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Reviewing ambulance design for clinical efficiency and paramedic safety

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Abstract

This study aimed to review the layout of the patient compartment in a UK ambulance for paramedic efficiency and safety using: (1) link analysis; (2) postural analysis. Paramedics were observed over 16 shifts (130 h) carrying out a range of clinical tasks. The most frequently occurring clinical tasks were checking blood oxygen saturation, oxygen administration, monitoring the heart and checking blood pressure. Access to the equipment and consumables to support these tasks had been designed for the attendant seat (head end of the stretcher), however, a link analysis found that paramedics preferred to sit along side the stretcher which resulted in increased reach distances. The higher frequency tasks were found to include over 40% of working postures which required corrective measures. It was concluded that future ambulance design should be based on an ergonomics analysis (including link analysis and postural analysis) of clinical activities.
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1. Introduction

High incidences of musculoskeletal problems are commonly reported among ambulance services worldwide (Boocock et al., 2002; Letendre and Robinson, 2000; Rodgers, 1998; Doormaal et al., 1995). Boocock et al. (2002) reported the findings of a survey of seven UK ambulance Trusts by the Ambulance Services Working Group. This group focussed on the handling of loads by ambulance staff and found a mean manual handling incident rate of 178 per 1000 employed, which represented an 18% risk of musculoskeletal injury due to moving and handling loads. The type of ergonomics risk factors for musculoskeletal injury that ambulance workers are exposed to include: heavy lifting and force exertion; stooped working posture; whole body vibration; psychosocial factors and prolonged sedentary work interceded by intense physical exertion.

The design of an ambulance patient compartment is a complex challenge with design options constrained by space limitations and the requirements of emergency driving. Paramedics in the UK National Health Service (NHS) respond to a wide range of medical calls from non-emergency patient transfers to emergency life-threatening situations. The provision of the different services require ambulances to be equipped with a wide range of equipment which will be both frequently used and/or reserved for critical situations. As a tightly confined space the ambulance patient compartment is difficult to design because altering the specification to support one clinical task will affect other areas of equipment placement and storage.

Doormaal et al. (1995) analysed paramedic posture in the patient compartment and found that during non-emergency calls, 24% of observed postures required corrective measures in the near future and that for emergency calls this increased to 56%. However, the study did not describe the most harmful tasks performed in the patient compartment nor

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recommended solutions to reduce the frequency or severity of these postures.

In Canada, Letendre and Robinson (2000) surveyed ambulance work in more detail. Paramedics reported that the most physically demanding activities in the patient compartment were performing cardiopulmonary resuscitation (CPR), accessing the patient, accessing equipment, loading the stretcher, intubating the patient and working from the seats. Duval (1999) found that the location of the attendant seat was incompatible with the tasks of administering oxygen and performing cardiac resuscitation so paramedics would move around while the ambulance was in motion. To further investigate the range of paramedic tasks, Louis-Smith (1986) used qualitative analysis to establish four design priorities which would:

1. facilitate CPR by providing restraints for equipment and paramedics, handrails, soft non-protruding walls and easily accessible equipment;
2. enhance the general comfort and habitability by improving seating, environment controls and noise levels;
3. remove obstructions and clutter; and
4. standardise equipment locations for easy access.

CEN 1789 (2000) is a European advisory code of good practice which aims to raise the standard of ambulance design by creating a base level of safety. There are differences in the working practices in different European countries, for example in the type of vehicle used, with car ambulances being used in the Netherlands (Mossink and Munnik, 1995). The standard focuses on equipment fixation and vehicle crash protection whereas routine activities relating to clinical activities and patient handling are not discussed. Ambulance services and manufacturers are finding solutions to meet the standard with respect to the fixation of stretchers, lockers and oxygen cylinders but these solutions may be achieved at the cost of clinical efficiency and user (paramedic and patient) safety.

In the UK the design of the technical specification of an ambulance usually has multiple inputs from operational, clinical, financial, health and safety, engineering and maintenance staff of the ambulance service as suggested in the following quote.

