A STUDY OF THE SPACE REQUIREMENTS OF WHEELCHAIR USERS

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THIS study was sponsored by the Royal Institute of British Architects to provide information on the body dimensions and space requirements of wheelchair users. Architects and designers have been considerably hindered by lack of reliable anthropometric data from which the space requirements of the man-chair unit can be estimated in planning houses and public buildings, particularly hospitals, suitable for wheelchair users. The provision of suitable domestic and industrial surroundings for wheelchair users is of considerable importance, for both psychological and economic reasons, in view of the increasing number of younger people who, as a result of serious injury, are forced to spend the rest of their lives in wheelchairs. In this study particular emphasis was placed on determining the distances which can be reached from the wheelchair in various directions, since these are of great importance to architects and designers.

The study was carried out at the National Spinal Injuries Centre, Stoke Mandeville. The subjects were 76 male and 28 female paraplegics, on whom body

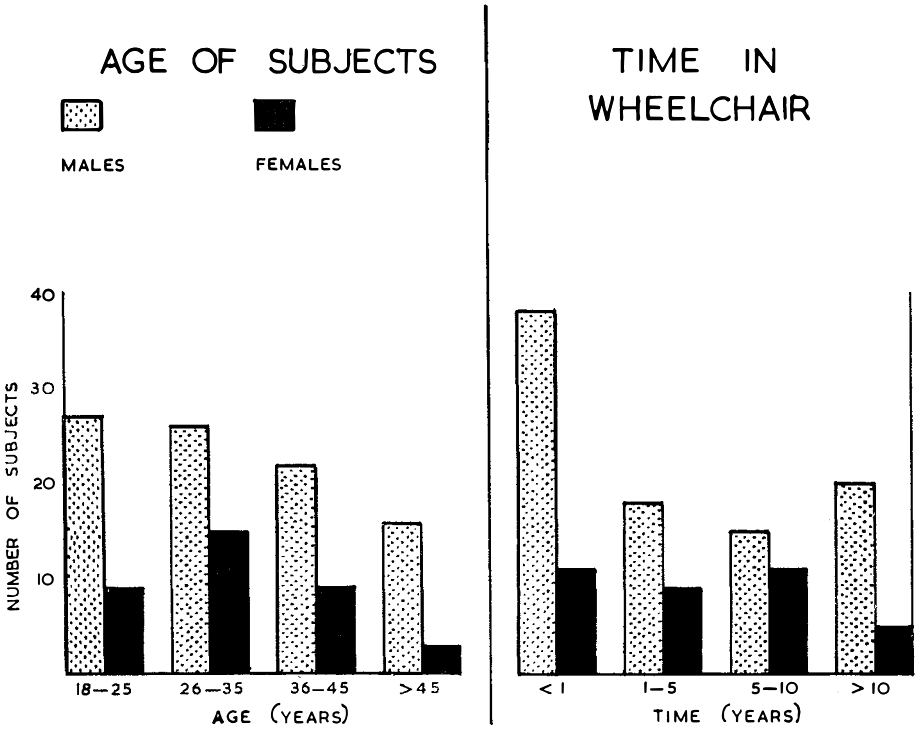

FIG. 1

Age distribution of subjects and length of time spent in wheelchair.

measurements and reaching measurements were taken. Body measurements only were taken on a further 15 male and 8 female tetraplegic subjects who had little or no arm movement.

Details of age, time spent in chair, level of spinal cord lesion, whether it was complete or incomplete, and the type of wheelchair used were recorded for each subject.

Forty-two per cent. of the subjects were hospital patients. These patients were sufficiently recovered to spend most of the day in their chairs, and to attend physiotherapy, occupational therapy and sports sessions.

Of the remaining 58 per cent. of the subjects, approximately half were former patients returning to the hospital for a few days to undergo a routine medical examination, and the others were paraplegics visiting Stoke Mandeville to take part in the National Paraplegic Games held during the course of this study. Thus the subjects can be regarded as representative of varying degrees of rehabilitation.

FIG. 2
Measurement of head height.

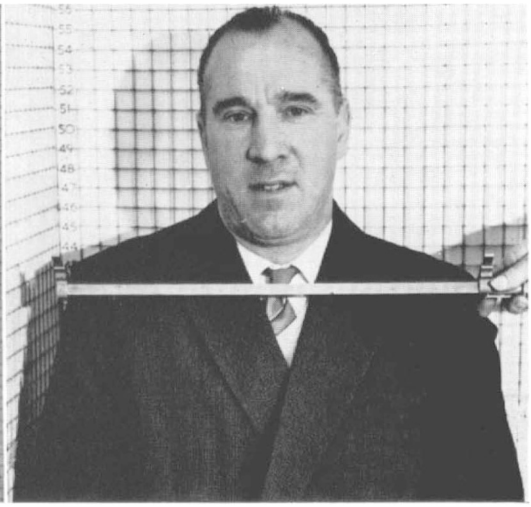

FIG. 3
Measurement of shoulder width.

