Ministry of Defence

Defence Standard

00-25(PART 3)/Issue 2 24 January 1997

HUMAN FACTORS FOR DESIGNERS OF EQUIPMENT

PART 3: BODY STRENGTH AND STAMINA

This Defence Standard supersedes
Def Stan 00-25 (Part 3)/Issue 1
Dated 16 April 1984

AMENDMENTS ISSUED SINCE PUBLICATION

AMD NO	DATE OF ISSUE	TEXT AFFECTED	SIGNATURE & DATE

Revision Note

This revision aims to provide up-to-date technical advice, guidance and data which reflects recent advances on Body Strength and Stamina of male and female personnel including the effects of repetitive lifting, the difference between male and female strength characteristics. The off centre of gravity and distance covered upon ease of carriage of loads.

Historical Record

This Defence Standard supersedes Defence Standard 00-25 (Part 3)/1 published on 16 April 1984 which had its origins in "Human Factors for Designers of Naval Equipment" (a naval handbook in two volumes) published in 1971.

Arrangement of Defence Standard 00-25

Human Factors for Designers of Equipment
Part 1 - Introduction
Part 2 - Body Size
Part 3 - Body Strength and Stamina
Part 4 - Workplace Design
Part 5 - Stresses and Hazards
Part 6 - Vision and Lighting
Part 7 - Visual Displays
Part 8 - Auditory Information
Part 9 - Voice Communication
Part 10 - Controls
Part 11 - Design for Maintainability
Part 12 - Systems
Part 13 - Human Computer Interaction
Part 14 - Training and Instruction (not yet published)

HUMAN FACTORS FOR DESIGNERS OF EQUIPMENT

PART 3: BODY STRENGTH AND STAMINA

PREFACE

This Defence Standard supersedes Def Stan 00-25 (Part 3) Issue 1 dated 16 April 1984

i This Part of the Defence Standard is concerned with the limits of strength and endurance of muscular outputs of force and movement relevant to the operation of infrequently-used controls, for lifting and handling, in maintenance tasks and in using hand tools.

ii This Part of the Defence Standard is published under the authority of the Human Factors Subcommittee of the Defence Engineering and Equipment Standardization Committee (DEESC).

iii This Standard has been agreed by the authorities concerned with its use and is intended to be used whenever relevant in all future designs, contracts, orders etc and whenever practicable by amendment to those already in existence. If any difficulty arises which prevents application of the Defence Standard, the Directorate of Standardization shall be informed so that a remedy may be sought.

iv Any enquiries regarding this Standard in relation to an invitation to tender or a contract in which it is incorporated are to be addressed to the responsible technical or supervising authority named in the invitation to tender or contract.

v This Standard has been devised for the use of the Crown and its contractors in the execution of contracts for the Crown. The Crown hereby excludes all liability (other that liability for death or personal injury) whatsoever and howsoever arising (including, but without limitation, negligence on the Part of the Crown its servants or agents) for any loss or damage however caused where the Standard is used for any other purpose.

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HUMAN FACTORS FOR DESIGNERS OF EQUIPMENT

PART 3: BODY STRENGTH AND STAMINA

Section One. General

0 Introduction

As technology advances, human muscle is less used at work as a primary source of power. However, muscular outputs of force and movement are of importance in control systems, and the limits of strength and endurance are relevant to the operation of infrequently-used controls, for lifting and handling, in maintenance tasks and in using hand tools.

(adapted from: Morgan and Adamson, 1968)

1 Scope

1.1 This Part of the Standard provides a brief presentation of important factors concerned in the use of safe postures and loads at work.

1.2 This Part of this Standard also discusses biomechanical factors in materials-handling activities and general factors affecting materials - handling capacities.

1.3 In addition, this document lays down technical data relating to the following: joint movement ranges and optimum positions for specific activities; hand strengths with both power grips and precision grips; male capacities for force application by the hands, in both free space and restricted space; muscular work and rest pauses; load carriage.

2 Related Documents

2.1 The documents and publications referred to in this Part of the Standard are listed at Annex A.

2.2 Related documents can be obtained from:

DOCUMENT	SOURCE
HSE L23 Manual Handling Guidance on Regulations	PO Box 276 LONDON SW8 5DT
Mil-STD-1472D Human Engineering design criteria for Military Systems, Equipment and facilities	DTD Technical Indexes RAPIDOC Willoughby Road Bracknell, Berkshire RG12 4DW

DOCUMENT	SOURCE
British Standards (BS) and (BS EN) Publications	BSI Sales Department Linford Wood MILTON KEYNES MK14 6LE
Defence Standards	Directorate of Standardization (Stan 1) Kentigern House 65 Brown Street GLASGOW G2 8EX

2.3 Reference in this Part of the Standard to any related document means in any invitation to tender or contract the edition and all amendments current at the date of such tender or contract unless a specific edition is indicated.

3 Definitions

3.1 Biomechanics. The mechanics of movements in living creatures.

3.2 Body strength. For the purposes of this Part of this Standard, body strength is interpreted as the measure of force which the body can apply to external objects.

3.3 Percentile. Variation in human data is often described in terms of percentiles (%iles). For any dimension in any population of individuals, ‘n’ per cent of people are weaker than the ‘nth’ percentile. Hence 3% are lighter in weight than the 3rd %ile, 97% are lighter than the 97th %ile, and so on. For most practical purposes, we may consider the 50th percentile and the ‘average’ or ‘mean’ to be one and the same. (See Defence Standard 00-25 Part 2 clause 2 for further information).

3.4 Stamina. For the purposes of this Part of this Standard, stamina is defined as the capacity of an individual to perform continuous physical work.

3.5 Standard deviation. The standard deviation describes the extent to which values might be expected to deviate from the mean. (See Defence Standard 00-25 Part 2, Annex A).

Section Two. Description of, and Factors Affecting, Body Strength and Stamina

4 Body Strength

4.1 Maximum body strength is of limited use to the designer, since:

(a) it is highly fatiguing to use maximum force exertions repeatedly or for significant periods of time;

(b) repeated exertion of forces near the maximum may result in body damage.

4.1.1 In designing equipment for general use, it must be clearly within the safe working capacity of a selected percentile. Thus, in general, the forces indicated hereafter are those which are generally accepted as being within the capacity of young, fit, subjects, based as far as possible upon observations on military personnel.

4.1.2 The forces given are, thus, 'usually maximum strength consistent with long-term safety' and not ‘maximum body strength’, as might be exerted in athletic competition or, in emergency, under fire when on active service.

4.1.3 It is particularly important to consider the (generally) lesser strength of woman when designing equipment which is to be used by both sexes. A Statement about the differing strengths of males and females is given at **4.8.**

4.2 Stamina

4.2.1 As far as the individual’s stamina is concerned, it depends, in part, on the person’s physical fitness; particularly on the capacities of their heart and lungs and, in part, on their body strengths.

For further details on stamina refer to **4.4.2(a).**

4.2.2 Physical fitness, in general, determines the rate at which work can be performed continuously. If this rate is exceeded, then the individual will become fatigued after a period and will have to rest before resuming the work. Since external physical work reflects the ability of the muscles to burn their fuels by combining them with oxygen, there is a very close correlation between physical work performance, oxygen uptake and body heat production/energy consumption. Human physiology work is commonly measured in terms of heat expressed as kilocalories (kcal) per unit time - (1 kcal = 4186.8 joules).

NOTE: The kilocalorie is not an SI metric unit; therefore, throughout the remainder of this document the recognised SI unit for work, the joule (J), will be used. (NB: 1 Joule = 1 Newton Metre = 1 Wattsecond = 10^7 ergs = 0.74ft lbs) (Ref: Uranov and Chapman (1977) Dictionary of Science SI)

4.3 Work-rate and Energy Expenditure

4.3.1 Measurement of energy expenditure is a complex matter and, since oxygen is carried to the muscles by the blood circulation, one can sometimes use pulse-rate as an indicator of work-rate. Unfortunately, pulse-rate is affected by many factors, among them mental stress, so that one has to be sure that the subject is well habituated to the circumstances, and not under mental load, before using pulse-rate as the sole arbiter of work-rate.

4.3.2 The heat production of an adult male generated under general living conditions, including the energy needs of his occupation, is about 9630 kJ per 24 hours.

4.3.3 Additional heat production, due to occupational activity involving the whole body, can be classified as follows:

	Additional Heat Production in kJ/24th		Equivalent pulse-rate in beats per minute
	Male	Female	
Resting	0	0	60 to 70
Light work	2930	2093	75 to 100
Moderate Work	5440	3770	100 to 125
Heavy Work	11300	5020	125 to 175

4.3.4 Where the subject is seated, and the physical work is being performed by the hands and arms, there is a reduced capacity for heat production; the equivalent occupational heat outputs are:

	Additional Heat Production in kJ/24th		Equivalen pulse-rate in beats per minute
	Male	Female	
Light work	1880	1470	75 to 100
Moderate Work	3560	2510	100 to 130
Heavy Work	7540	3350	130 to 175

4.4 Work and pulse-rate

4.4.1 In general, for continuous activity, work output can only be sustained for long periods if the average work-rate over an 8 hour period requires less than 33% of maximum energy production. The pulse-rate equivalent to this 33% level is an average increase of about 30 beats per minute, giving an average pulse-rate of about 100 beats per minute for a fit young male. Higher work-rates can be maintained for shorter periods:

50% of maximum energy production being maintainable for 1 hour, but no longer.

4.4.2 When an operator is not required to work continuously, but only for one hour (not eight hours), then his energy production is regarded as 50% of maximum, not 33% of maximum. These percentage reductions refer to whole-body activities, and not part-body activities, carried on continuously for the periods specified.

(a) As indicated at **4.6.1** static muscular components of the work may further reduce stamina.

4.4.3 If harder work has to be performed, the pulse-rate will not level out but continue to rise until exhaustion. A comparison of two work-rates is given in Fig 1. This shows that after the high work-rate, the pulse-rate is very slow to recover to its original resting state. If work requires over 30 additional beats per minute, and the pulse-rate has not returned to resting level within 15 minutes after stopping work, then appropriate rest periods must be given.