> Everybody has a view as to how the ambulance should be laid out, but there is no real scientific evidence to support particular patient compartment layouts or design features…… (UK Ambulance Manufacturer)

The extent of the input from operational staff (frontline paramedics) may be limited to reviewing previous ambulance models with senior managers then drawing on their past experience to augment the operational interface design. As far as we are aware, a systematic approach to analyse paramedics working within the patient compartment has not been incorporated in the design of current ambulance technical specifications.

This study aimed to review the layout of one UK ambulance design with respect to clinical efficiency by link analysis and then to further investigate the impact of the layout on the musculoskeletal well-being of the paramedics using postural analysis.

2. Method

2.1. Ambulance design

This study reviewed one ambulance design in the UK (Renault UVG Premia, Figs. 1–3) which is used by several ambulance services (Trent, 2002). Figs. 2 and 3 show the internal layout for the off- and near-side walls. On the off-side wall (Fig. 2), the stretcher is bolted to the floor with an attendant seat (seat A) at the head end and oxygen and ventilation consumables on the treatment wall. On the near-side wall (Fig. 3) there is a side door and two passenger seats (including seat B). The boxed cupboard on the off-side wall encloses the wheel arch when the ambulance is lowered (air suspension) to facilitate loading and unloading.

2.2. Participants

The ambulance service from which participants were recruited is the second largest provincial service in England. It employs over 1650 staff at 38 ambulance stations serving a population of 2.7 million resulting in excess of 284,000 calls per year, with a fleet of 205 accident and emergency vehicles. Paramedics work 8-hour shifts and rotate to morning (07:00–15:00), day (10:00–18:00), evening (15:00–23:00) or night (23:00–07:00) shifts every 4 days. Ethical approval for

Fig. 1. UK ambulance.

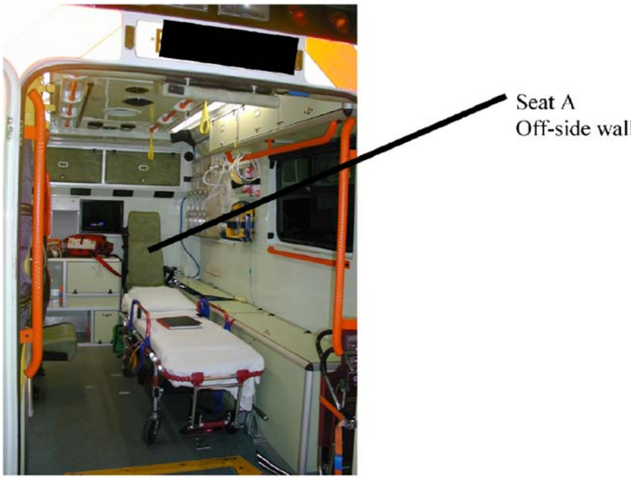

Fig. 2. Patient compartment (off-side wall).

Fig. 3. Patient compartment (near-side wall).

the study was obtained from the ambulance service on the condition that the researcher (J.F.) could be dropped from the shift at any time if warranted by the patient condition or safety concerns. Convenience sampling was adopted to avoid disrupting the shift patterns, crew partnerships and team roles. Paramedics were asked to participate in the study by being given an information sheet. If they chose to be involved they were asked to sign a consent form which stated that they could withdraw from the study at any time. This resulted in the recruitment of 10 male and 4 female participants with a range of age and experience as shown in Table 1.

2.3. Data collection

Observational data were collected over 6 weeks in June and July 2002 on four morning, 2 day, seven evening and three night shifts.

During a shift, the paramedics worked in pairs and shared the responsibility of driving and attending to patients. On arrival at the incident, the primary attendant would focus on treatment and observation of the patient. The driver would typically assist by

Table 1
Participant age and experience

Participants	n	Mean age ± SD (years)	Mean experience ± SD (years)
Males	10	41 ± 12	14 ± 11
Females	4	43 ± 10	5 ± 5
Combined	14	42 ± 12	11 ± 10

retrieving and storing equipment in the ambulance, gathering information from emergency personnel and witnesses, and attending to other needs of the patients and their relatives/carers. Data collection focussed on the primary attendant whenever patient treatment occurred in the ambulance. If patient treatment occurred outside the ambulance, data were collected about the driver whenever they entered the ambulance patient compartment.

