Blankets (1 wool and 1 heat-retaining foil)	2·90
First-aid kit of dressings, bandage, slings, etc.	1·50
Reflective waistcoat-type jacket	5·00
4 Warning triangles (special purchase—normally £2·47½ each)	2·00
Large hand-torch	2·15
Minor rescue equipment including: hacksaw, jemmy bar, tools, rope, and asbestos gloves	2·00
Fire extinguisher	0·92½
12-volt floodlight	12·00
Mediflash	6·30
Pneumatic horns	12·60
Radiotelephone (selective calls, 10 channels)	343·75
Portable radiotelephone (short-term trial)	—
Photographic equipment (personal property)	—
Information on poisons	1·00
Selective vehicle detector remote traffic-light switch	5·00
Studded snow tyres	24·55
Total	927·19½

Medical Aspects of Ambulance Design

ROGER SNOOK

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Summary

Various observations have shown that the interior layout of many ambulances leaves much to be desired. The lighting levels are inadequate, heat loss could be prevented, vehicle identification and passage through traffic could be improved, and measurable differences exist between the ride characteristics of commercially available ambulances, a prototype purpose-built ambulance, and a private car. Moreover the condition of some patients may be affected by the motion of the vehicle either directly or indirectly. Even though they form a small percentage of the total number carried, they represent a very considerable financial risk. A personally conducted survey of ambulance chief officers showed a deep interest and involvement in the upgrading of the service with a general dissatisfaction with many of the vehicles currently available. Hence there is a market for the purpose-built ambulance, which would benefit the patient and the ambulanceman alike.

The inadequacies of many vehicles currently in use as ambulances have been shown to work against the interests of the patient requiring life support treatment, and it is suggested that this warrants urgent attention and action. A more extensive research project involving medical observations on the supine sick and injured, attendant task performance, and instrumentation analysis of linear and angular vehicle motions should enable the harmful effects of ride motion to be identified.

None of these investigations, however, will be of any value unless they are used in developing future ambulances. Such development must also parallel an increase in the awareness of the importance of ambulance design and its relation to the increased comfort and chance of survival of the patients carried.

There has been relatively little research into medical aspects of ambulance design. With the notable exception of Bothwell's patented ambulance specification[1 2] most of the published papers relate to general or outline specifications of future design requirements or simply draw attention to the inadequacy of existing design. London[3] has said, "although the need for special ambulances is negligibly small on a commercial scale this fact does nothing to ease the discomfort of the person travelling in a vehicle designed without the least regard for the effects of illness and injury." The Committee on Acute Medicine of the American Society of Anaesthesiologists[4] reported that "most vehicles presently in use are unsatisfactory for life support."

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Experience with travelling with patients in the ambulance during the research project on providing medical aid at an accident[5] and on interhospital emergency transfers indicated that further investigations of the ambulance environment were needed. This paper describes the results of personal observations and investigations of such factors as the heating, lighting, sound insulation, identification, and vehicle motion with reference to the treatment, comfort, or condition of the patient. The observations were made on a variety of commercially available ambulances in service with several local authorities.

The positions in the ambulances at which various instrument readings were taken are indicated in Fig. 1.

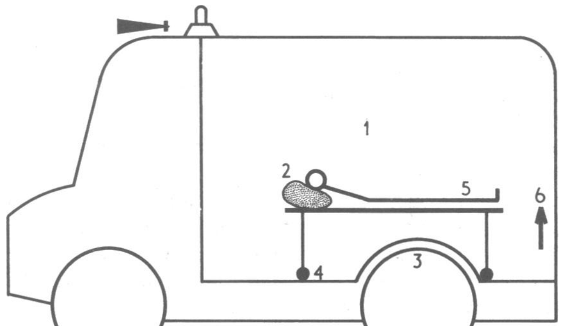

FIG. 1—Positions in ambulances at which various instrument readings were taken. Measurements taken at positions indicated were: 1. Temperature. 2. Light and sound. 3. Vibration over axle. 4. Vibration within wheelbase. 5. Vibration on patient's leg. 6. Hot air curtain updraught.