The age distribution of the subjects studied is shown in Figure 1. The age-range was from 18 to 70 years, but approximately 60 per cent. of the subjects were under 35 years.

Figure 1 also shows the number of years spent by the subjects in their wheelchairs. Forty-two per cent. of the males had spent less than one year in their chairs, but an almost equal number had been disabled for more than five years. Eighty-five per cent. of the subjects studied had Everest and Jennings wheelchairs. The other chairs were of nine different makes, similar in overall dimensions to the types of chair normally issued by the Minstry of Health.

Nine body measurements were recorded for each subject to provide sufficient data for designers and for comparison with other work. The measuring apparatus, similar to that described by Morant (1947), consisted of two boards marked in one-inch squares, fixed rigidly at right angles. Each board was 8 ft. high, one was 4 ft. wide and the other 5 ft. Measurements were taken with the subject sitting in his usual chair, upright against the back-rest. Figure 2 illustrates the method of measuring head height. Eye, shoulder, elbow and knee height were measured in a similar way, by levelling a metre rule against the appropriate part of the body and reading the corresponding height off the measuring board correct to the nearest ½ in. Standard measuring equipment was used to take four other body measurements. These were, shoulder width (Fig. 3), thigh width, lower leg length and the length of the foot extending beyond the footrest.

The data on subjects who had full use of their arms were initially analysed separately from those of subjects who had only limited arm movement. Further statistical analysis showed that there was no significant difference in body measurements due to a greater degree of paralysis, and the two sets of data were therefore combined to give the final values, shown in Table I.

TABLE I—Means, Standard Deviations and 5th and 95th Percentile Values of Body Measurements

MALES. Total 91 subjects

	5th percentile	Mean	95th percentile	S.D.
Floor to vertex	49·1	52·4	55·7	2·0
Floor to eye	44·7	48·1	51·5	2·1
Floor to shoulder	38·4	40·8	43·2	1·5
Floor to elbow	24·9	27·3	29·7	1·5
Floor to thigh	23·3	25·4	27·5	1·3
Shoulder width	14·3	16·8	19·3	1·5
Hip width	12·2	14·1	16·0	1·2
Toe projection	3·7	5·1	6·5	0·9
Lower leg length	15·7	17·3	18·9	1·0
Age in years	—	34·7	—	—

FEMALES. Total 36 subjects

	5th percentile	Mean	95th percentile	S.D.
Floor to vertex	46·9	50·4	53·8	2·1
Floor to eye	42·7	46·4	50·1	2·2
Floor to shoulder	35·4	39·3	42·2	1·8
Floor to elbow	23·2	26·7	30·2	2·1
Floor to thigh	22·8	24·7	26·6	1·2
Shoulder width	13·5	15·1	16·7	1·0
Hip width	12·0	14·3	16·6	1·8
Toe projection	2·6	4·1	5·6	0·9
Lower leg length	14·4	16·2	18·0	1·1
Age	—	32·1	—	—

The results of the analysis of body measurements agreed closely with data on wheelchair users (Goldsmith, 1963). Agreement with data relating to old people reported by Roberts (1960) was also good, but agreement with data (Barkla, 1961) relating to able subjects aged 18 to 40 years was less close. This could be caused by slight posture differences resulting from measuring subjects in their wheelchairs rather than seated on a standard chair. Another possible explanation is that some types of disablement may lead to particular postures and sitting habits. In making these comparisons with other data, seat height in the wheelchair was calculated as 19 in. from the floor.

In making measurements of reaching distances for paraplegic subjects with full use of their arms, the aim was to determine the boundary of a three-dimensional shell which would outline the space in which wheelchair users could manipulate objects and use equipment around them.

Distinction was made between distances which could be reached comfortably, and those which could be reached only with maximum effort. A comfortable reach was defined as one in which the erect sitting posture was maintained, and only the reaching arm was moved, whereas in determining maximum reach any body movement was allowed provided that the subject remained in contact with the seat. Preliminary studies showed that there was very little difference in the reaching ability of the two arms. Since the time available for this study was limited, all but two of the measurements were made on the right arm only.

FIG. 4
Measurement of maximum upward reach.

FIG. 5
Measurement of maximum downward reach.

The measuring board used for the body measurements was also used to measure vertical reaching distances upwards and downwards. In each case both comfortable and maximum measurements were made. The subject held a wooden stylus in his closed fist and pointed it on to the board, from which the appropriate height could be read. Figure 4 shows the measurement of maximum upward reach. Comfortable reach was measured in the same way except that the subject sat erect in his chair and lifted his arm vertically upwards without stretching.

Comfortable and maximum downward reach was measured in a similar way with the subject reaching down over the arm of his chair. Figure 5 shows the measurement of maximum downward reach.