2.4. Link analysis

Link analysis was used to examine the patient compartment layout with respect to task performance. Links between paramedics and equipment in the patient compartment were recorded on a data recording sheet. Links were defined as movements of position, communication and, whenever observable, attention (Kirwan and Ainsworth, 1992; Stanton and Young, 1999). Data were categorised and recorded by the type of call received (e.g. cardiac arrest, collapsed patient, road traffic accident).

2.5. Postural analysis

Data were collected and analysed using the Ovako Working posture Analysis System (OWAS, Karhu et al., 1977). OWAS uses a coding system to describe the body posture, force application and the activity of the worker resulting in a relative risk score (action category) on a four point scale. The researcher (J.F.) was trained in OWAS by an experienced user (S.H.) and an acceptable level of inter-rater reliability was achieved using data from previous healthcare research (Hignett, 1996). The action category (AC) gives an indication of the level of urgency with which corrective measures are required on a four point scale from AC1, no action required, through to AC4 corrective measures required immediately.

Postures were selected using 'snap shot' time sampling (30 s intervals) over a designated sampling period. To ensure that the sampling period was not influenced by clinical activity, the recording of the first posture was randomised over 20 s from the moment when the paramedic stepped into the patient compartment.

Mann-Whitney U tests were used to compare action category scores for:

- emergency and non-emergency transport to the hospital; and
- tasks performed when the ambulance was stationary on scene and tasks performed during transport to the hospital.

3. Results

The paramedics responded to an average of 4.5 calls per shift and spent an average of 1 h 52 min (24%) of an 8 h shift treating patients in the patient compartment. The amount of this time spent treating patients while the ambulance was stationary ranged from 14 to 85 min, with an average time of 33 min (29%) in an 8 h shift. The remaining time in the patient compartment, ranging from 51 to 118 min (81 min on average), was spent attending to the patient while the ambulance was travelling to the hospital. It can be seen in Table 2 that the most frequently occurring clinical tasks (bold) were:

1. pulse oximeter to check the pulse and blood oxygen saturation (51% of calls);
2. oxygen administration (27%);
3. monitoring the heart using the cardiac monitor (23%); and
4. checking blood pressure (21%).

3.1. Link analysis

Table 3 shows the individual links and Fig. 4 summarises the schematic links between the paramedics and the equipment. The passenger seat (seat B) was used for the majority of the time (71%), but paramedics also treated patients by sitting on the stretcher (14%), the rear passenger seat (11%), the attendant seat (seat A) (2%) and the paramedic box (2%). The selection of their seat depended upon:

- The patient's preferred seat. For example a patient with severe back pain might prefer to sit in a passenger chair rather than on the stretcher.
- The number of people involved. In a road traffic accident multiple patients might be treated and transported; for example, a driver with two children.
- The type of call.

Table 2
Frequency of clinical tasks

Task	Percentage each task occurred (total number of calls = 71)
Check pulse/blood oxygen saturation	**51**
Administer oxygen	**27**
Monitor ECG pattern/use cardiac monitor	**23**
Check blood pressure	**21**
Administer drugs/IV fluids	18
Patient transfer from chair to stretcher	16
Check blood glucose concentration	16
First aid treatment (e.g. clean wounds)	7
Cardiac massage	1

3.2. Postural analysis

Table 4 summarises the action categories for the 1288 postural observations recorded in the patient compartment for ambulance motion and type of call. A Mann–Whitney U test was used with the null hypothesis that, for the three sets of independent variables, there would be no difference in the mean rank of action categories for the observed postures. Paramedic postures were found to have significantly higher ACs ($p<0.05$) when treating an emergency patient compared to a non-emergency patient and when the ambulance was stationary. Table 5 shows the OWAS action category codes for the clinical tasks.