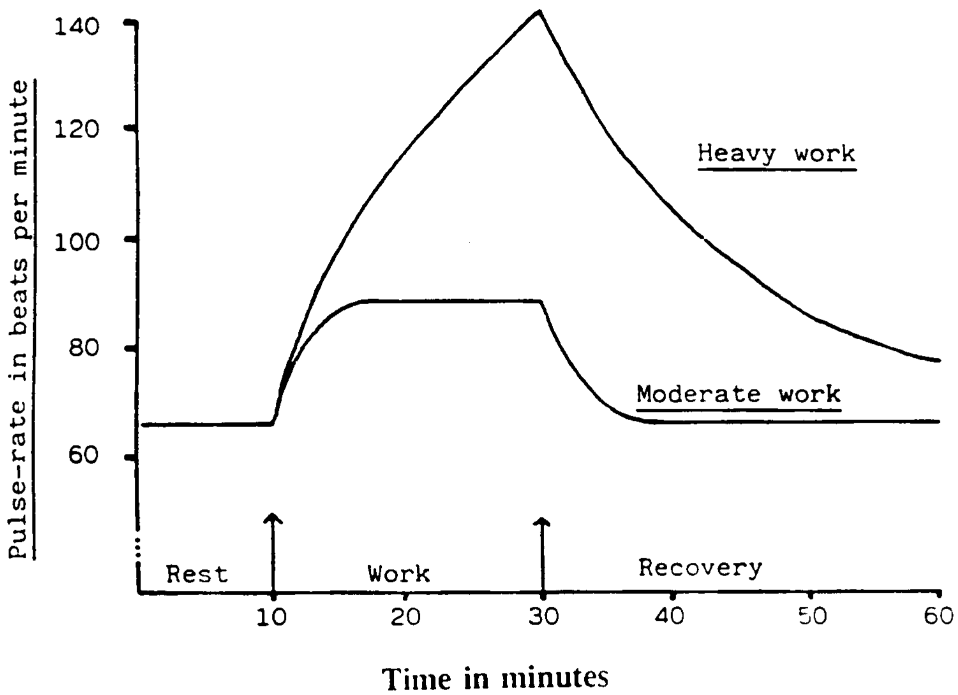


Fig 1 Pulse-Rates in Heavy and Moderate Work

In heavy work, the pulse-rate continues to rise, and at about 140 pulses per minute the subject may be forced to rest, and recovery can be slow. At a moderate work-rate, the heart-rate levels out at about 90 pulses per minute, and recovery is rapid.

(from: Fitting the task to the man by E Grandjean, 1980).

4.5 Rest Periods

4.5.1 Research and experience in industry have shown that regular periods of rest during the working day, increase output and decrease sickness absences. In hot conditions, and during heavy work, rest periods also give opportunities for ensuring adequate fluid, food and salt intake.

4.5.2 While it is possible for people physically to work hard, without rest, for considerable periods of time in emergencies, such periods are inevitably followed by periods of low output; and the total work done over a longer time will be less than that which would have occurred had those emergencies not arisen. The same is true of mental tasks.

4.5.3 Rest pauses are required in both physical and mental work to allow recovery. They are also important in monotonous tasks, to offset the effects of boredom. In any job, if adequate rest periods are not provided, the worker may insert them in disguised form into his/her routine; and where he/she is part of a team, output is likely to fall because of disruption of the team’s work.

4.5.4 The calculation of appropriate periods of rest is a complex task. But, generally speaking, for light tasks in which the pulse-rate does not exceed 100 beats per minute, the total of disguised, spontaneous, and prescribed rest pauses will amount to 15% to 20% of total working time. Thus, in a regular 8 hour shift, one will obtain some 6½ hour of useful work. This work will be more productive if one deliberately inserts rest periods, totalling 14 hours, into the routine. The usual way of doing this is to have 1 hour for lunch, with 15 minute breaks for coffee and tea. If the work is particularly monotonous, then more frequent and shorter work periods should be planned.

4.5.5 If the work makes heavy physical demands, longer rest periods must be provided, and the percentage time for useful work drops extremely rapidly as work load increases above the moderate rate:

Physical work classification	Rest time in 8 hour shift
Light	1½ hours
Moderate	2 hours
Heavy	2¾ hours
Very Heavy	3¾ hours

4.5.5 (Contd)

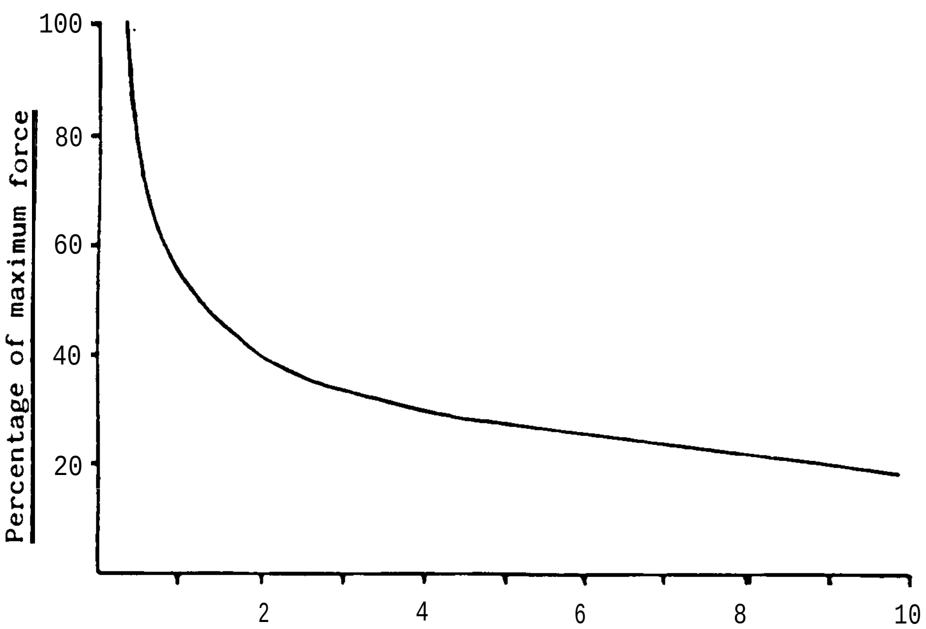
With heavy physical work the standard coffee, lunch and tea breaks should be provided, and the additional break time divided into frequent short intervals.

4.6 Muscular activity. Muscles are used at work in two ways: namely, static activity and dynamic activity.

4.6.1 Static activity. A static activity is one involving no movement and requiring continuous contraction of a muscle or group of muscles. In this condition, the flow of blood to the muscles is impeded, they become rapidly fatigued, and work tolerance is low. The relationship between force and duration of continuous muscular contraction is summarised in Fig 2.

(a) In simpler terms, the static force that can be achieved drops to 50% of the initial maximum after about a minute and to 20% after about 10 minutes.

(from: J.van Dieen & H.Oude Vrielink, The use of the relation between relative force and endurance time. 1994).



Possible duration of contraction in minutes

Fig 2. Duration of Static Muscular Contractions at different Percentages of Maximum Force

(from: Contributions à l'ètude du travail statique by H Monod, 1956).

4.6.2 Dynamic activity. A dynamic activity is one in which the muscles rhythmically contract and relax; it promotes the blood supply to the muscles, and work tolerance is high.

4.6.3 Many existing task designs require mixtures of static and dynamic activity: maintenance engineers commonly have to maintain a stooping posture by static activity in leg and back muscles, while using the arms in dynamic fashion to unscrew and screw up nuts and bolts, etc. In most cases, the limiting factor in such situations is the static work, not the dynamic. Thus, tasks should be designed to avoid static activity as far as possible.

4.6.4 If a large force has to be exerted, the tissues of the body have to be stretched above their elastic limit, and they will need time to recover fully. If, however, such forces are frequently repeated within the recovery period, then tissue breakdown will eventually occur. This process of cumulative injury is involved in a number of disorders:

(a) at the wrist, repeated overstress of tendons can result in their inflammation in a day or so - a condition called wrist tenosynovitis; this has been a common problem with typists for many years. It is now becoming even more frequent with the increasing number of VDU and keyboard operators. Those suffering are often referred to as victims of Repetitive Strain Injuries (RSI).

(b) 'tennis' elbow (epicondylitis) is similarly caused;

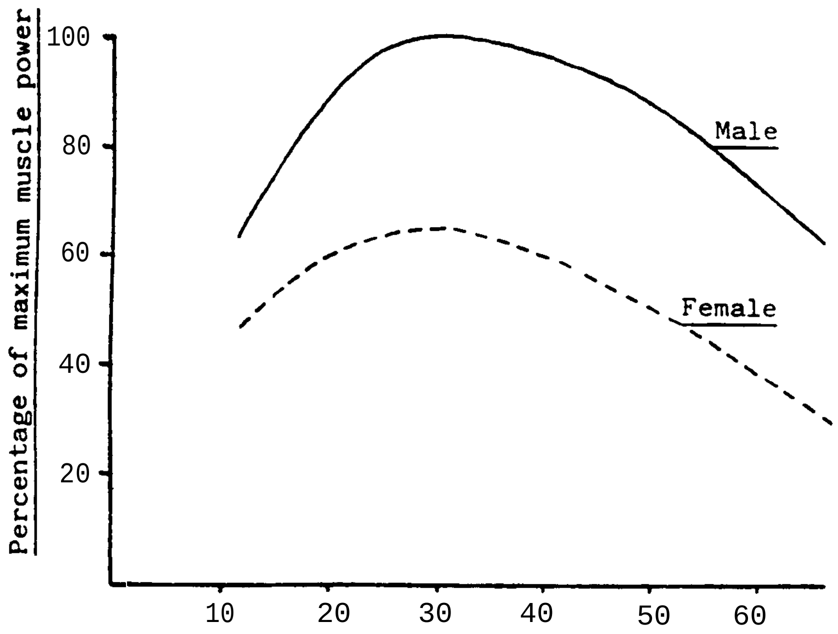
(c) recent studies have shown that severe back-strain disorders can be caused by the subjection of the back, over periods of weeks or months, to too frequently repeated high stresses.

4.7 Effects of age

4.7.1 In general, men and women have reached approximately 90% of their ultimate strength by the age of 20. Maximum strength is reached at 30 years of age, and there is then a decline to 90% of this capacity at about 45; by the age of 60, most people have retained 75% to 80% of their past capacity. (See Fig 3).

4.7.2 However, whilst this is the general rule, there are differences in detail; for example, people over 50 years of age have a greater proportional decline in capacities when kneeling than when standing.

4.8 Strengh comparisons of the sexes. Whilst there is, at present, less information concerning the strengths of female Service personnel than there is for males, a figure of 50-60% of male capacities would seem to be reasonable. This is only a generalization, and variations upon this figure will be encountered for different muscle groups.



Age in years

Fig 3. Muscle Strength with Age and Sex

(from Muskel Kraft bei M'ánnern und Fravern by T HeHinger 1960

Section Three. Posture and Work Capacity

Posture refers to the overall position of the body and limbs relative to each other and their orientation in space.

5 Body Posture

5.1 The human species is so designed that a comfortable standing position, with the feet slightly apart, can be maintained with minimum muscular contraction. When sitting, static muscular contract will occur unless the back is supported, but less muscle activity is required to maintain an unsupported kneeling position. Stooping for short or long periods should be avoided. Maintenance of a stooping posture, without external support of the upper trunk, requires large and continuous contraction of the back muscles and can lead to early fatigue. If stooping cannot be designed out of the system, then the task should be so arranged that either the chest can rest comfortably on a support, or the trunk can be supported on the elbows or on one hand. These requirements need particular consideration when designing for the maintenance of machinery: injuries arising from enforced bad posture are all too common in maintenance engineering.