A separate movable measuring board 5 ft. wide was used to record the other reaching measurements. Horizontal reaching distances were measured in three vertical planes at each of five heights. Thus a total of 30 measurements, that is, comfortable and maximum reaching distances in each of 15 directions, were made. The three vertical planes in which measurements were taken were sidways; obliquely at an angle of 45°; and forwards. Figures 6 to 10 illustrate some of these measurements.

Figure 6 shows the subject making a comfortable reach sideways to a height of 61 in. The distance measured was the point on the 61 in. line to which the subject could reach with the stylus held in his closed fist. The measuring board was positioned against the chair wheel and at right angles to it, so that distances were in fact measured from the edge of the chair, rather than from the subject's body. The other four heights at which similar measurements were made are also marked on the board. These heights were 53 in. (approximate head height), 42 in. (approximate shoulder height), 29 in. (height of chair arm)

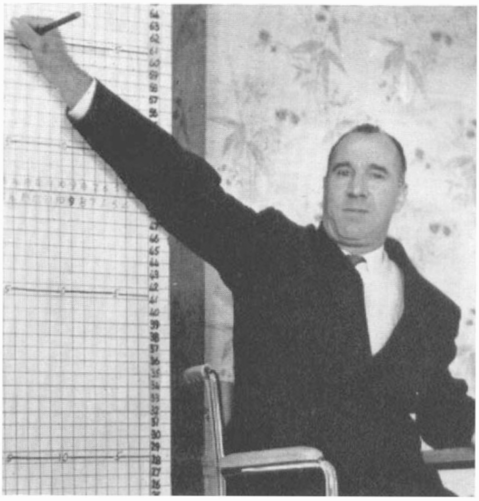

FIG. 6
Measurement of comfortable sideways reach at height of 61 inches.

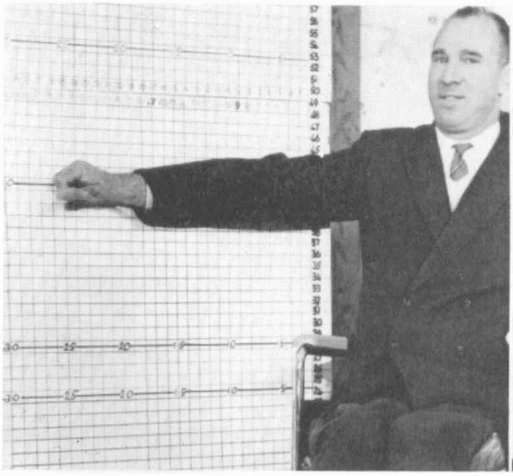

FIG. 7
Measurement of comfortable reach at oblique angle at height of 42 inches.

FIG. 8
Measurement of maximum reach at oblique angle at height of 42 inches.

and 25 in. (approximate knee height). At each height the corresponding maximum measurement was also made.

In Figures 7 and 8 the measuring board has been turned, relative to the wheelchair, through an angle of 45° to measure the oblique reaching distances at the same five heights. The edge of the board was positioned against the wheel, and at 45° to it. Comfortable and maximum reaching distances were again measured.

Figures 9 and 10 show the board in position for the corresponding forward measurements. The subject held his arm directly forwards, and pointed the wooden stylus on to the board which was parallel to the chair wheel. The edge of the board was against the hub of the chair, in line with the subject's shoulder.

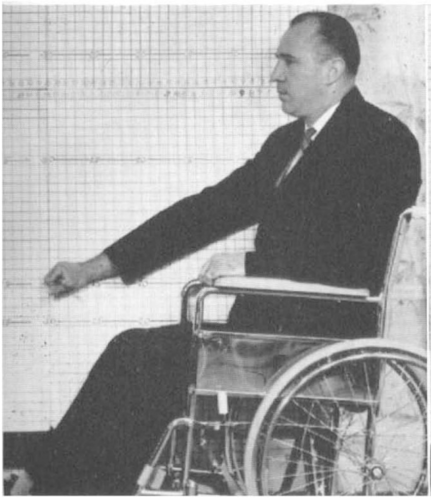

FIG. 9

Measurement of comfortable forward reach at height of 29 inches.

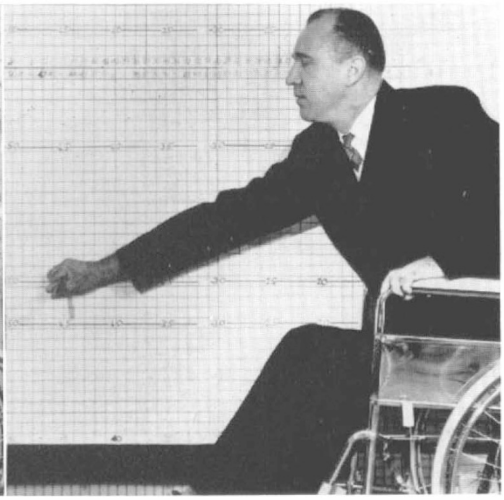

FIG. 10

Measurement of maximum forward reach at height of 29 inches.