Overall, only 26% of time-sampled postures within the patient compartment required some corrective measures (AC = 2, 3 or 4). The dominance of AC 1 (no corrective measures required) postures was due to long periods of time when the paramedic sat in the seat B conversing with patients and completing patient information forms. The tasks where corrective measures were required of at least 40% of observed postures are shown in Table 5 and include disposing of sharps and rubbish (91%), using the cardiac monitor to perform an electrocardiogram (40%), checking blood pressure (43%) and administering oxygen (41%). These were typically performed while the ambulance was stationary prior to travelling to the hospital. These contributed to the significantly greater proportion ($p<0.05$) of postures requiring corrective measures when the ambulance was stationary (Table 4).

Although postural risks were found to be greater when the ambulance was stationary (Table 4), other hazards were observed when the ambulance was in motion. 11% of the postures were recorded as non-sitting postures during transportation, indicating that paramedics were moving about the patient compartment.

4. Discussion

An ideal layout of the patient compartment would enable paramedics to access all the equipment and consumables needed to provide a full range of clinical

Table 3
Link table of all calls ($n = 32$)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44
(1) Attendant seat																																												
(2) Stretcher (patient)	263	6																																										
(3) Defibrillator	32	54																																										
(4) Pulse oximeter	23	41	7																																									
(5) Front bench work surface	29	35	2	1																																								
(6) Technician's box	2	4	1		2																																							
(7) Vehicle based drug box	15	1	2																																									
(8) Paramedic box	23	16			3																																							
(9) Green resus bag	1	8	1			2		6																																				
(10) Gloves	1	3																																										
(11) Clipboard	35	2	1		12			8	1																																			
(12) Rubbish/sharps	8	5	1	1	1																																							
(13) Carry chair		13	1	1	1			1																																				
(14) Rear door	10	126	2		2		4	1	5	4		3	13																															
(15) Side door	11	20	4	4	4	14	2	11	18		5	1	2	2																														
(16) Ventilation consumables	3	1	1			1									1																													
(17) O_2 valve	2	24	4	2		1			2					1		7																												
(18) Rear chair	47	39			1	3		1			1	2	1	10	3		1																											
(19) Wipes	3	3	1									3		1				1																										
(20) First aid consumables		2	1											1	1																													
(21) Incontinence blankets		6																																										
(22) CPR chair	11	6	10	10	3									4	3	1		1																										
(23) Blanket	2	14	2	1									4	2																														
(24) BP Cuff &/or stethoscope	4	7	13	2	7	1	2		1	1					1			1																										
(25) Bulkhead window	18	4						1			5			1				4						1																				
(26) Cervical collar		2												2																														
(27) Off-side rear bench	2	3		1										2	1	1	1	2																										
(28) Water	4	2			3			2							2				2																									
(29) Paper towel		2	1																																									
(30) Vomit bins	3	4																										1																
(31) Portable Entonox bag	4	4																																										
(32) Portable O_2 cylinder	1	3		1					2				2				8					2																						
(33) Air conditioning controls												1		2											1																			
(34) Lighting controls		1	1																																									
(35) Drug locker key																												1																
(36) Water cup																											1								1									
(37) Tissue		4																1																										
(38) Black drug box		3			1		2	1	1					2	2										1									1										
(39) Bulkhead door	1											1	1																									1						
(40) Fluids bag													1																															
(41) Hanging fluids bag	1	12	1																													1								1				
(42) Blue drug box																																									1			
(43) Suction		2																				1																						
(44) Bulkhead phone	2		1																																									

Each link represents an interaction between a location and equipment in the patient compartment.