5.1.1 Factors to be considered with regard to sitting and standing are included in Part 4 of this Defence Standard.

5.1.2 Kneeling can be on one or both knees. For preference, one knee should be used, as this allows the operator to change knees from time to time and avoid postural fatigue. If a task requires prolonged kneeling on hard or abrasive surfaces, knee pads should be provided. For heavy work, the one-knee position allows the operator to rest one elbow on the other knee and thus reduce the stresses otherwise acting on the operator’s trunk.

5.1.3 Squatting is a posture commonly held for long periods in Asian countries and for example in British mines. It takes less floor space than kneeling. Western peoples generally find that squatting postures become uncomfortable after a few minutes, and tasks requiring prolonged squatting should be avoided.

5.2 Head Posture. With the trunk in a balanced uprightness, the head is best held in balance when the work is in an area between 23° and 37° below a horizontal plane through the eyes, when standing; and between 15° and 45° below the horizontal, when sitting. Outside these limits, neck strain occurs and work capacity is reduced. The weight of protective helmets will further exacerbate the problem. See Part 2 of this Defence Standard, section 6.6.1 for further details.

5.3 Arm Posture. For most purposes, arm postures which allow the elbows to be close to the trunk are least fatiguing; and if an arm posture has to be maintained for long periods, arm rests should be available for precision control wrist supports are required. This is particularly true if fine-precision movements are required for the work.

Section Four. Hand Grips

6 Definition

While the hand is used for many activities other than gripping, such as button pushing, trigger pulling and so on, its main use in manual handling is grasping. There are two distinct families of grip, and it is highly important that design of an object allows the correct grip to be used. (See Fig 4)

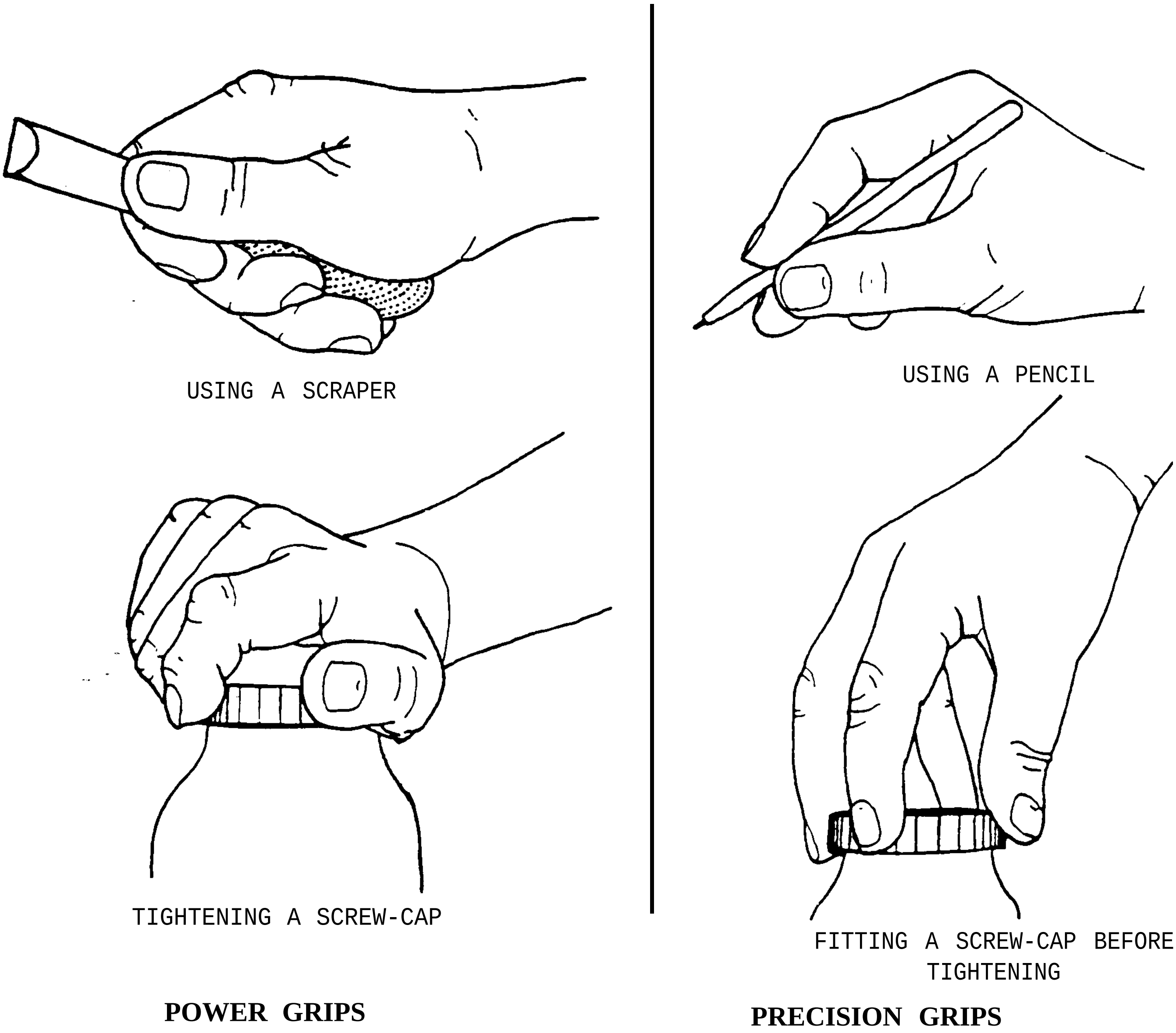
6.1 Precision grip. The characteristic of this grip is opposition of the thumb. In opposition, the thumb rotates so that its soft digital pad opposes the soft pads of the middle and index fingers. The thumb is usually fairly straight, and the fingers bent at the knuckle (metacarpophalangeal) joint; the finger joints themselves being relatively straight.

NOTE: There are no values currently available for the non-preferred hand using the precision grip.

6.1.1 Power grip

(a) In this grip the thumb is not rotated, and is often flexed; the knuckle joint is usually less bent than the joints of the fingers.

(b) A variant of the power grip, used in carrying, is the hook grip, in which the knuckle joints are straight, and the finger joints fully flexed.



NOTE: In all varieties of precision grip, the thumb is opposed to the index and middle fingers, which are relatively straight; in power grips, the thumb is not opposed, and the fingers are relatively more flexed.

Fig 4 Comparison between Power Grips and Precision Grips

6.1.2 Strength and fatigue factors

(a) The precision grip uses the small muscles of the hand, which have very accurate nervous control but are usually relatively weak and may be easily fatigued. A precision grip is only about 20% as strong as a power grip, it becomes easily fatigued, and recovery from fatigue is slow. Thus, if the hand is fatigued by heavy work during loading or carrying, activities such as the joystick control of missiles may be severely limited for considerable periods.

(b) Power grips use the more robust muscles of the arm, which are less well controlled but fatigue less readily.

(c) Either grip is strongest when the wrist is being applied in a mechanical effect or partially extended. If the wrist is not positioned in a mechanical effect and is bent towards the side of the little finger, and is then used repeatedly for powerful activities, there is a large increase in the likelihood of cumulative disorders such as epicondylities ('tennis' elbow) and inflammation of wrist tendons (tenosynovitis) - see also **4.6.4 (a)**.

Section Five. Ranges of Joint Movements

7 Power

The power available at a given joint varies within its range of movement. In general, force is greatest at joint mid-positions: although, for instance, that at the knee is greatest close to full extension. In task design, it is generally advisable to avoid movements to extreme positions.

7.1 Range of movement. The mean angular ranges of joint movements in males, together with the ranges encompassing 94% of the population, are summarized in Figs 5, 6 and 7.

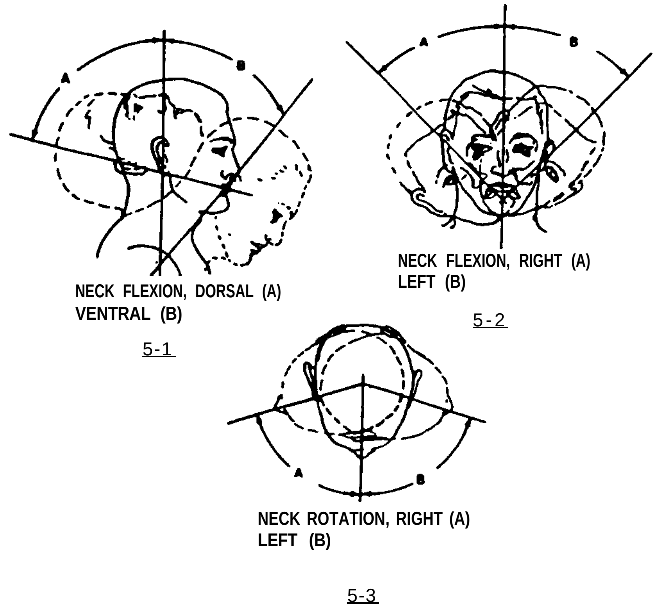


Fig 5 Neck Movement and Rotation

TABLE 1: RANGE OF MOVEMENT AT THE JOINT OF THE NECK OF MALE CIVILIANS

		Type of Movement	Percentile			
			3	50	97	Standard Deviation
			Range of Movement (Degrees)			
Fig 5-1	A	Dorsal flexion	44	61	88	27
	B	Ventral flexion	48	60	72	12
Fig 5-2	A and B	Right or left flexion	34	41	48	7
Fig 5-3	A and B	Right or left rotation	65	79	93	14

(from: HE Design Data Digest, US Army Redstone Arsenal, Alabama, 1984)

NOTE: The range of movement at the joint of the neck of male civilians are tabulated. A decrease may be encountered in those over 50 years of age.

