symptoms.

Does this study give us any information on the aetiology of back pain?

It must be made clear that the questionnaire related to pain associated with an activity, rather than chronic pain. Neither have back disorders been investigated. Under these circumstances one might consider psychological stress, lack of physical fitness or poor seating as causal factors. However:

- The Grand Prix drivers are an elite, international group of highly professional drivers. A driver will drive an F1 car some 200 hours during the year (races and practice). Apart from this he will spend a great deal of time in travel by air and road and race other types of car. The profession is extremely competitive and the job clearly dangerous. One would expect the professional F1 driver to be under considerable stress. However, the interviews were carried out during routine testing and drivers then appeared relaxed. No reports were encountered of drivers using back pain as an excuse to avoid driving.
- Most drivers are aware of a need to keep fit and most follow a fitness training programme comparable with that of athletes.
- The seating arrangements provide firm, tailored lateral support and tight full-harness seat belts prevent any fore/aft movement whilst in the seat. The angle of the backrest is such that optimal lumbar intradiscal pressures and myoelectric back muscle activity should be achieved (Andersson *et al,* 1974), whilst their sitting position of flexed knees will preclude any reduction of lordosis from hamstring stretch (Stokes and Abery, 1980). An area in which F1 seats are lacking, however, is that lumbar support is often minimal.

Even if stress, lack of fitness and poor posture could be argued to lead to increased back pain in this case, they do not account for the relative reduction in back pain between 1982 and 1983 and anecdotal evidence of increasing back pain between 1979 and 1982 when suspension stiffness was also increasing.

Epidemiological studies of complaints in drivers of heavy vehicles suggest that the vibration and mechanical shock may lead to back problems. Klein and Hukins (1983) have suggested that mechanical loading may lead to micro fractures in cancellous vertebral bone, and Junghanns (1979) has suggested that dynamic loading leads to degeneration in the lumbar spine. Both Radin (Radin and Paul, 1971; Simons and Radin, 1972; Radin *et al,* 1972, 1973; Pugh *et al,* 1973) and Voloshin *et al* (1981) and Voloshin and Wosk (1982) hypothesise that excessive dynamic loading leads to degenerative diseases in synovial joints, whilst Sandover (1981, 1983) has hypothesised that dynamic loading in the lumbar spine leads to fatigue-induced damage to vertebral tissues and consequent degeneration in the lumbar spine.

It must be stressed that the situation is complex. Both Light *et al* (1980) and Sandover (1983) suggest that transient loads are of greater importance than continuous vibration, although ISO 2631 does not take transients into account particularly. Also, Smeathers and Biggs (1980), Klein and Hukins (1983) and Huijgens (1977) have shown that the concept of the disc being the spinal shock absorber is too simplistic. Muscle action, changes in spinal curvature, and venous blood flow may have a shock and vibration absorption action.

However, the above discussion of dynamic loading relates to chronic back pain or back disorders – not to the job-related transitory pain addressed in the questionnaire, and we have opinion (Watkins, 1983) that the F1 drivers are not unusual as regards prevalence of back disorders. The epidemiological studies of Dupuis and Christ (1972) indicated early onset of degenerative disorders in tractor drivers, and Sandover (1981, 1983) has suggested that high dynamic loads may lead to accelerated degeneration and early onset of back disorders rather than direct injury. The F1 driver usually leaves the profession before the age of 40. Could it be that the transitory back pain observed in this study is an indication of troubles to come?

Conclusions

Grand Prix drivers have a relatively high incidence of back pain. Both poor posture and job stresses could be expected to be contributory factors, but changes in incidence and severity of back pain associated with changes in car suspension characteristics suggest that driving-related back pain may be related to mechanical shock and vibration.

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References

Andersson, G.B.J., *et al*
1974 *Scand J Rehabil Med,* **6**, 101–114. Lumbar disc pressure and myoelectric back muscle activity during sitting.