General Design

Ambulances transport a variety of patients, including sitting cases and routine and emergency stretcher cases, and so the interior requirements of the vehicles vary correspondingly. The interior layout of most ambulances is inflexible and makes treatment of the patient during transit unnecessarily difficult. For example, when resuscitation or supportive measures are required during a journey it is an advantage to have the stretcher centrally mounted. In most presentday ambulances the attendant either stands or kneels on the floor alongside the stretcher, which is mounted along the sidewall of the patient compartment (Fig. 2).

Ideally the attending ambulanceman or doctor should be able to sit at the patient's head to operate aspiration or ventilation equipment. To place this attendant's seat so that it faces rearward involves moving the patient nearer to or directly over the rear axle. By reversing the position of patient and attendant the former would remain within the wheelbase and the latter would be able to see where he was going. This would make it easier to perform delicate tasks such as inserting an aspirator mount into the patient's pharynx, besides reducing the likelihood of the attendant being made travel sick by riding in an unusual position.

During interhospital journeys hospital equipment as well as medical and nursing staff may have to travel with the patient. It would be an advantage, therefore, if the interior of an ambulance could be based on the modular principle so that various items within the ambulance could be positioned to suit the particular need. Adoption of the Modura Danish rail system, used in many hospitals, was discussed with the manufacturers and considered very suitable. Cupboards, stretchers, and other internal furnishings could be attached to a rail at any point around the inside of the patient compartment. The blanket cupboard would be detachable from the rail and be fitted with small castors to allow it to be easily moved. A cupboard of similar size could be used in the accident department and be designed to hold medical equipment including a portable cardiac monitor and other resuscitation equipment. It could then be used as a trolley in the

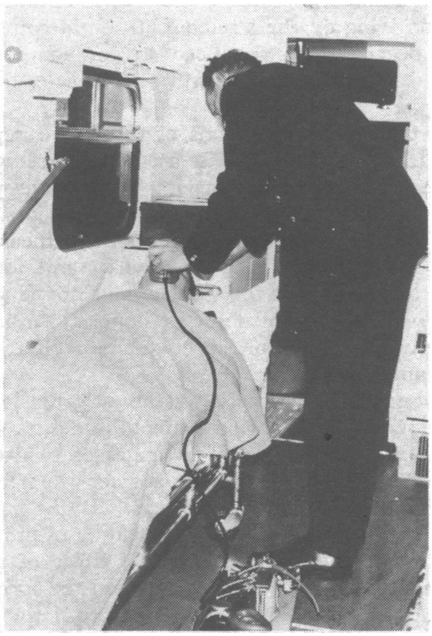

FIG. 2—Interior of ordinary ambulance with attendant standing alongside patient and equipment on floor showing poor ergonomic attendant-patient relationship.

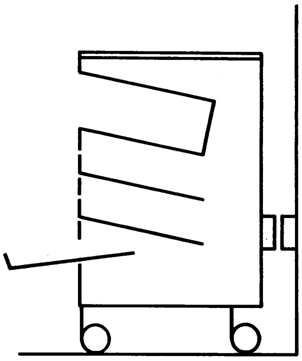

FIG. 3—Medical equipment trolley with working top, space for monitoring apparatus, and pull-out trays of resuscitation equipment displayed in cut-out recesses.

department and when required could be taken with a patient to the ambulance and clipped to the rail in place of the blanket cupboard (Fig. 3). In this way equipment would be readily available and could be positioned in the ambulance to best advantage.

From the ambulanceman's point of view the loading height of the rear platform of an ambulance is important. In a survey of 28 ambulancemen nine had been off work with "backache" for periods ranging from one to 16 weeks and totalling 52 weeks in a five-year period. Loading heights were found to vary from 1 ft 6 in (46 cm) in a research ambulance (Fig. 4) to 2 ft 6½ in (77·5 cm) in a B.M.C. Leyland ambulance. To the same end the design of cab seats in most ambulances could be improved to give correct postural support in view of the length of time the ambulancemen spend in them.