Limitations of the measuring equipment made it impossible to carry out an equally detailed study of the subjects' ability to reach behind them, but an ordinary ruler was used to measure the distance each subject could reach behind the back of his chair at shoulder level. Since this movement could not be described as comfortable, only a maximum measurement was made.

The data obtained in this way for the 76 males and 28 females were analysed with an IBM 1620 computer programmed to derive means, standard deviations, and 5th and 95th percentile values for males and for females. The range between these percentile points accommodates 90 per cent. of the males and of the females measured. If a wider or smaller range is required it can readily be calculated from the values of the means and standard deviations.

The full results of this analysis are shown in Tables II and III, giving values of reaching distances at each height in the forward, oblique and sideways vertical planes, for males and females.

Table II

Means, Standard Deviations and 5th and 95th Percentile Values of Reaching Distances

Males

	Upwards				Downwards			
	5th	Mean	95th	S.D.	5th	Mean	95th	S.D.
Vertical reach:								
Com. . . .	61·8	65·4	69·0	2·2	18·5	15·5	12·4	1·9
Max. . . .	64·5	68·3	72·1	2·3	8·7	3·2	Zero	3·3

Height	Forwards				45° Angle				Sideways			
	5th	Mean	95th	S.D.	5th	Mean	95th	S.D.	5th	Mean	95th	S.D.
61″ Com.	10·5	16·2	21·8	3·4	4·5	10·2	15·9	3·5	1·9	7·6	13·2	3·4
Max.	19·2	28·5	37·8	5·6	9·6	18·3	27·0	5·3	6·9	14·0	21·1	4·3
53″ Com.	20·3	23·7	27·2	2·1	13·8	17·3	20·9	2·2	11·1	14·7	18·2	2·2
Max.	28·1	35·8	43·4	4·6	18·9	25·7	32·6	4·2	15·2	20·9	26·7	3·5
42″ Com.	23·9	27·0	30·1	1·9	17·0	20·8	24·5	2·3	14·7	17·6	20·5	1·8
Max.	32·7	40·4	48·2	4·7	23·8	30·4	37·0	4·0	19·7	25·1	30·5	3·3
29″ Com.	21·7	25·7	29·6	2·4	15·8	19·5	23·3	2·3	13·1	16·1	19·0	1·8
Max.	33·5	41·9	50·3	5·1	24·3	31·6	38·9	4·4	20·2	25·8	31·4	3·4
25″ Com.	20·8	24·5	28·2	2·2	13·8	17·9	22·0	2·5	11·1	14·3	17·6	1·9
Max.	33·1	41·8	50·5	5·3	23·6	31·2	38·7	4·6	19·3	25·1	30·9	3·5

	5th	Mean	95th	S.D.
Backward reach . .	16·0	23·1	30·2	4·3

These results were originally reproduced as transparencies showing the position of the chair and the distances which could be reached from the chair. These could conveniently be superimposed on the architect's or designer's own drawings, and he could see immediately whether his intended layout was suitable for wheelchair users. Figures 11 to 15 have been adapted from these transparencies.

TABLE III

Means, Standard Deviations and 5th and 95th Percentile Values of Reaching Distances

FEMALES

	Upwards				Downwards			
	5th	Mean	95th	S.D.	5th	Mean	95th	S.D.
Vertical reach:								
Com. . . .	58·2	62·5	66·8	2·6	18·8	15·4	12·0	2·1
Max. . . .	59·4	64·8	70·2	3·3	10·2	4·7	Zero	3·4

Height	Forwards				45° Angle				Sideways			
	5th	Mean	95th	S.D.	5th	Mean	95th	S.D.	5th	Mean	95th	S.D.
61″ Com.	1·4	11·0	20·5	5·8		5·6	11·9	3·9	—	3·7	9·2	3·3
Max.	5·4	20·4	35·3	9·1	1·5	11·9	22·3	6·3	0·9	8·9	16·9	4·9
53″ Com.	15·9	20·9	26·0	3·1	9·5	14·0	18·5	2·7	7·0	11·6	16·1	2·8
Max.	23·5	31·0	38·5	4·6	13·9	21·2	28·5	4·4	11·9	17·4	22·9	3·3
42″ Com.	21·1	25·2	29·2	2·5	14·6	18·2	21·9	2·2	11·9	15·7	19·5	2·3
Max.	27·0	35·6	44·2	5·2	20·6	27·1	33·7	4·0	17·3	22·4	27·4	3·1
29″ Com.	20·5	24·8	29·2	2·6	14·3	18·1	21·8	2·3	10·4	14·8	19·1	2·6
Max.	29·1	37·9	46·8	5·4	22·0	28·8	35·6	4·1	17·5	23·3	29·1	3·5
25″ Com.	19·5	23·9	28·2	2·6	12·7	16·7	20·7	2·4	9·2	13·3	17·4	2·5
Max.	28·2	37·6	47·0	5·7	21·6	28·7	35·8	4·3	16·6	22·8	28·9	3·7

	5th	Mean	95th	S.D.
Backward reach . .	16·7	22·0	27·3	3·2

Figure 11 illustrates the posture of a subject reaching sideways, and the position of the wheelchair. On the left the subject is shown sitting erect in his chair making a comfortable reach to a height of 42 inches and on the right leaning over to make a maximum reach to the same height. The diagrams have been drawn to scale according to the body measurements of the average male, and the chair dimensions are those of the adult Everest and Jennings chair. The small diagram in the top left-hand corner is merely an additional view of the subject's posture as seen from directly above. The zero line of measurement is against the edge of the subject's chair. All measurements are given in inches.