It must be emphasised that head movement can be further severely restricted by clothing, seat restraining harness and surrounding equipment, such as an ejection seat head box. See Part 2 of this Defence Standard clause **4.2.6.**

TABLE 2: RANGE OF MOVEMENT AT THE JOINTS OF THE HAND AND ARM OF MALE USAF PERSONNEL

		Type of Movement	Range of Movement (Degrees)	
			Average	Standard Deviation
Fig 6-1	A	Wrist flexion	90	12
	B	Wrist extension	99	13
Fig 6-2	A	Abduction	47	7
	B	Adduction	27	9
Fig 6-3	A	Forearm supination	113	22
	B	Forearm pronation	77	24
Fig 6-4		Elbow flexion	142	10
Fig 6-5	A	Shoulder flexion	188	12
	B	Shoulder extension	61	14
Fig 6-6	A	Shoulder adduction	48	9
	B	Shoulder abduction	134	17
Fig 6-7	A	Shoulder Lateral	34	13
	B	Rotation: Medial	97	22

(from: Barter et all, 1957)

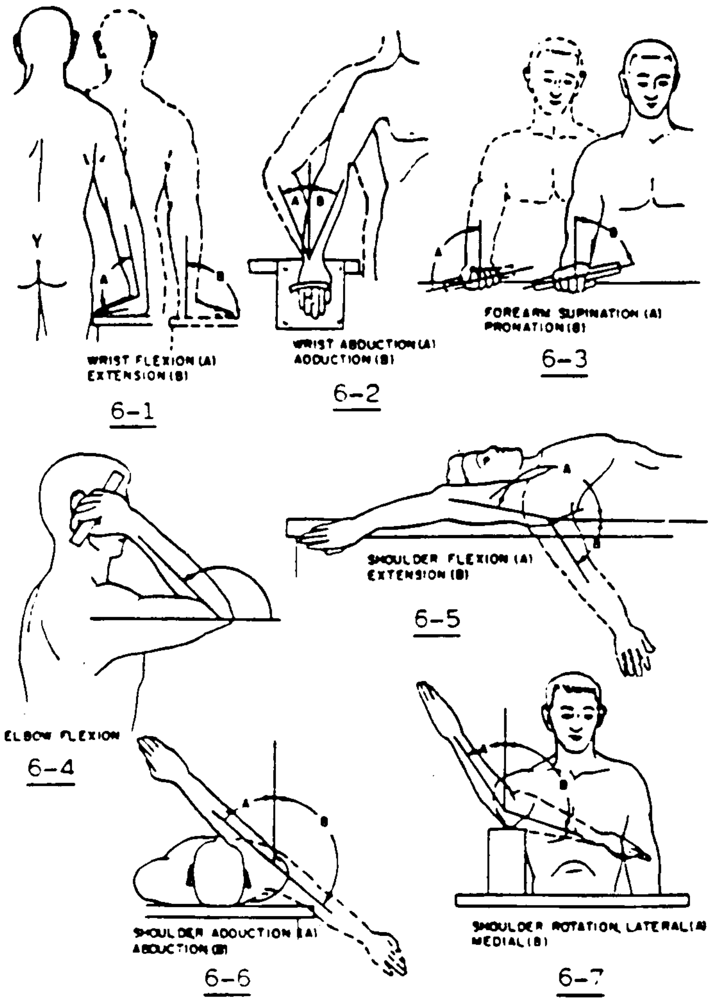


Fig 6. Wrist, Shoulder and Elbow Movements

TABLE 3: RANGE OF MOVEMENT AT THE JOINTS OF THE FOOT AND LEG OF MALE USAF PERSONNEL

		Type of Movement	Range of Movement (Degrees)	
			Average	Standard Deviation
Fig 7-1	A	Ankle plantaflexion	38	12
	B	Ankle dorisflexion	35	7
Fig 7-2	A	Ankle abduction	23	7
	B	Ankle adduction	24	9
Fig 7-3 to Fig 7-5	7-3	Knee flexion: Standing	113	13
	7-4	Knee flexion: Kneeling	159	9
	7-5	Knee flexion: Prone	125	10
Fig 7-6	A	Knee Medial	35	12
	B	Rotation: Lateral	43	12
Fig 7-7		Hip flexion	113	13
Fig 7-8	A	Hip adduction	31	12
	B	Hip abduction	53	12
Fig 7-9	A	Hip rotation Medial	39	10
	B	(prone): Lateral	34	10
7-10	A	Hip rotation Lateral	30	9
7-10	B	(sitting) Medial	31	9

(from: Barter et all, 1957)

NOTE: Ranges of movement at the joints of the foot and leg of male USAF personnel are tabulated. A decrease in the range of knee movement may be encountered in those over 50 years of age.

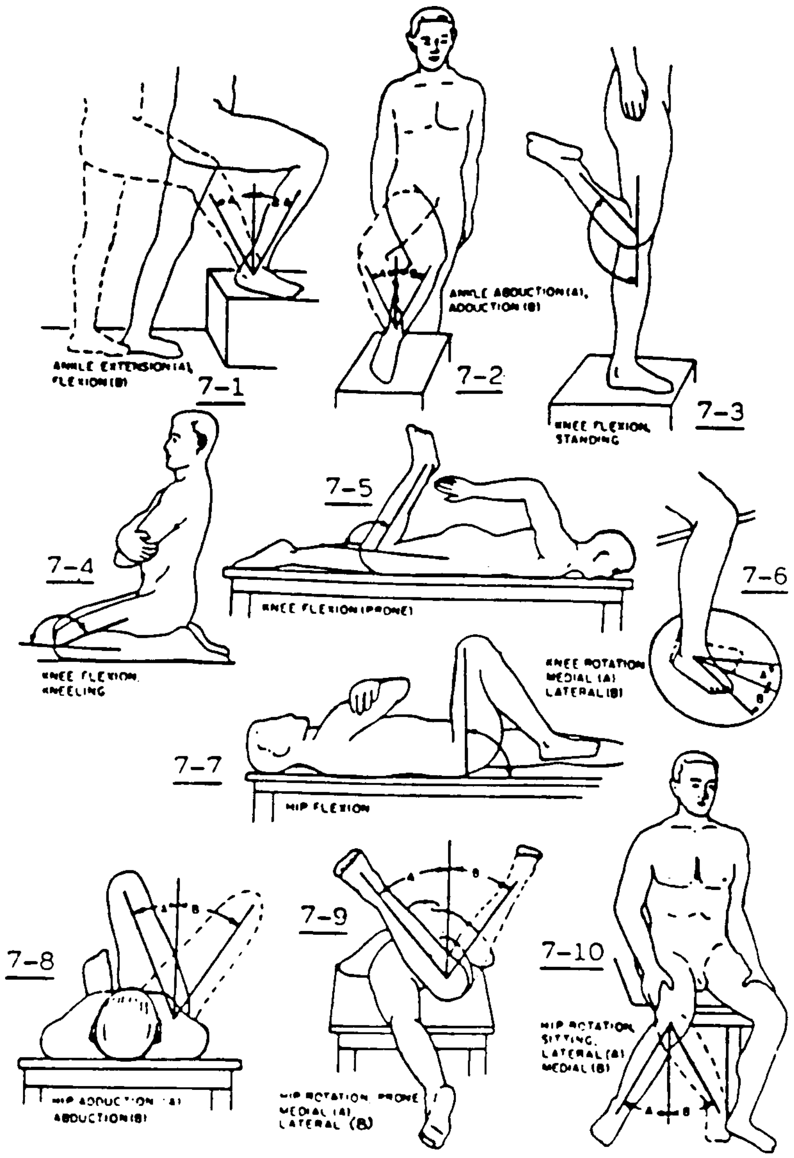


Fig 7. Ankle, Knee and Hip Movements

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Section Six. Joint Strengths

8 Definition

For most purposes, the strengths of single joints have a limited value in task design, since situations where only one joint is involved in an activity are rare. Of far greater value are the strengths of limbs or of the whole body as functional units. The strengths of different parts of the body are shown at **8.1;** and guide-lines to strengths of whole-body activities are discussed at section **7.**

8.1 Strengths of part of the body

8.1.1 Upper limb. Data given are for the 5th percentile group. Values, shown in Tables 4 and 5 are given in Kgf (ION Ωc. 1 Kgf = 0.1 Kg).

Table 4

Hand Grips

Type of Grip	Male		Female	
	Left	Right	Left	Right
Power (wrist cocked) Momentary hold	255	265	137	147
Sustained hold (up to 1 minute)	137	147	69	78
(up to 5 minutes)	59	69	39	39
Precision (Wrist cocked) (thumb/finger tip) Momentary		59		39
Sustained (1 minute)		29		20
(5 minutes)		15		10

Table 5

Elbow

		Flexor Force		Extensor Force	
		Male	Female	Male	Female
Using preferred hand	Straight (180°)	98	59	226	118
	Flexed to 150°	118	69	186	98
	120°	132	74	157	83
	90°	147	78	157	83
	60°	196	108	167	88

8.1.2 Lower Limb

The strength of knee extension is determined by the angle between the hip and the trunk. The data given here are for 5th percentile males only, for force exertion on a pedal, with the heel level with the plane of the seat cushion (see Fig 8).

NOTE: "Mil Std" 1472D suggests female leg strength is approximately 66% of the value of males.

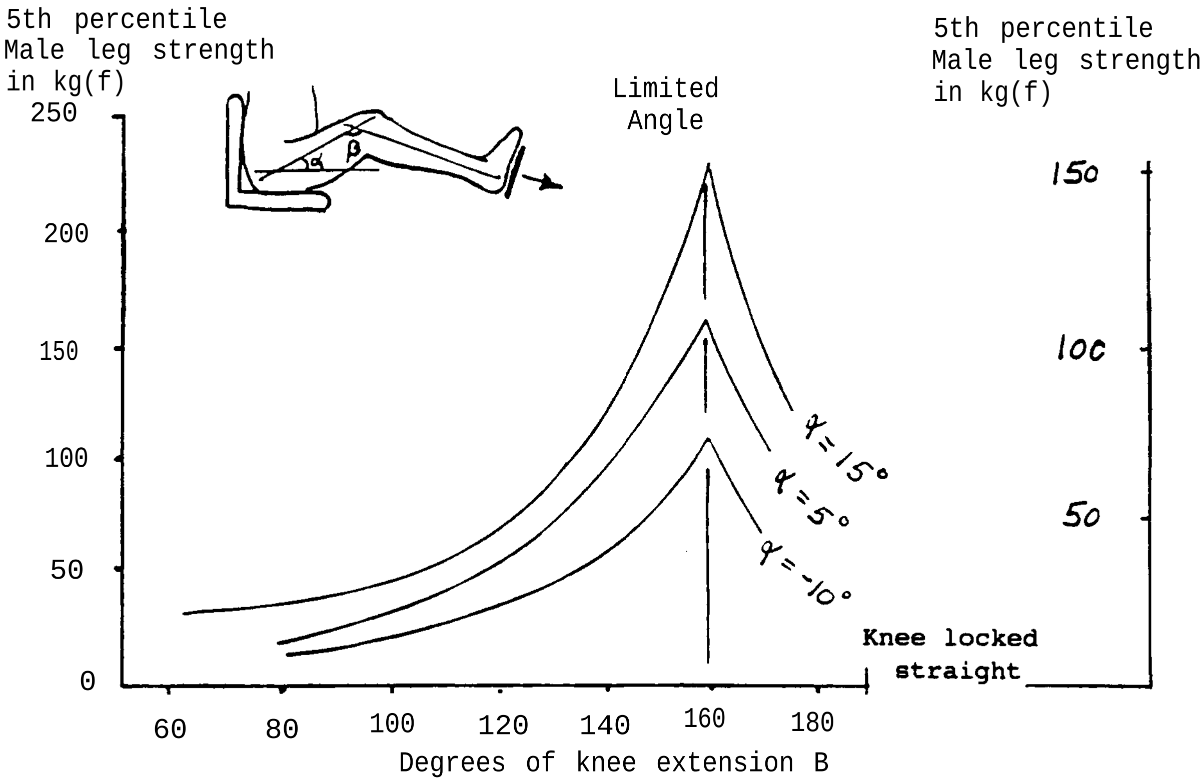


Fig 8 Variation of leg strength with different angles of the thigh and the knee

(from: Mil-Std-1472D, 1989)