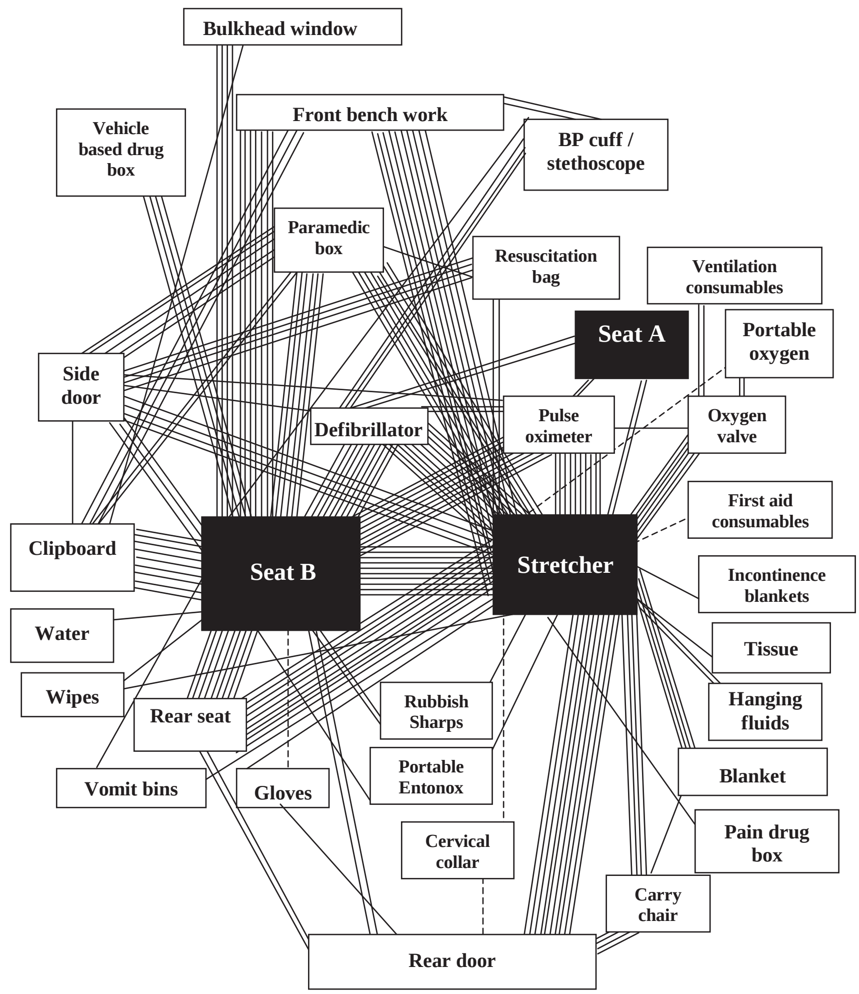

Fig. 4. Schematic link analysis (each line represents 4 links up to a maximum of 40 links, dotted lines indicate important links that occurred less than 4 times).

Table 4
OWAS action category

Situation	N	AC = 1 (%)	AC = 2 (%)	AC = 3 (%)	AC = 4 (%)
Overall	1288	74	24	1	1
Stationary ambulance[a]	408	60	36	3	1
Moving ambulance[a]	880	81	19	—	—
Non-emergency patient[a]	1155	76	22	1	1
Emergency patient[a]	133	57	39	2	2

[a]Indicates significant difference ($p < 0.05$).

services from a safe working position. The technical specification of the ambulance reviewed for this study had identified seat A as the work seat for paramedics. This has resulted in most of the equipment being clustered at the head end of the stretcher on the trauma wall (off-side, Fig. 2). However the results of the link analysis found that seat A was rarely used, with paramedics preferring to sit in seat B, with seat A only being used during CPR treatment, which was the least frequently recorded clinical task (Table 2).

Following the identification of the preferred working location, the reach envelopes for both seats A and B were measured for a 2.5th percentile UK male (Fig. 5, Corlett and Clark, 1995). The outer reach boundary of the envelope from seat B only just touches the patient stretcher so the paramedic would have to sit forward or stand to treat with the patient and access equipment. This was observed to result in non-use of seat belts.