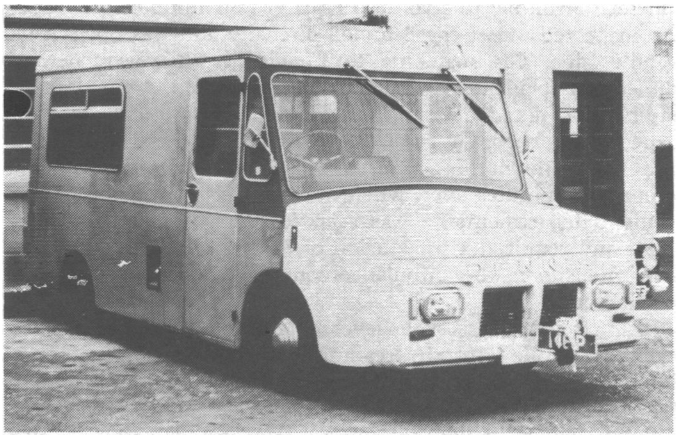

FIG. 4—Dennis FD.4 research ambulance engineering prototype. This vehicle is not in production commercially.

Heating

Mann[6] showed that variations in the temperature inside an ambulance were clearly related to the external temperature and the frequency with which the doors of the vehicle were opened and closed. During the winter the effect of temperature variation would be uncomfortable for adults and potentially serious for babies in an incubator. The Ogle feasibility report[7] on emergency ambulances suggested an internal set of doors to retain heat, but these were felt to be impracticable with present vehicle design. The application of the "hot air curtain" principle used in shop doorways was therefore explored in a series of tests.

With an external temperature of 6°C the interior of the ambulance could be maintained at 35°C with all the heating full on (measured with a thermistor in the centre of the patient compartment). The internal temperature was then measured again after the rear door had remained open for one minute with the hot air curtain blowing. The mean temperature was found to be 27·5°C and showed that the principle would prevent rapid heat loss during loading and unloading. For convenience the system could be controlled by a door-operated switch, similar to a car courtesy light, and in this way heat loss would be controlled automatically.

Lighting

Artificial lighting in ambulances is usually by means of tungsten bulbs or small fluorescent tubes. Nine ambulances, representing the various types and positions of lighting equipment in common use, were then selected for measurements of lighting intensity using a Protimeter photometer on the stretcher pillow. The tests were conducted at night and time was allowed for stabilization of light output.

With the tungsten bulbs the light intensity ranged from 1 to 2 lumens, and with the fluorescent tubes 3 to 12 lumens. Daylight gave an average of 70 lumens.

The senior lighting engineer of Thorn Lighting Ltd. kindly advised that the minimum illumination required to detect whether a patient's skin is pale, pink, or slightly blue would be 27·9 lumens. The best of the ambulances used in the initial tests was then temporarily fitted with two 4 ft (122 cm) 40 watt Kolorite fluorescent tubes and PPD4 diffusers. These were positioned on the inside of the roof alongside the standard 24 in (61 cm) 20 watt fluorescent tubes fitted to the vehicle and further comparative readings were taken. The two standard fluorescent tubes gave 12 lumens unscreened and 8 lumens with the attendant bending over the stretcher, and the Kolorite tubes 29 lumens unscreened and 27 lumens with the attendant bending over the stretcher.

A simple visibility test for cyanosis was conducted by applying a finger tourniquet to a volunteer. After four minutes the finger was inspected under the 8-lumen intensity and was not recognizably blue. On switching to 27 lumens, however, it was immediately evident that the finger was cyanosed. A comparable finding was noted at an actual accident. A motorcyclist was inspected by torchlight at the scene and again in the back of the ambulance and nothing unusual was noted about his general colour. Six minutes later, when he was being wheeled into the accident department, he was seen to have pronounced facial pallor and required a transfusion of four bottles of blood. The light intensity in the ambulance concerned was later found to be 1 lumen.