(b) However, when seated, the force which can be exerted on a pedal also varies with the height of the seat cushion in relation to the pedal (see Figs 9a and 9b)

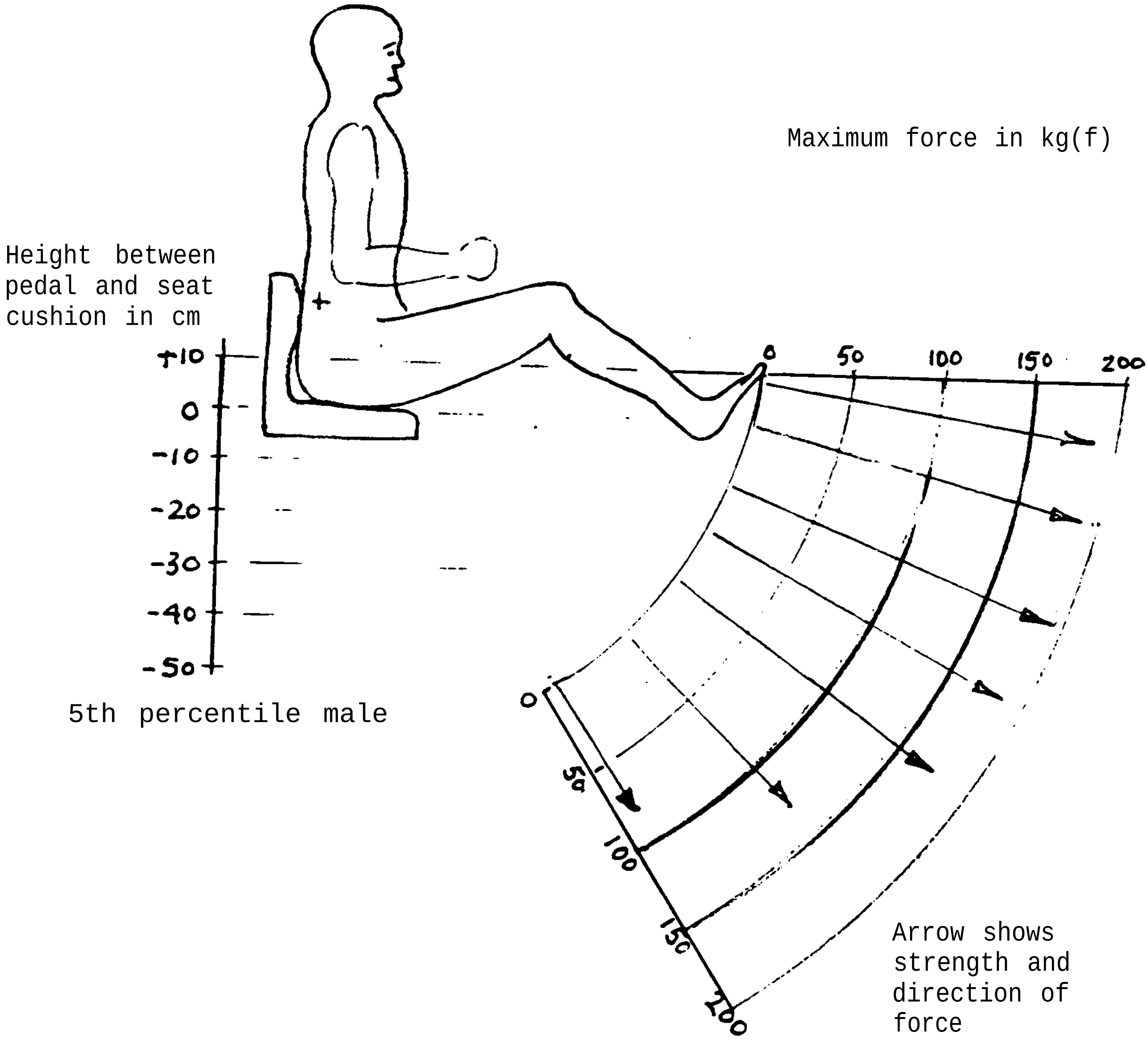


Fig 9a <u>5th Percentile Male Maximum Pedal Pressure when sitting (Male)</u>

Note: The most acceptable range, as chosen by subjects, is between 10cm and 20cm below the height of the seat cushion.

(from Diegunstite Anordnung in Sitzenbetogtiger Fusshabel. by EA Mueller in arbeitsphysiol 9, P125-137 (1936).)

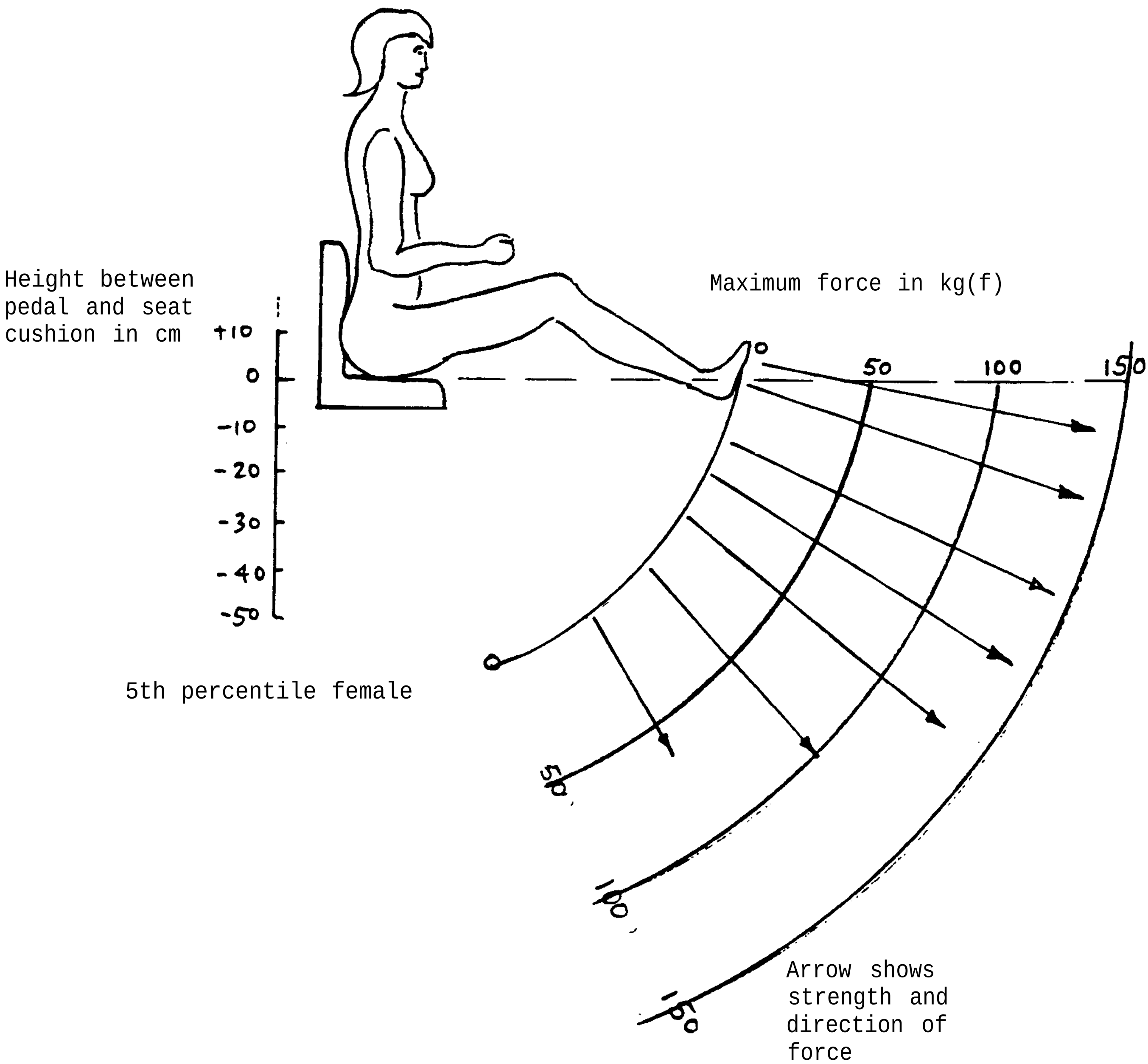


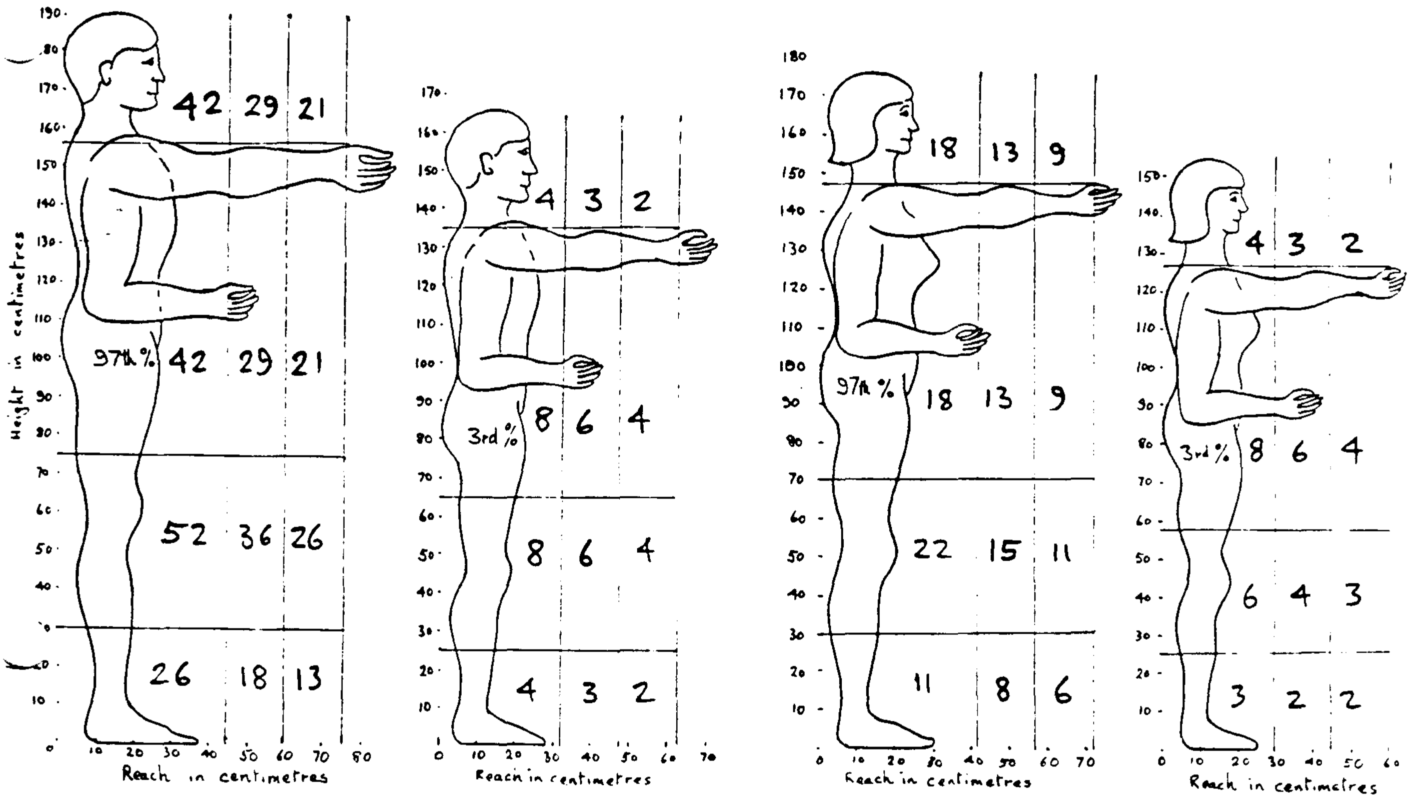
Fig 9b 5th Percentile Maximum Pedal Pressure when sitting (Female)

Note: The most acceptable range, as chosen by subjects, is between 10cm and 20cm below the height of the seat cushion.