By combining the task frequency, link analysis and postural analysis it can be demonstrated that clinical

Table 5
OWAS action category for clinical tasks (higher frequency tasks in bold)

Task	*N*	AC = 1 (%)	AC = 2 (%)	AC = 3 (%)	AC = 4 (%)
Writing on clipboard	297	94	6	—	—
Interaction with patient	292	70	30	—	—
Idle	194	100	—	—	—
Interaction with carer	74	82	16	—	2
Accessing equipment[a]	56	41	54	3	2
Using cardiac monitor[a]	55	60	40	—	—
Using pulse-oximeter	51	67	27	4	2
Loading/unloading patient	45	62	27	7	4
Other[a]	38	47	50	3	—
Cannulation/drug administration[a]	31	32	68	—	—
Blood pressure check[a]	30	57	43	—	—
Blood glucose check[a]	26	58	42	—	—
Rubbish/sharps disposal[a]	23	9	91	—	—
Oxygen administration[a]	17	59	41	—	—
Non-specific motion	16	75	25	—	—
Talking to driver/ on phone[a]	12	25	75	—	—
First aid treatment[a]	11	57	43	—	—
Transferring patient[a]	9	11	22	56	11
Listening with stethoscope[a]	8	50	50	—	—

[a]Indicates tasks with at least 40% of postural observations requiring corrective measures.

efficiency is impaired by the layout of the equipment on the trauma (off-side) and bulkhead walls. Clear examples of this can be seen with the higher frequency tasks of using the pulse oximeter, cardiac monitoring, checking blood pressure and administering oxygen. The equipment and consumables required for these tasks are within the reach envelope for seat A but beyond the reach envelope for seat B (Fig. 5). Often, tasks required a link with one location (e.g. sharps and rubbish disposal on the off-side wall, Fig. 5) which resulted in paramedics reaching over the patient/stretcher (with associated poor working postures) or, as was often observed, clinical waste bags being taped to the wall behind seat B.

There are several limitations to link analysis. The link analysis could only evaluate the patient compartment layout based upon the frequency of interactions between the equipment, patient and paramedic. However, a comprehensive patient compartment analysis should also consider task sequences and important circumstances for treating critical patients. Despite link analysis of 32 calls, the schematic link diagram (Fig. 4) only includes data from one major cardiac arrest and no major trauma incidences. Also, there were several items that paramedics considered to be vital equipment, which were not observed in use during the study, for example, the scoop stretcher (Fig. 5). Nonetheless, the schematic link diagram was found to be useful for describing the complex activity within the patient compartment and exploring alterations to the layout at the end of project debriefing with the ambulance service. An additional limitation to this project is the limited data about the use of equipment and consumables in life-threatening emergencies. Only one example of cardiac resuscitation is included in the data (out of 71 calls, Table 2). In order to make robust recommendations which could inform the revision of the CEN standard a much larger data set is required. Limitations of using direct observation for postural analysis are well documented (Corlett, 1995, Hignett, 1994). Burdorf et al. (1992) found large differences and a correlation of only 0.52 between direct observation and continuous measurement of trunk bending during dynamic task performance. By sampling postures at 30 s intervals, some rapidly occurring postures within the sampling period could have been missed, for example, when loading patients into the ambulance or when transferring patients from the carry chair to the stretcher. Problems of using OWAS for health care activities have also been found in the past (Hignett, 1994). In this instance, OWAS was particularly insensitive to neck flexion which was often observed for long periods when paramedics wrote on their lap.

This study found that, during non-emergency responses, 24% of paramedic postures within the patient compartment had an AC of 2 or greater, which is consistent with the findings of Doormaal et al. (1995). The findings were discussed with the managers and operational staff at the ambulance service and provided a framework for future vehicle specifications (Ferreira, 2002).