In an attempt to assess the level of lighting accepted by normal people on public transport, readings were taken at eye level on a single-deck 'bus fitted with fluorescent lighting. The maximum level was 25 lumens and was certainly not considered too bright.

Hence evidently lighting intensity in ambulances must be improved if serious consequences are to be averted. It is not enough to provide a bright spotlight or floodlight as an alternative to adequate normal lighting as this will be neither satisfactory for observation nor acceptable to the patient because of the glare.

Noise

Sound measurements were taken in the patient compartments of three ambulances using a decibel meter weighted to equal human ear sensitivity. The readings were obtained with the microphone at the head of the stretcher (Table I) (A 1 dB difference is the smallest that can be detected by the human ear and an increase of 10 dB represents a doubling of loudness)

TABLE I—*Noise Readings (in dBA) Taken in Three Ambulances at Various Speeds*

Vehicle No.	30 m.p.h. (48 k.p.h.) in Street	40 m.p.h. (64 k.p.h.) in Low Gear up Hill	50 m.p.h. (80 k.p.h.) on Flat Open Road	Horns/Siren at 50 m.p.h. (80 k.p.h.)
1 ..	70	82	71	91
2 ..	70	74	—	95
3 ..	70	77	—	97

The ambulances were not of the same type. Vehicle 1 had two-tone horns on the roof, vehicle 2 had two-tone horns in the engine compartment, and vehicle 3 had a siren on the roof. In comparison average family cars may be expected to give a noise reading of 61-64 dBA at 30 m.p.h. (48 k.p.h.) and 76-82 dBA at 70 m.p.h. (113 k.p.h.), and high-quality cars 55 db at 30 m.p.h. and 67-69 dBA at 70 m.p.h.* These figures certainly indicate that there is scope for reducing noise levels in ambulances, and observations suggest engine noise as being the principal problem.

Sound-proofing material on the bulkhead between the engine compartment and the cab, in the partition between cab and patient compartment, and in the roof lining beneath the roof-mounted two-tone horns would probably appreciably reduce the internal noise levels, as at present many commercially available ambulances have very little such insulation. The increasing use of the forward control position, with the engine encroaching on the central cab area, will make sound proofing even more necessary.

*Figures by courtesy of *Drive*.

As an indication of the noise problem in a forward control ambulance with a siren fitted in the engine compartment, an extension radiotelephone loudspeaker had to be fitted to enable the crew to hear messages when on an emergency run.

Vehicle Progress and Identification

Experience of travelling with patients from the accident showed that one of the more noticeable forces exerted was the ambulances's braking, which was frequently due to the unpredictable events of traffic lights changing and late recognition of the presence of an ambulance by other road users. Braking caused discomfort to some patients and difficulties to the ambulance attendants when treating the patient. The difference in the ride between an ambulance fitted with a manual gearbox and one fitted with an automatic gearbox was very noticeable even to a normal person lying on the stretcher. In an attempt to reduce further the decelerations produced in the longitudinal axis the questions of traffic-light control and vehicle identification were investigated.

Following the recommendations of the Millar report[8] most ambulances are now white. Unless a colour is reserved for the exclusive use of the emergency services recognition will depend on flashing beacons and audible warning devices. There is insufficient frontal area for the adoption of the linear identification pattern suggested in the Ogle report,[7] and identification by a symbol on the side of the vehicle is of no value in traffic. To make a vehicle conspicuous as opposed to identifiable, however, the use of a band of reflective tape around the vehicle could be advantageous.

The design of the blue beacon was investigated in detail and the results showed that attention to detail in design would offer appreciable benefits.[9] The audible ranges of twin-tone horns and sirens were compared and the former were found to be greatly superior especially on motorways.