Figure 12 shows the comfortable and maximum distances reached sideways at the various heights. The broken lines represent the mean values and it can be

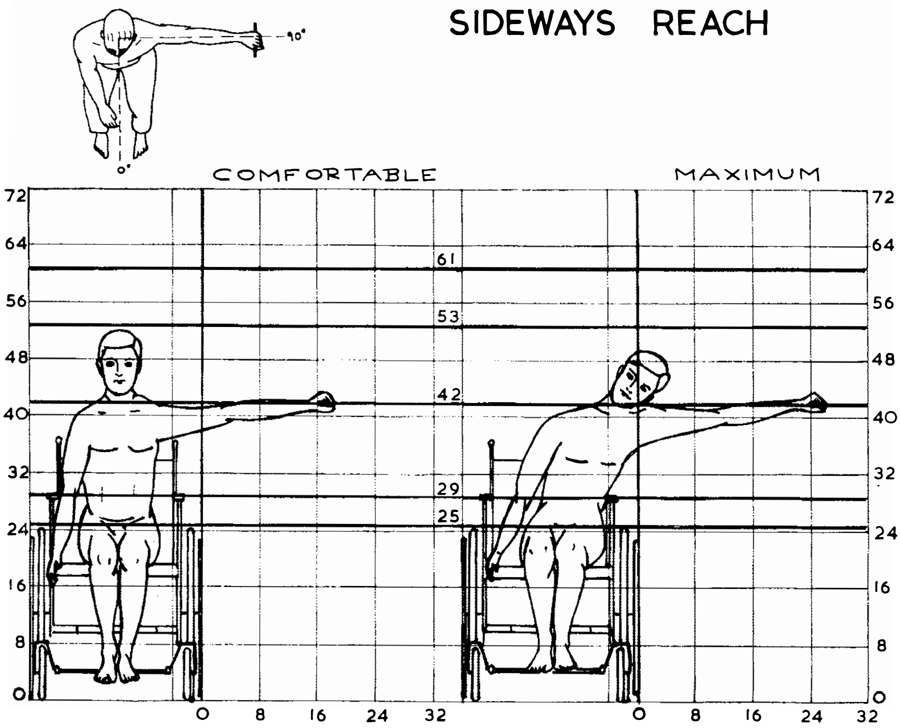

FIG. 11

Position of wheelchair and posture of subject for sideways reaching measurements at height of 42 inches.

seen that there is relatively little difference between these mean values for the males and the females. The solid lines are of greater importance to designers as these represent the values for the 5th percentile female and for the 95th percentile male. Thus the range between these two lines includes all but the extreme 5 per cent. of small females and the extreme 5 per cent. of large males. This is the range that the designer can reasonably hope to accommodate. From Figure 12 it can be seen that the large majority of wheelchair users are not able to reach the floor from their chairs, although the average wheelchair user can reach to within about 4 in. of the floor. Although males can reach upwards about 3 in. higher on average than the females, downwards reach is approximately equal for both.

Figure 13 shows the corresponding reaching distances in the oblique, or 45° angle, direction. It can be seen that at heights below shoulder level a considerable increase in reach from comfortable to maximum value is possible because, when reaching obliquely, the subject is not obstructed by the chair arms as much as in the sideways position.

Figure 14 shows the position of the wheelchair and the subject's posture when reaching forward. The zero line from which measurements were made was the vertical line passing through the hub of the chair wheel. It can be seen that, when