Burton, A.K.
1983 *Br J Sports Med,* **17**, 150–151. Back pain in Grand Prix drivers.

Cavigneaux, A., and Laffont, H.
1969 Etude des lombalgies chez des conducteurs de taxi. INRS Paris, Note 653-56-59.

Cremona, E.
1972 Die Wirbelsaule bei den Schwerarbeitern der Eisen- und Stahlindustrie sowie des Bergbaus. EEC Comm Generaldir Soz Angelegenheiten. Doc No 1911/72d.

Desse, G.
1956 *Rheumatologie,* **5**, 200–202. Lombo-sciatique des tracteurs.

Dupuis, H., and Christ, W.
1972 Untersuchung der Moglichkeit von Gesundheits-schadigungen im Bereich der Wirbelsaule bei Schlepperfahrern. Max Plank Inst, Bad Kreuznach. Heft A72/2.

Fishbein, W.I., and Salter, L.C.
1940 *Ind Med and Surg,* **19**.9. The relationship between truck and tractor driving and disorders of the spine and supporting structures.

Fitzgerald, J.G., and Crotty, J.
1972 The incidence of backache among aircrew and ground-crew in the RAF. FPRC/1313.

Frymoyer, J.W., Pope, M.H., Rosen, J., Goggin, J., Wilder, D., and Costanza, M.
1979 Epidemiological studies of low back pain. 6th Ann Mtg ISSLS, Goteborg, May/June.

Gruber, G.J.
1976 Relationships between wholebody vibration and morbidity patterns among interstate truck drivers. Nat Inst Occ Safety and Health, Cincinnati. NIOSH Rept 77–167.

Haluzicky, M., and Kubik, S.
1957 *Pracovni Lek,* **2**.9, 121–124. Myalgie a bolesti v krizoch u traktoristov. (Myalgia and low back pain in tractor drivers.)

Henzel, J.H., Mohr, G.C., and Von Gierke, H.E.
1968 *Aerosp Med,* **39**.3, 231–240. Reappraisal of biodynamic implications of human ejections.

Huijgens, J.M.M.
1977 *J Biomech,* **10**, 443–444. Bending vibrations in the human vertebral column.

International Organisation for Standardisation
1974 Guide for the evaluation of human exposure to whole-body vibration. ISO 2631.

Junghanns, H.
1979 Die Wirbelsaule in der Arbeitsmedizin. Parts I & II. Hippokrates Verlag, Stuttgart.

Kelsey, J.L., and Hardy, R.J.
1975 *Am J Epid,* **102**, 63–73. Driving of motor vehicles as a risk factor for acute herniated lumbar intervertebral disc.

Klein, J.A., and Hukins, D.W.L.
1983 *Engineering in Medicine,* **12**, 83–85. Functional differentiation of the spine.

Kohl, U.
1975 *Arch d malad prof,* **35**.3, 145–162. Les dangers encourus par les conducteurs de tracteurs (The hazards of tractor driving).

Kohne, G., Zerlett, G., and Duntze, H.
1982 Ganzkorperschwingungen auf Erdbaumaschinen. Schriftenr "Humanisierung des Arbeitslebens" 32. VDI Dusseldorf, 1–366.

Lewis, C.H., and Griffin, M.J.
1978 *J Sound & Vibr,* **56**.3, 415–457. A review of the effects of vibration on visual acuity and continuous manual control. Pt II. Continuous manual control.

Light, L.H., MacLellan, G.E., and Klenerman, L.
1980 *J Biomechanics,* **13**, 477–480. Skeletal transients on heel strike in normal walking with different footwear.

Magid, E.B., Coermann, R.R., and Ziegenruecker, G.H.
1960 *Aerosp Med,* **31**, 915–924. Human tolerance to whole body sinusoidal vibration.

Milby, T.H., and Spear, R.C.
1974 Relationship between whole body vibration and morbidity patterns among heavy equipment operators. Nat Inst Occ Safety & Health, Cincinnati. NIOSH Rept 74-131.