The time taken to reach an incident can be of prime importance.[5] Because of the more immediate effect of an audible warning compared with visual identification the former can be essential under certain traffic conditions, both for reasons of safety and for prevention of unnecessary delay.[10] To the same end, and to reduce the deceleration from braking, the automatic control of traffic lights by emergency vehicles was also investigated. A miniature transmitter on the vehicle fed a signal into a loop of wire buried in the road. The system was installed in such a manner that by the time of arrival at the junction the lights were phased green for the emergency vehicle. The system proved very successful in practice and is reported in detail elsewhere.[11]

VEHICLE RIDE

Evidence was sought to indicate whether vehicle ride could affect the condition of the patient. Theoretically the effects of the ride motion of an ambulance could be direct and indirect. The former would be mainly those of discomfort or pain and physiological changes, which might possibly influence the patient's overall condition or even survival. The latter would be mainly those of interference with the ability of the ambulance attendant to perform life-support tasks.

Three cases were observed during this research in which spasm and pain were associated with movement at a femoral shaft fracture site. The first was a patient with a poorly splinted fracture of the femoral shaft who developed spasm and angulation during a short journey, and in another almost identical case the spasm and angulation developed during extrication and loading of the patient into the ambulance on the stretcher trolley. The third patient had a fractured shaft of femur and complained of severe pain and muscle spasm when cornering and going over bumps during the journey to hospital.

A fourth case was seen involving the interhospital transfer of a confused, irritable patient with a subarachnoid haemorrhage. Three times on the 13-mile (21km) journey the ambulance had to be stopped to allow the patient to settle, as he became extremely restless and disturbed with the vehicle motion, especially when the road had a poor surface.

In another study I made some personal observations by lying on a stretcher after drinking sufficient water to give bladder sensation. Initial observations showed that the discomfort was increased by peaks of vertical acceleration most noticeably, and also by certain coarse, low-frequency vibrations related to the type of road surface.

Measurements of E.C.G., blood pressure, pulse, and respiration rate were felt to be the most likely criteria to show correlation with ride disturbance. One such case was seen which clearly illustrates the question of survival. During the journey to hospital from the scene of an accident (accident 6 in the accompanying paper) the condition of a critically injured patient deteriorated sharply in response to visible, vertical jogging of his badly fractured leg on the ambulance stretcher. The response to the ride was serious enough to warrant stopping the ambulance and then continuing very slowly. Confirmation of the cause of the severe drop in blood pressure was obtained in hospital when the same leg was moved up and down for inspection before amputation, again with the same response.

The 22-year-old patient with injuries to the head and chest and severe compound injuries of both legs was resuscitated at the scene, the treatment including rapid fluid replacement with 500 ml of Macrodex. His blood pressure rose from "unrecordable" to 70 mm Hg systolic before leaving the scene. The infusion was continued but after less than five minutes of the journey time to hospital he was obviously seriously affected by the ride and his blood pressure dropped to 50 mm Hg systolic. The ambulance was stopped on a steep down-hill slope at the end of one of the Georgian crescents in the city and a further 500 ml of Macrodex was transfused rapidly with a drip-set pump. The blood pressure reading increased to between 70 and 80 mm Hg systolic and the journey to hospital was continued very slowly. On arrival at the accident department his blood pressure was 85 mm Hg systolic. Total fluid replacement in the next three hours, in addition to the litre of Macrodex, was 2 bottles of plasma and 7 bottles of blood. During preparation in the theatre for emergency below-knee amputation the severely crushed lower limb was moved for inspection and the patient's blood pressure again fell sharply, confirming the effect of movement during resuscitation. After surgery he made an excellent recovery.

A similar finding was reported by Cullen,[12] who noted a severe effect on a patient's blood pressure in response to noticeable jogging. The patient subsequently died, and it was concluded that it was "impossible to exonerate the ambulance ride from being an important secondary factor contributing to his death." Pichard [13] described a series of 430 ambulance journeys in which 6% involved the patient in cardiovascular disturbances related to movement, including fall in blood pressure, cardiac arrythmia, and arrest.

Thus ride may affect both the comfort and condition of the patient. Unfortunately observations on patient response to ride conflicted with the major part of the research on early medical treatment and pain relief. This had the effect of maintaining the condition of most of the patients and at the same time allowed a slower journey to hospital, and it was obvious that this section had to take precedence over the more academic study of patient response to ride vibration.