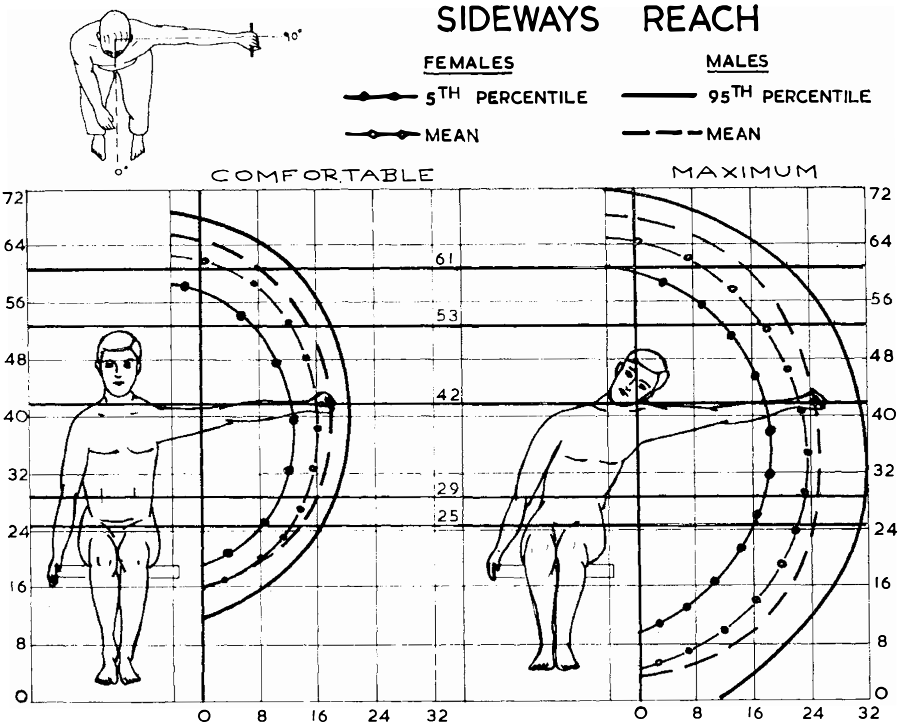

FIG. 12

Comfortable and maximum distances reached in the sideways position.

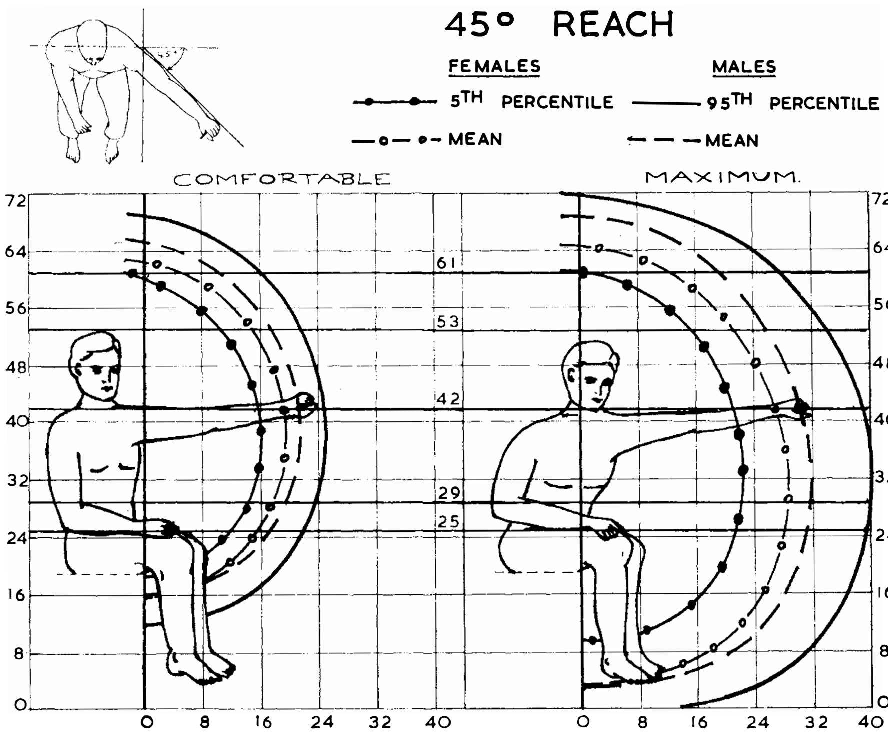

FIG. 13

Comfortable and maximum distances reached in the 45° or oblique position.