Muller, E.A.
1939 *Arbeitsphysiol,* **10**.5, 459–476. Die Wirkung sinusformiger Vertikalschwingungen auf den sitzenden und stehenden Menschen.

Mungo, A., and Gaurina, A.
1957 *Reumatismo,* **6**, 364–372. Alterazioni della colonna vertebrale nei conducenti automezzi pesanti.

Murray, G.
1983 Designer, Motor Racing Developments (personal communication).

Pugh, J.W., Rose, R.M., and Radin, E.L.
1973 *J Biomechanics,* **6**, 657–670. A structural model for the mechanical behaviour of trabecular bone.

Radin, E.L., and Paul, I.L.
1971 *Arthritis & Rheum,* **14**.3, 356–362. Response of joints to impact loading. I: in vitro wear.

Radin, E.L., Paul, I.L., and Rose, R.M.
1972 *The Lancet,* **1**, 519–522. Role of mechanical factors in the pathogenisis of primary osteoarthritis.

Radin, E.L., *et al*
1973 *J Biomechanics,* **6**, 151–157. Response of joints to impact loading III.

Raymond, V.
1956 *Arch Mal Prof de med du travail et sec soc,* **17**.1, 5–18. Action des trepidations sur les conducteurs d'engins automobiles lourds.

Rosegger, R., and Rosegger, R.G.
1960 *J Agr Eng Res,* **5**, 241–275. Health effects of tractor driving.

Sandover, J.
1981 Vibration, posture and low-back disorders of professional drivers. Dept Human Sc, Loughborough Univ Tech, Rpt DHS 402. May.

Sandover, J.
1982 Measurement of frequency response characteristics of man exposed to vibration. PhD Thesis, University of Technology, Loughborough. Oct.

Sandover, J.
1983 *Spine,* **8**.6, 652–658. Dynamic loading as a possible source of low-back disorders.

Schulte-Wintrop, H.C., and Knoche, H.
1978 Backache in UH-ID helicopter crews. AGARD-CP-255.

Shanahan, D.F., and Reading, T.E.
1984 *Aviation, Space and Environmental Medicine,* **55**.2, 117–121. Helicopter pilot back pain: a preliminary study

Simon, S.R., and Radin, E.L.
1972 *J Biomechanics,* **5**, 267–272. The response of the joints to impact loading II. In vivo behaviour of subchondral bone.

Sliosberg, R.
1962 A propos des doulers vertibrales du pilote d'helicopteres. Analyse, etiologie, traitement et prophylaxie. XI Int Aero & Cosmo Med Cong, Madrid. (RAE Trans).

Smeathers, J.E., and Biggs, W.D.
1980 Mechanics of the spinal column. In 'Engineering Aspects of the Spine'. London. I Mech E Publications. 103–109.

Spear, R.C., Keller, C.A., and Milby, T.H.
1976a *Arch Env Health,* **31**.3, 141–145. Morbidity studies of workers exposed to whole body vibration.

Spear, R.C., Keller, C.A., Behrens, V., Hudes, M., and Tarter, D.
1976b Morbidity patterns among heavy equipment operators exposed to whole-body vibration – 1975 (Follow up to a 1974 study). US DHEW Pub No (NIOSH) 77-120.

Stokes, I.A.F., and Abery, J.M.
1980 *Spine,* **5**, 525–528. Influence of the hamstring muscles on lumbar spine curvature in sitting.

Troup, J.D.G.
1978 *Applied Ergonomics,* **9**, 207–214. Driver's back pain and its prevention.

Voloshin, A., Wosk, J., and Brull, M.
1981 *J Biomech Engrng,* **103**, 48–50. Force wave transmission through the human locomotor system.

Voloshin, A., and Wosk, J.
1982 *J Biomechanics,* **15**, 21–27. An in vivo study of low back pain and shock absorption in the human locomotor system.

Watkins, S.
1983 Medical consultant to Grand Prix drivers (personal communication).