Further investigations were therefore concentrated on observations on attendant task performance tests and on vehicle ride analysis.

TASK PERFORMANCE TESTS

In an attempt to relate vehicle motion to performance a simple test was devised using a Laerdal Resusci-Anne training aid fitted with indicator manometers to assess the correct application of external cardiac massage and intermittent positive-pressure respiration by bag and mask. The technique was first practised by the ambulancemen and then repeated as the ambulance was driven at constant speed on a smooth run and, finally, repeated with the introduction of a bumpy surface, cornering, and braking.

External cardiac massage was successful every time when on a straight, smooth run but failed in 10% with two over-compressions during cornering, when on a fast, bumpy run with corners (a repeat fast, bumpy run also gave a 10% failure rate), and in 14% when on a fast bumpy run with braking. Intermittent positive-pressure ventilation was also achieved every time when on a straight, smooth run but failed in 17% when cornering and braking; a repeat of this last test gave a 15% failure rate.

This very simple test was carried out to show that performance of resuscitation could be related to vehicle motion. In particular performance was noted to be related to cornering and braking, and this was confirmed by observations during the course of treating patients when roll and deceleration forces were again found to interfere with treatment. Subjective tests in the research ambulance, which had a low chassis and low roll characteristics, proved that from the attendant's position, and to a less extent the patient's position, the reduction in roll was noticeable and made the vehicle more comfortable both to work and to ride in. In combination with the Laerdal vacuum mattress, which provided body splinting, the feeling of security in combination with low roll characteristics made the ride even more comfortable. In contrast another ambulance built on a commercially available chassis with a high platform gave slow pitch and roll motions and made patients, attendants, and me on test runs feel the nausea preceding motion sickness after as short a period as 15 minutes. Apart from the considerations of comfort, ride-induced nausea or vomiting could have serious consequences for the patient suffering from acute myocardial infarction. The extra stress from the effort of vomiting could possibly affect survival under these circumstances.

RIDE ANALYSIS

Oliver and Aspinall,[14] of the Motor Industry Research Association, developed a technique of measuring linear acceleration in vehicles and showed vertical acceleration to have a good correlation with subjective assessment of comfort. AM.I.R.A. "ride meter" was therefore hired and extensive tests were conducted with various ambulances under constant conditions. The tests were conducted at a constant speed (40 m.p.h. (64 k.p.h.) except where indicated) on the same stretch of average quality straight road and showed a high degree of repeatability. The readings were taken on the floor in the midline of the vehicle over the rear axle with the "load" representing two patients, attendant, driver, and equipment except where stated. The values obtained with the research ambulance are given in Table II, and represent g r.m.s. for vertical acceleration in the range 0·2-50 Hz.

TABLE II—*Vertical Acceleration Rates recorded in Research Ambulance*

Laden, 40 m.p.h. (64 k.p.h.)	0·104
Unladen, 40 m.p.h. (64 k.p.h.)	0·103
Nearside, 40 m.p.h. (64 k.p.h.)	0·104
Offside, 40 m.p.h. (64 k.p.h.)	0·091
Laden, 30 m.p.h. (48 k.p.h.)	0·096
Laden, 50 m.p.h. (80 k.p.h.)	0·135

The readings at 30 and 40 m.p.h. (48 and 64 k.p.h.) showed that small numerical differences in the values were significant, as it was quite easy to detect the difference in ride subjectively. More energy was found to be transmitted on the nearside of the vehicle than the offside, speed increased the energy, but load made little if any difference, showing the effectiveness of the variable rate suspension. These results gave an index of comfort in the seated position for normal people and were useful as a means of quickly assessing measurable differences before making a more detailed analysis of the vibration characteristics of various vehicles.