5. Conclusions

This project reviewed the layout of a UK ambulance with respect to clinical efficiency and paramedic postural

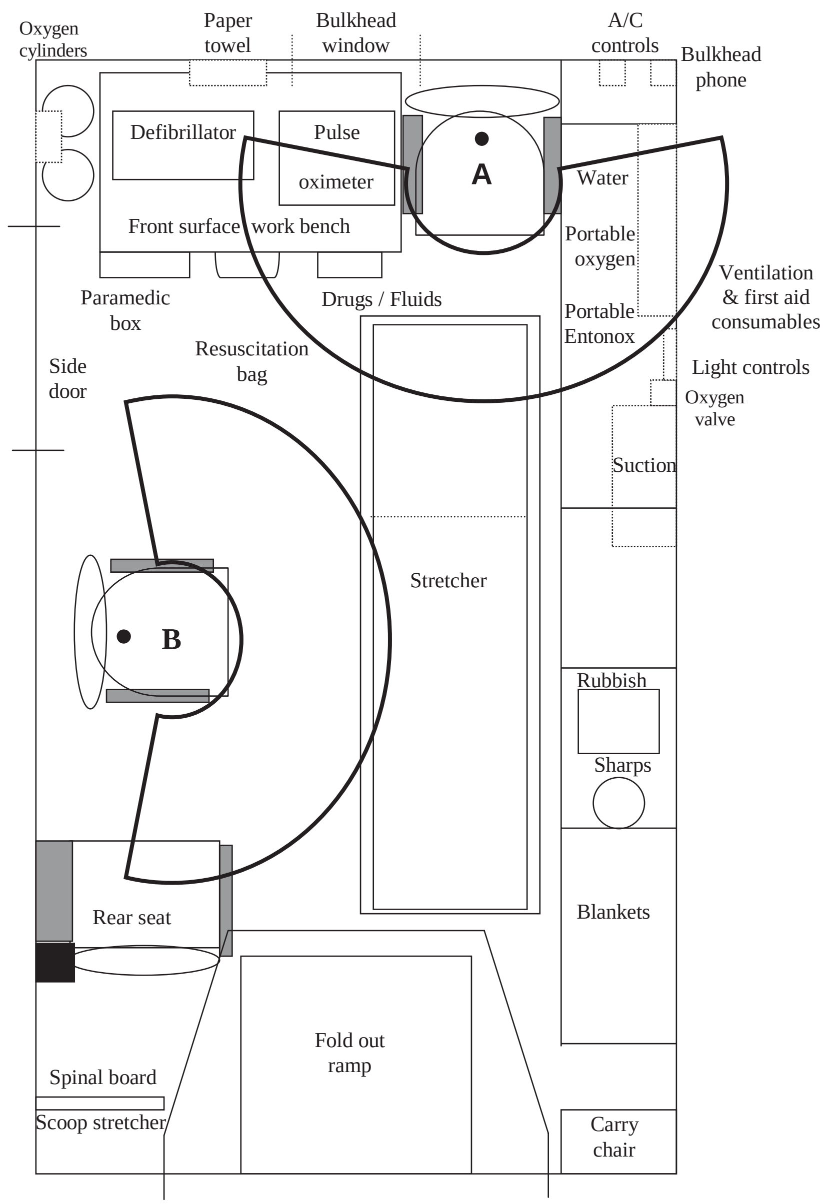

Fig. 5. Reach envelopes for Seat A and Seat B.

safety. The most frequently occurring clinical tasks were checking blood oxygen saturation, oxygen administration, monitoring the heart and checking blood pressure. Access to the equipment and consumables to support these tasks had been designed for the attendant seat (head end of the stretcher), however, a link analysis found that paramedics preferred to sit along side the stretcher which resulted in increased reach distances. Some of the higher frequency tasks were found to include over 40% of working postures which required corrective measures. The findings from the link and postural analysis produced evidence-based recommendations which were successfully delivered to the ambulance service.

We suggest that the ambulance sector requires further ergonomics input to improve patient compartment design with respect to the health, comfort and performance of all users. Additional research is needed about the tasks performed and postures adopted by paramedics for patient loading and unloading, treatment of critical patients and major disaster scenarios.

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