Section Seven. Strength of Whole-Body Activities

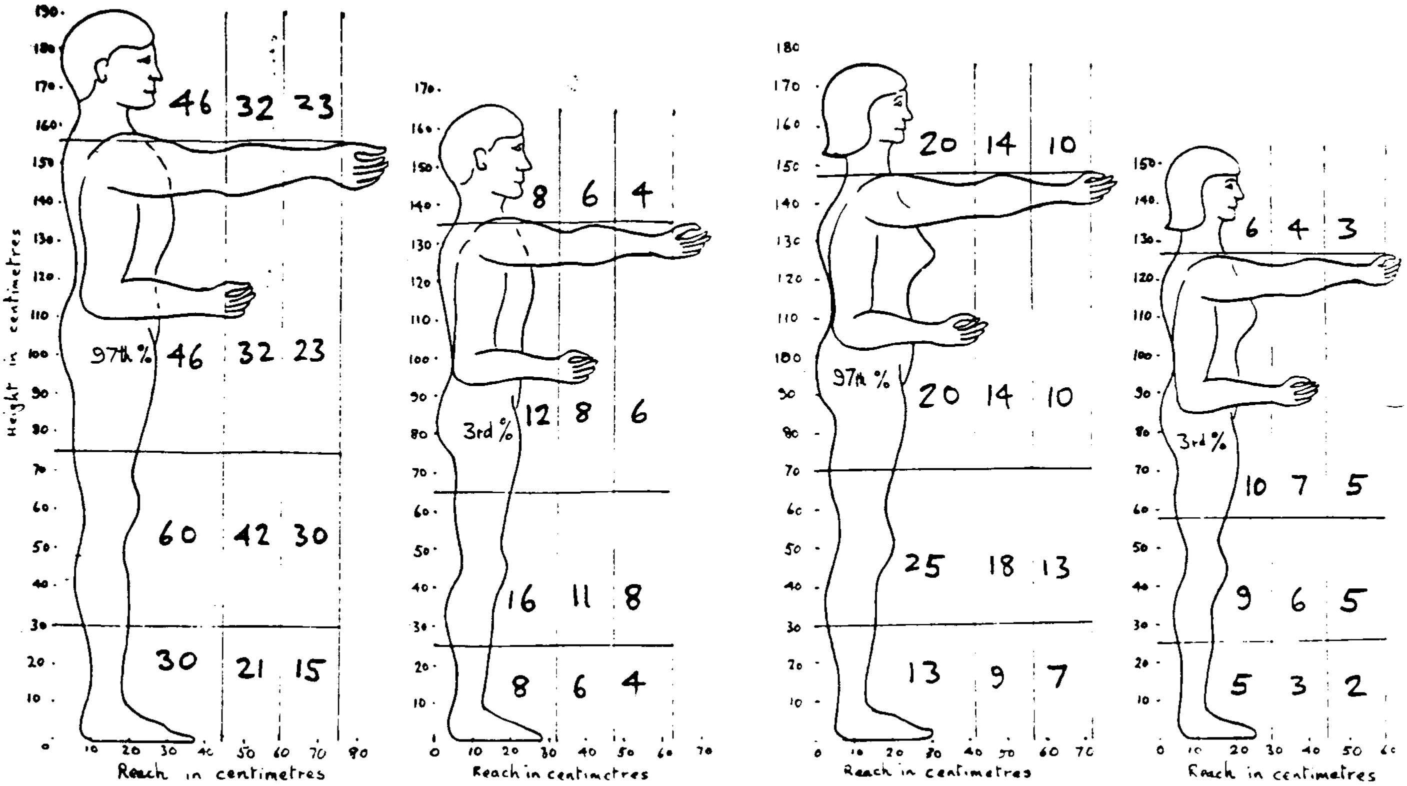
9 Manual force guide-lines

9.1 It should be clear from the foregoing material in this Part of this Standard that maximum strength and power production, plus the strength of individual joints, are of limited value in task design. What is required is an accurate indication of forces which can be exerted in the different directions within the reach of the individual. Since there is great variation in size and strength between individuals, designs should accommodate the full range of possible users; and the forces to be exerted should not exceed the level above which the user would suffer cumulative injury.



NOTE: Each rectangular area show spaces through which a load may be lifted or lowered from a standing or squatting position in Kg.

Fig 10 Lifting and lowering load guidelines
(Two handed standing or squatting) at 1 per minute or less often



NOTE: Each rectangular area show spaces through which a load may be lifted or lowered from a standing or squatting position in Kg.

Fig 11 Lifting and lowering load guidelines (Two handed standing or squatting) at 2 per hour or less often

9.1.1 The data given in Figs 10 and 11 have been calculated in such a way that they are suitable for use by Service populations in a stable environment. The effects of ship movement are as yet only partially understood. However, it has been established that small ship (164 ton trawler) motions do increase the load on the musculo-skeletal system during work. Prolonged lifting or holding of loads of 20 Kg in conditions of large motion within a ship are likely to produce compression forces in the lumbar regions large enough to create back injuries.

(from: Working on a moving surface by M Torner et al 1994)

9.2 Lifting and Lowering Guidelines (2 handed)

9.2.1 Each rectangular area in Figures 10 and 11 show spaces through which a load may be lifted or lowered from a standing or squatting position. Each area contains the recommended acceptable load in Kg for 3rd and 97th percentile male and female personnel. Figure 10 shows the loads for lifting and lowering at a rate of 1 per minute or less. Fig 11 shows the equivalent loads for slower rate of 2 per hour or less. An indication of relative limb and body size is also shown. Further information on body size is given in Part 2 of this Defence Standard.

9.2.2 Equipment designers should design for the weaker personnel who are likely to use the equipment. Hence, the guidelines for 3rd percentile personnel are given.

9.2.3 It should be noted that the recommended acceptable load values shown in the space boxes are presented in a simplified format for easy use. If the equipment designer has to design for the 5th percentile case, he should still use the 3rd percentile values given here, since the 3rd and 5th percentile values are of the same magnitude as the approximations used in the calculation of the simple box values. Should the designer need to know the recommended acceptable load for the 50th percentile, it lies mid way between the 3rd and 97th percentile values.

9.3 Assumptions and Limitations (for symmetrical loads)

9.3.1 The recommended acceptable loads assume a typical load size of 34 cm wide by 25 cm high by 30 cm deep with handles. A larger, bulkier, load would reduce the recommended acceptable load. For example, doubling the width of the load to 68 cm would reduce the value by 20%. If the load has no handles or handholds, the load should be reduced by 15%.

9.3.2 If the body has to twist through more than 15° and up to 45°, the recommended acceptable loads should be reduced by 20%. However, twisting while lifting, lowering or supporting a load is not recommended.

9.3.3 If the lifting or lowering operation is repeated 5 to 8 times per minute, the Fig 10 and 11 load values should be reduced by 50%.

9.3.4 Figures 10 and 11 apply to personnel up to 50 years old. The load values should be reduced by 20% for those personnel over the age of 50.

9.3.5 When designing for personnel working in a confined area such as a turret of a tank, the larger bodies may have the strength to lift heavy objects but be restricted by lack of space. It should also be noted that the 97th percentile personnel are likely to be both stronger and larger

9 (Continued)

than lower percentile personnel but not necessarily in all dimensions. (See Part 2 of this Defence Standard Clause **2.3.2).**

9.4 WORKING WITHIN THESE GUIDELINES DOES NOT MEAN THE WORK IS SAFE, JUST AS WORKING OUTSIDE THEM DOES NOT NECESSARILY MEAN THAT IT IS DANGEROUS.

9.5 Lifting technique

9.5.1 The further away that a load is held from the body, the less that can be lifted or lowered. It is also less easy to control when held away from the body. Conversely, a load held close to the body has the advantage of friction between the load and the clothing. This helps to support and steady the load.

9.5.2 Poor posture during manual handling increases the risk of loss of control of the load which, in turn, can produce a sudden, unexpected increase in physical stress and change of injury.

9.5.3 Injury risk is increased if the feet and hands are not positioned correctly to transmit forces between load and floor, such as when the feet are too close together, or the trunk is twisted.

9.5.4 Stress on the lower back is also increased if the lifter bends the back or leans forward with a straight back. It is better to bend the knees, especially when lifting or lowering loads from and to floor level. However, care must be taken not to overflex the knees.

(from: Manual Handling - Guidance on Regulations, HSE 1992).

9.6 NIOSH Alternative Method for Calculating Load Guidelines

9.6.1 Although it is recommended that the guidelines shown in Figures 10 and 11 for 3rd percentile operators are used in determining the acceptable loads that can be lifted by most of the population, the loads shown are approximations of complex data, derived from references Snook et al and Walters et al, listed at annex A.

9.6.2 The US National Institute for Occupational Safety and Health (NIOSH) have devised an equation and guidelines which may be used to determine acceptable loads and forces where more detailed considerations are required.

9.6.3 It should be noted that the NIOSH recommendations tend to permit higher loads than those indicated in Figs 10 and 11. This is because the NIOSH guide covers only the upper 75% of the female population and 90% of the male population, "but lower absolute maximum loads (ie 23Kg). They do, however, provide the designer with a useful method for exploring the effects of changing factors to determine which are the most critical.