Disturbance of task performance, comfort, and health may also be related to particular frequency ranges. Whole-body resonances are known to occur at 4 Hz and breathlessness and

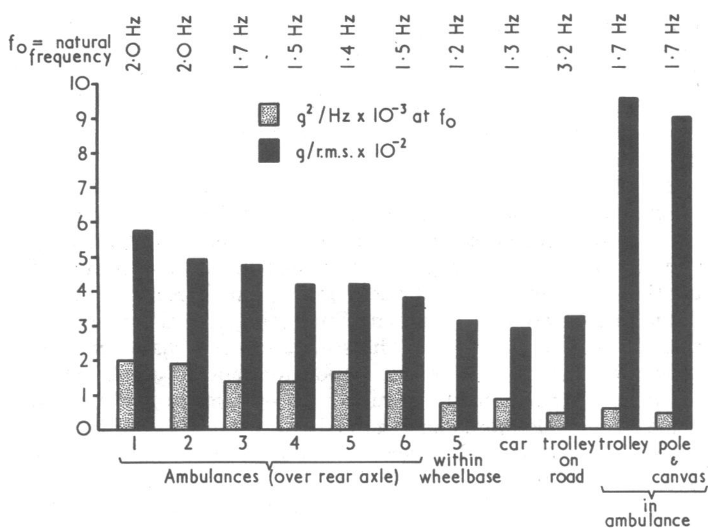

FIG. 5—Vertical acceleration in ambulances showing peak acceleration at natural frequency and *g* r.m.s. values for 0-60 Hz.

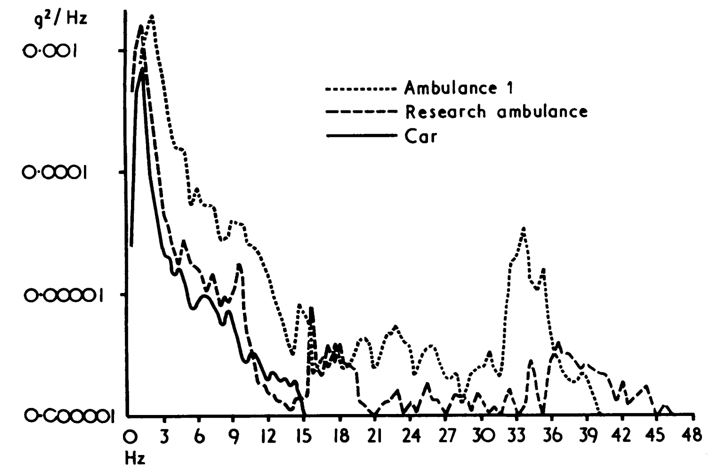

FIG. 6—Graph showing vertical acceleration in an ambulance, the research ambulance, and a private car as a power spectral density.

trunk pain in the range 2·4-13·5 Hz, and particularly in the 4-8 Hz range,[15] and Pichard[13] showed that cardiovascular disturbances could be related to frequencies of 5, 7, and 10 Hz, and so vibration readings in ambulances were also taken using an instrumentation recorder to permit later computer analysis of the results. Recordings were made under the same constant conditions of speed and road conditions as the M.I.R.A. ride meter readings and then subjected to computer analysis at the Institute of Sound and Vibration Research at Southampton University.

The results (Figs. 5 and 6; a detailed account of which will be published elsewhere) clearly show measurable differences between the levels of vertical acceleration in commercially available vehicles and that these levels can be reduced with attention to suspension design. Positioning the stretcher within the wheelbase should also reduce vertical acceleration. While acceleration in the vertical axis is undoubtedly very important it is not the only factor to be considered in relation to vehicle motion. Other linear and angular motions, such as vehicle roll, may be of particular significance and may be influenced by alterations to existing vehicle suspension systems. For instance, account must be taken of the fact that the commercially available ambulance (ambulance 6) that compared most favourably had roll levels four times higher than the research vehicle (No. 5.)

The vibration transmitted through the vehicle suspension to the patient was shown to be of clinical importance and varied according to the vehicle and stretcher. The problem is complex and is unlikely to be solved by making isolated, empirical alterations to existing vehicles. Firstly the harmful frequencies and levels must be identified and related to the supine patient, then acceptable levels defined, and, lastly, vehicles designed to comply with the recommendations.

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