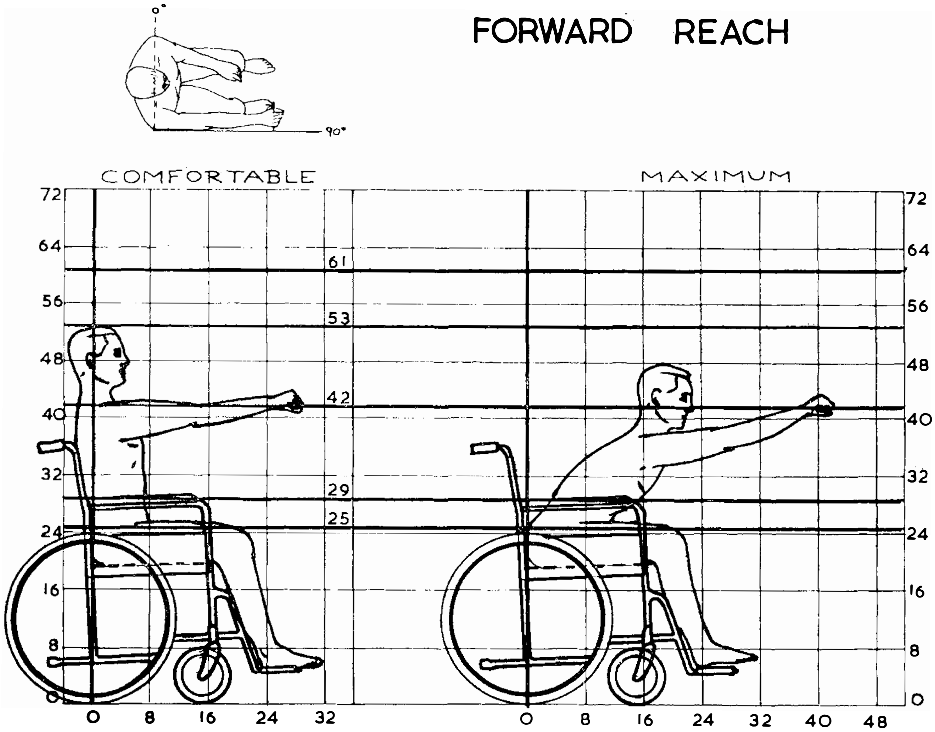

FIG. 14

Position of wheelchair and posture or subject for forward reaching measurements at height of 42 inches.

reaching comfortably forward at shoulder level, the average male can reach a point vertically above the footrest of his chair. Thus he has to lean forward to reach anything positioned beyond the footrest.

Figure 15 shows reaching distances in the forwards direction for males and females. It can be seen that in this direction the upper part of the body can be used most effectively to increase reach from the comfortable to a maximum value.

In assessing the results of this study it must be emphasised that the sample of females was only about one-third as large as that of males and thus the data for the females are likely to be less reliable.

In using these results the designer should first consider whether maximum or minimum measurements are critical, and whether males, females, or both are likely to be primarily concerned. For instance, the layout of a factory workbench may only need to accommodate males, whereas domestic fittings should be designed for both male and female users. In some cases it may be necessary to provide an adjustable fitting to achieve this. For instance, the underneath of a working surface should be high enough to allow the 95th percentile male (and therefore also smaller individuals) to bring his chair close to it. But such a surface may well be too high to provide comfortable working level for the smaller female. In cases such as this fittings should, wherever possible, be made adjustable to the require-

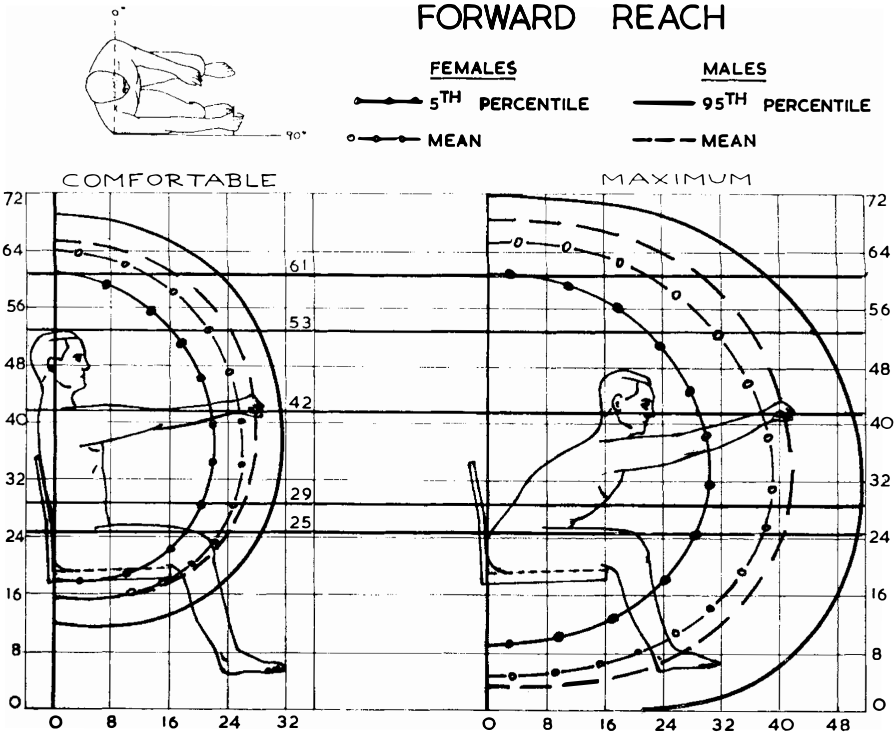

FIG. 15
Comfortable and maximum distances reached in the forward position.

ments of individual users. The range of adjustment necessary can be determined from the diagram.

In some cases expense and space considerations may limit the range of adjustment possible. Even if this is unavoidable the designer should take great care that nothing is positioned outside the maximum reach of the 5th percentile female as, for instance, attempting to pick up an object just out of reach is likely to cause accidents.

In designing for wheelchair users it must be remembered that the user and the chair form an inseparable unit and allowances must always be made for manoeuvring the chair and for the space it occupies. For this reason measurements were made relative to the wheelchair rather than to the subject's body.