9.7 The NIOSH equation

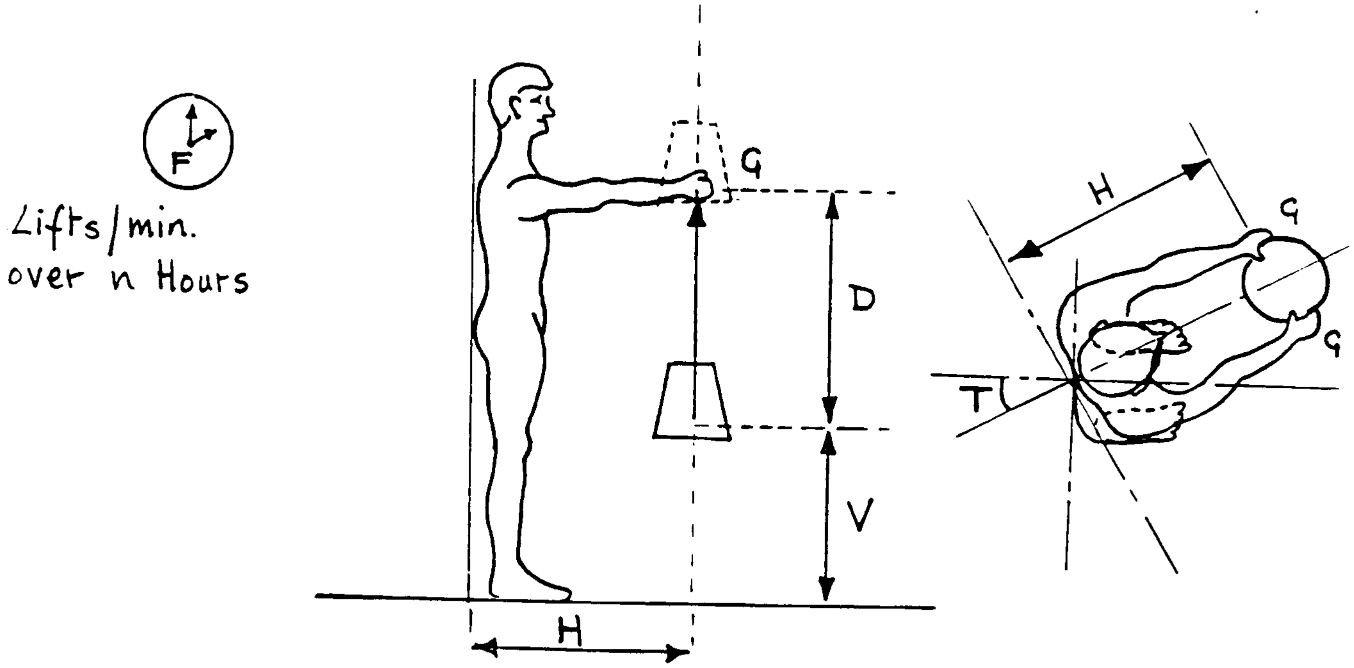


Fig 12 Definition of H, V, D, T, F and G

9.7.1 The NIOSH equation uses 6 factors, together with their "multipliers" from which the recommended lifting limit is calculated. A simplified version is defined as follows:

The Lifting Limit (LL) = hm_1 x vm_2 x dm_3 x tm_4 x fm_5 x gm_6 x c

where: - H is the horizontal distance from the vertical line contacting the centre of the shoulders and buttocks (standing erect) to the mid point of the hands when grasping the load, (in cm). (See Fig 12)

hm_1 is the horizontal multiplier, from the NIOSH lifting tables (from table 6) V is the vertical height of the hands above the floor when grasping the load at the start of the lift, (in cm)
vm_2 is the vertical multiplier (from table 6)
D is the vertical distance the load travels during the lift, (in cm).
dm_3 is the vertical distance multiplier, (from table 6).
T is the angle of the load relative to the lifter's normal fore/aft axis (in degrees)
tm_4 is the twisting multiplier, (from table 6).
F is the number of lifts per minute and the number of hours of lifting.
fm_5 is the frequency multiplier (from table 6).
G is the effectiveness of the hand grip on the load, (good, fair or poor). For a good grip, the hand wraps comfortably around the object to be lifted.
Handles or handholds are less than optimal.
For a fair grip, the hand can flex only about 90 degrees around the object.
Handles or handholds are less than optimal.
Poor grips are due to non rigid bags, loose parts, irregular objects that are bulky or have sharp edges.
gm_6 is the grip multiplier, (from table 6).
The load constant (c) is 23 kg.

To use the equation to calculate the Lifting Limit, the values of each of the multipliers (hm_1 x vm_2 x dm_3 x tm_4 x fm_5 x gm_6) must be read from the table against the H, V, D, T, F, G values. The resulting six multiplier values are multiplied together with the load constance c of 23 kg to give the weight limit for the task.

9.7.2 Example. A soldier has to lift ammunition boxes from 30 cm(v) above the ground through 40cm(D) to a shelf. The horizontal location of the hands (H) is 50 cm from the back datum of the start of the lift. The soldier has to twist 45° (T) to pick up the object. This task is completed every 5 minutes (0.2 lifts per minute) for up to 2 hours per day (F). The load grip (G) is rated as fair because the box, although rigid, has no handles and is too large for a good grip. The ammunition box load limit (LL) is calculated by reading from the table the appropriate multipliers for H, V, D, T, F and G.

Thus for H = 50, hm_1 = 0.63
V = 30, vm_2 = 0.87
D = 40, dm_3 = 0.93
T = 45, tm_4 = 0.86
F = 0.2 for 2 hour, fm_5 = 0.95
G = Fair, gm_6 = 0.95

9.7 (Continued)

LL = 0.63 x 0.87 x 0.93 x 0.86 x 0.95 x 23kg = 9.1 kg

It will be noted that this load of 9 kg is considerably higher than the figures recommended for 3rd percentile personnel in Fig 10. However, the 9 kg applies to the upper 75% of the female population and upper 90% of the male population.

9.8 Use of the Lifting Equation to help quantify design change effects

9.8.1 This workload example of load lifting can be used to indicate how to reduce the risks involved, or to increase the load that can be lifted safely. e.g. in the example above, if the load to be lifted is brought closer to the body from 50 cm to 30 cm, the horizontal multiplier will increase from 0.63 to 0.83. Similarly, if body twisting is eliminated, the twisting multiplier will increase from 0.86 to 1. If the ammunition box is provided with good handles the grip multiplier will increase to 1.

The resulting multiplier equation will now be

LL = 0.83 x 0.87 x 0.93 x 1 x 0.95 x 1 x 23 = 14.7kg, or a 50% increase in lifting ability.

Thus by inserting different figures into the equation, the importance of the various parameters can be explored and the equipment designer can have a better appreciation of which of the limiting factors are most effective to change.

Table 6

Multiplier Chart to Assess Lifting Tasks

Horizontal Multiplier		Vertical Multiplier		Distance Multiplier		Twisting Multiplier		Frequency Multiplier							Grip Multiplier	
H	hm_1	V	vm_2	D	dm_3	T	tm_4	F Lifts /Min	Duration of lifting tasks fm_5						Grip Type G	gm_6
≤35	1.00	0	.78	≤25	1.00	deg	-	-	≤1hr		2hr		8hr		Good	1
38	.89	10	.81	40	.93	0	1	V	>75	≤75	>75	≤75	>75	≤75	Fair	0.95
40	.83	20	.84	55	.90	15	.95	0.2	1.00	1.00	.95	.95	.85	.85	Poor	0.9
42	.78	30	.87	70	.88	30	.90	0.5	.97	.97	.92	.92	81	81		
44	.74	40	.90	85	.87	45	.86	1	.94	.94	.88	.88	.75	.75		
46	.69	50	.93	100	.87	60	.81	2	.91	.91	.84	.84	.65	.65		
48	.66	60	.96	115	.86	75	.76	3	.88	.88	.79	.79	.55	.55		
50	.63	70	.99	130	.86	90	.71	4	.84	.84	.72	.72	.45	.45		
52	.60	80	.99	145	.85	105	.66	5	.80	.80	.60	.60	.35	.35		
54	.57	90	.96	160	.85	120	.62	6	.75	.75	.50	.50	.27	.27		
56	.54	100	.93	175	.85	135	.57	7	.70	.70	.42	.42	.22	.22		
58	.52	110	.90	>175	-	>135	-	8	.60	.60	.35	.35	.18	.18		
60	.50	120	.87					9	.52	.52	.30	.30	-	.15		
62	.48	130	.84					10	.45	.45	.26	.26	-	.13		
64	.46	140	.81					11	.41	.41	-	.23	-	-		
66	.45	150	.78					12	.37	.37	-	.21	-	-		
68	.43	160	.75					13	-	.34	-	-	-	-		
70	.42	170	.72					14	-	.31	-	-	-	-		
73	.40	175	.70					15	-	.28	-	-	-	-		
>73	-	>175	-					>15	-	0	-	-	-	-		

(   ) X (   ) X (   ) X (   ) X (   ) X (   ) x 23 = Load Limit

Note: Where a- appears in the table this is because there are no reliable data for the values of these multipliers. In these circumstances the use of these extreme values is to be avoided where possible.

Table 7

Limit values for pulling (in kg) for males

Initial forces

	2 m pull							7 m pull							15 m pull							30 m pull					45 m pull					60 m pull			
Height of Hands	One pull every 6s	12s	1m	2m	5m	30m	8h	One pull every 15s	22s	1m	2m	5m	30m	8h	One pull every 25s	35s	1m	2m	5m	30m	8h	One pull every 1m	2m	5m	30m	8h	One pull every 1m	2m	5m	30m	8h	One pull every 2m	5m	30m	8h
144 cm	17	19	22	22	23	24	28	14	15	20	20	21	21	26	16	18	19	19	20	20	24	14	16	19	19	23	12	14	16	16	20	12	14	14	17
95 cm	23	27	31	31	32	33	39	19	21	28	28	29	30	36	22	25	26	26	28	28	33	20	22	26	26	32	17	19	22	22	28	16	19	19	24
64 cm	27	30	34	34	37	37	44	21	24	31	31	33	34	40	24	28	29	29	31	32	38	22	25	29	29	36	19	22	25	25	31	19	21	21	27

Sustained forces

144 cm	10	13	16	17	19	20	23	8	10	13	14	16	16	19	9	10	12	12	14	14	17	9	10	12	14	16	7	9	10	11	14	7	8	10	11
95 cm	13	17	21	22	25	26	30	11	13	17	18	20	21	25	11	14	15	15	18	18	22	12	13	16	18	21	10	11	13	15	18	9	11	13	15
64 cm	14	19	23	23	26	27	32	11	14	19	19	22	22	26	12	14	16	17	19	19	23	12	14	17	19	23	10	12	14	16	19	10	11	13	16

Limit values for pulling (in kg) for females

Initial forces

	2 m pull							7 m pull							15 m pull							30 m pull					45 m pull					60 m pull			
Height of hands	One pull every 6s	12s	1m	2m	5m	30m	8h	One pull every 15s	22s	1m	2m	5m	30m	8h	One pull every 25s	35s	1m	2m	5m	30m	8h	One pull every 1m	2m	5m	30m	8h	One pull every 1m	2m	5m	30m	8h	One pull every 2m	5m	30m	8h
135 cm	16	19	20	21	24	25	26	16	17	19	19	21	22	24	12	14	16	16	18	19	20	14	16	17	18	20	14	16	17	18	20	14	15	16	18
89 cm	16	19	21	22	25	26	27	17	18	19	20	22	23	25	12	15	17	17	19	20	21	15	16	18	19	21	15	16	18	19	20	15	16	18	20
57 cm	17	20	22	23	26	27	28	17	19	20	21	23	24	26	13	15	17	18	20	21	22	16	17	18	20	22	16	17	18	20	22	15	16	18	20

Sustained forces

135 cm	8	12	13	14	15	16	20	9	11	12	12	13	14	18	7	9	10	10	11	12	15	8	9	10	10	14	8	9	9	9	12	7	7	7	10
89 cm	8	12	13	13	15	16	19	9	10	11	12	12	14	17	7	8	10	10	11	12	14	8	9	9	10	13	7	8	9	9	12	6	7	7	9
57 cm	7	11	12	12	13	14	18	8	9	11	11	12	13	16	7	8	9	9	10	11	13	7	8	9	9	12	7	8	8	8	11	6	6	6	9

Table 8

Limit values for pushing (in kg) for males

Initial forces

	2 m push							7 m push							15 m push							30 m push					45 m push					60 m push			
Height of Hands	One push every 6s	12s	1m	2m	5m	30m	8h	One push every 15s	22s	1m	2m	5m	30m	8h	One push every 25s	35s	1m	2m	5m	30m	8h	One push every 1m	2m	5m	30m	8h	One push every 1m	2m	5m	30m	8h	One push every 2m	5m	30m	8h
144 cm	26	28	32	32	34	34	41	18	20	27	27	28	28	34	21	23	25	25	26	27	32	19	21	25	25	31	16	18	21	21	26	16	18	18	23
95 cm	28	31	34	34	36	36	44	21	23	30	30	32	32	39	24	27	28	28	30	30	36	21	24	28	28	35	18	21	24	24	30	18	21	20	26
64 cm	25	28	31	31	33	33	40	16	19	26	26	27	28	33	19	21	24	24	26	26	31	18	21	24	24	30	16	18	21	21	26	15	18	18	22

Sustained forces

144 cm	13	17	21	22	24	25	30	10	12	17	18	20	21	25	11	13	15	16	18	18	22	11	13	16	18	21	10	11	13	15	18	9	11	13	15
95 cm	14	18	22	22	25	26	31	11	13	17	18	20	21	25	11	13	15	16	18	18	21	11	13	16	18	22	9	11	13	15	18	9	11	12	15
64 cm	14	18	21	22	25	26	31	11	13	17	17	19	20	21	11	13	14	15	17	17	20	11	13	15	17	20	9	11	12	14	17	9	10	12	14

Limit values for pulling (in kg) for females

Initial forces

	2 m pull							7 m pull							15 m pull							30 m pull					45 m pull					60 m pull			
Height of hands	One pull every 6s	12s	1m	2m	5m	30m	8h	One pull every 15s	22s	1m	2m	5m	30m	8h	One pull every 25s	35s	1m	2m	5m	30m	8h	One pull very 1m	2m	5m	30m	8h	One pull every 1m	2m	5m	30m	8h	One pull every 2m	5m	30m	8h
135 cm	17	18	21	22	24	25	27	18	19	19	20	22	23	24	15	17	17	17	19	20	21	15	16	17	19	21	15	16	17	19	21	14	15	17	19
89 cm	17	18	21	22	24	25	27	17	18	20	20	22	23	25	14	16	17	17	19	20	21	15	16	18	19	21	15	16	18	19	21	15	16	17	19
57 cm	14	15	17	17	19	20	21	14	15	17	17	19	20	21	11	13	14	15	16	17	18	13	14	15	16	18	13	14	15	16	18	12	13	14	16

Sustained forces

135 cm	9	12	14	14	16	17	21	9	10	11	11	12	13	16	7	8	9	9	10	11	13	7	8	9	9	12	7	8	8	8	11	6	6	6	9
89 cm	8	11	13	13	15	16	19	9	10	11	11	13	13	17	7	8	9	10	11	11	14	8	9	9	10	13	7	8	8	9	12	6	6	7	9
57 cm	7	9	11	12	13	14	17	8	10	10	11	12	12	15	7	8	9	9	10	10	13	7	8	8	9	12	7	7	8	8	11	6	6	6	8

9.9 Pulling and Pushing Guidelines.

9.9.1 The guideline figure for starting or stopping a load is a force of about 25 kg. The guideline force for keeping the load moving is a force of about 10 kg. These guidelines are for manual handling activities involving pushing and puling and regardless of whether the load is slid, rolled or supported on wheels.

9.9.2 It is important to note that a heavy load which is moving easily on rollers or wheels (which have low friction) has considerable momentum which may require more than the recommended force to slow or stop it.

9.9.3 For a more detailed investigation of pushing and pulling forces the NIOSH tables (7 & 8) provide more detailed guides which cover the upper 75% of male and female industrial populations.

9.10 NIOSH Guidelines for Pushing and Pulling

9.10.1 Pushing and pulling limits for the upper 75% of male and female populations are given separately in Tables 7 and 8. Limits are given separately for initial and sustained forces, for frequency, distance and the height at which the force is applied.

The initial force is that required to start the object moving.

The forces given assume that personnel are standing on or moving over a firm non-slip surface.

(from: The Design of Manual Handling Tasks, S Snook and V Ciriello, 1991 and The Revised NIOSH equation for the design and evaluation of manual lifting tasks. T Walters et al. 1993).

Although the SI unit for force is the newton (N), for the purposes of assisting clearer presentation of the force values in the diagrams the unit (kgf) has been retained.

1 kg for Kp (Kilopond) = 9.807N

Section Eight. Load carrying over distance

10 Maximum recommended loads

10.1 While sections 7 and 8 provide guide-lines for lifting, pushing and pulling, they give little indication of the load that military personnel, (especially soldiers) should be expected to carry.

10.1.1 A review by Haisman (1988) indicates that there is no obvious definition of maximum load that can be carried, because of the widely varying conditions that might apply. However, there is some consensus of opinion (both in the UK, US and China) that one third of lean body weight of healthy young soldiers is a sensible recommended maximum load that can be carried.

10.1.2 This is 20 kg for a healthy young male with a lean body weight of 60 kg. For females, equivalent is 13 kg.

10.1.3 For UK female soldiers, 25 to 30% of their weight is body fat. This should be deducted from their weight when calculating the recommended maximum load that they can carry.

10.9 Distribution of the load

10.2.1 Care must be taken in the distribution of the load on the back. Ideally, a double pack (front and back) should be used, especially for loads greater than the recommended third of lean body weight. the double pack reduces forward lean and improves the walking gait.

10.2.3 Furthermore, there are 4 essentials required in the design of any load carriage equipment to ensure a minimum expenditure of energy and a minimizing of discomfort. They are:-

(a) elimination of local strain,

(b) maintenance of normal posture,

(c) maintenance of a normal and free gait, and

(d) chest freedom.

A.1 List of quoted references and related publications refered to in this Part of the Standard

DOCUMENT	LOCATION
Anon. Human Engineering Design Data Digest. Radstone Arsenal, Alabama. (1984)	Page 20 table 1
Barter J T et al 'A statistical evaluation of joint range data' from Report No WADC-TN-57-311 (1957)	Page 22 table 2
Def Stan 00-25 (Part 2) (Body Size) Human Factors for Designers of Equipment	Page 6 clause 3.3
Grandjean E 'Fitting the task to the man' (1980)	Page 9 clause 4.4.3
Haisman M F. Determinants of Load Carrying Ability, Applied Egonomics 19.2 June 1988	Page 40 clause 10.1.1
Hettinger J 'Muskelkraft bei männern and frauern' (1960)	Page 13 figure 3
HSE L23, Manual Handling. Guidance on Regulations (1992)	Page 32 clause 9.5.4
MIL-STD-1472D 'Human engineering design criteria for miliary systems, equipment and facilities' (1989)	Page 26 figure 8
Monod H 'Contributions a l'étude du travial statique (1956)	Page 10 clause 4.5.1
Morgan R E and Adamson G J. 'Circuit training' (1968)	Page 5 clause 0
Snook S H and Ciriello V M. The design of manual handling tasks: Revised tables of maximum acceptable weights and forces. Journal of Egonomics, Vol 34 No 9 (1991)	Page 39 clause 9.10.1
Torner M et al. Working on a moving surface, Journal of Ergonomics 16/37 No 2 (1994)	Page 31 clause 9.1.1
Walters T R et al Revised NIOSH equation fro the deisgn and evaluation of manual lifting tasks. Ergonomics, Vol 36 No 7 (1993)	Page 35 figure 12

Collation Page

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Published by and obtainable from:
Ministry of Defence
Directorate of Standardization
Kentigern House
65 Brown Street
GLASGOW G2 8EX

Tel No: 0141 224 2531/2
Fax No: 0141 224 2503

The following Defence Standard file reference relates to the work on this Standard - D/D Stan/328/01/03.

Contract Requirements

When Defence Standards are incorporated into contracts users are responsible for their correct application and for complying with contract requirements.

Revision of Defence Standard

Defence Standards are revised when necessary by the issue either of amendments or of revised editions. It is important that users of Defence Standards should ascertain that they are in possession of the latest amendments or editions. Information on all Defence Standards is contained in Def Stan 00-00 (Part 3) Section 4, Index of Standards for Defence Procurement - Index of Defence Standards and Specifications published annually and supplemented periodically by Standards in Defence News. Any person who, when making use of a Defence Standard encounters an inaccuracy or ambiguity is requested to notify the Directorate of Standardization without delay in order that the matter may be investigated and appropriate action taken.

DIRECTORATE OF STANDARDIZATION

MINISTRY OF DEFENCE

D Stan 4b, Room 1138,
Kentigern House, 65 Brown Street,
Glasgow, G2 8EX
Tel: 0141 224 2548
Fax: 0141 224 2503

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Our Ref: D/D Stan/328/01/03

Date: 17 November, 1997

AMENDMENT NOTICE

Def Stan 00-25 (Part 3)/Issue 2

Human Factors for Designers of Equipment Part 3: Body Strength and Stamina

Amendment 1 (Revised Text)

This notice has been agreed by the authorities concerned with the use of the above Standard.

1 **Page 25. Section 8.1.1 Remove : “Tables 4 and 5 are given in Kgf (I0N Ω c. 1Kgf = 0.1 Kg).”**

2 **Insert: “Tables 4 and 5 are given in Newtons (1 Newton = 0.1 Kgf).”**

3 **Make a note of this Amendment in the Amendment Record.**

G McBride
for Directorate of Standardization