It should be emphasised that, although the study is concerned with the functional anthropometry of wheelchair users it is vitally important that designs intended for disabled people should, as far as possible, also be suitable for the general population. Many design features which are essential for wheelchair users, for instance wide corridors and doorways, easily accessible handles, switches and control knobs, are also convenient for the general population.

The need to combine good design for the wheelchair user with good design for able people is obviously important, both to increase the independence of severely disabled people, and to facilitate their integration into the general community.

Summary

Ninety-one male and 36 female paraplegic and tetraplegic patients at the National Spinal Injuries Centre, Stoke Mandeville, were the subject of a study to determine the body dimensions and space requirements of wheelchair users with spinal cord lesions.

Apparatus was designed to measure nine anthropometric body dimensions, including head height, eye height, shoulder height, elbow height, shoulder and thigh widths, and lower leg length. Measurements were taken with the subjects sitting upright in their usual chairs and relevant details of age, time spent in chair, level of spinal cord lesion, whether complete or incomplete, and the type of wheelchair used were recorded.

In making measurements of reaching distances for 76 male and 28 female paraplegic subjects with full use of their arms, the aim was to determine the boundaries of a three-dimensional shell which would outline the space in which wheelchair users could manipulate objects and use equipment around them. Comfortable and maximum reaching distances in various directions were measured and a total of 35 reaching measurements for each subject was recorded.

The data obtained were analysed by computer programmed to derive means, standard deviations and 5th and 95th percentile values for males and for females. These values are presented in a series of tables and diagrams.

These anthropometric measurements are of importance to designers and also for comparison with other data.

Résumé

91 paraplégiques et tétraplégiques du sexe masculin et 36 du sexe féminin ont été étudiés au Centre National pour les Traumatisés de la Moelle Epinière de Stoke Mandeville; ceci avec but de déterminer les dimensions corporelles et l'espace requis pour une personne atteinte d'une lésion médullaire, utilisant une chaise roulante.

L'appareil a été construit de facon à mesurer les 9 dimensions anthropométriques du corps, parmi celles-ci la hauteur de la tête, des yeux, des épaules, des coudes, la largeur des épaules, des cuisses et enfin la longueur de la jambe.

Les mesures ont été prises avec les sujets assis droits dans leur chaise habituelle. Les détails concernant l'âge, la date de la lésion, le niveau de celle-ci (complète ou incomplète), et le type de chaise utilisée, ont été étudiés.

En faisant ces mesures pour la distance d'atteinte d'un objet pour 76 hommes et 28 femmes paraplégiques avec usage complet de leurs membres supérieurs, le but était de déterminer les frontières d'une coquille tridimensionnelle réalisant l'espace dans lequel les utilisateurs des chaises roulantes peuvant manipuler avec aise les objets, et utiliser l'équipement autour d'eux.

Les distances d'atteinte confortable et maximale dans différentes directions ont été mesurées et un total de 35 mesures pour chaque sujet a été inscrit. Les chiffres obtenus furent analysés par un ordinateur de facon à avoir les moyennes, les déviations standard, les valeurs à 5 et à 95% pour les hommes et les femmes. Ces valeurs ont été présentées dans une série de diagrammes et de tables. Les mesures anthropométriques sont d'importance pour les ingénieurs, et pour la comparaison avec d'autres mesures prises par ailleurs.

ZUSAMMENFASSUNG

91 männliche und 36 weibliche Paraplegiker und Tetraplegiker des National Spinal Injuries Centre, Stoke Mandeville, wurden untersucht, um die Körperdimensionen und Raumbedürfnisse von Rollstuhlfahrern mit Rückenmarksläsionen zu bestimmen.

Mit Hilfe eines Apparates wurden 9 anthropometrische Körperdimensionen incl. Kopf-, Augen-, Schulter- und Ellbogenhöhe sowie Oberschenkelweite und Unterschenkellänge vorgenommen. Die Messungen wurden am im Rollstuhl aufrecht sitzenden Patienten ausgeführt und wichtige Einzelheiten über Alter, Zeitdauer im Rollstuhl, Höhe und Schwere der Rüchenmarksläsion sowie der Rollstuhltyp wurden notiert.

Messungen der Reichweite wurden bei 76 männlichen und 28 weiblichen Paraplegikern mit vollem Gebrauch ihrer Arme unternommen, um die Grenzen einer 3-dimensionalen Wand zu bestimmen, innerhalb welcher Rollstuhlfahrer Gegenstände manipulieren können.

Einfache und maximale Reichweiten in verschiedenen Richtungen wurden gemessen und für jeden Untersuchten 35 Reichweitemessungen bestimmt.

Die Resultate wurden mittels Komputer analysiert, um Mittelwerte, Standardabweichungen und 5 und 95 prozentuale Werte für Männer und Frauen zu erhalten. Die Werte werden in einer Serie von Tabellen und Diagrammen wiedergegeben.

Die Bedeutung dieser anthropometrischen Messungen für Entwurfzeichner und auch für einen Vergleich mit anderen Daten wird betont.

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