J. Human Ergol., **21**: 47–55, 1992
Center for Academic Publications Japan. Printed in Japan.

WORK STRESS OF WOMEN IN SEWING MACHINE OPERATION

A. NAG, H. DESAI, and P. K. NAG

Ergonomics Division, National Institute of Occupational Health,
Ahmedabad 380 016, India

The study examined the work stresses of 107 women who were engaged in sewing machine operation in small garment manufacturing units. Of the three types of sewing machines (motor-operated, full and half shuttle foot-operated), 74% of the machines were foot-operated, where throttle action of the lower limb is required to move the shuttle of the machine. The motor-operated machines were faster than the foot-operated machines. The short cycle sewing work involves repetitive action of hand and feet. The women had to maintain a constant seated position on a stool without backrest and the body inclined forward. Long-term sewing work had a cumulative load on the musculo-skeletal structures, including the vertebral column and reflected in the form of high prevalence of discomfort and pain in different body parts. About 68% of the women complained of back pain, among whom 35% reported a persistent low back pain. Common sewing work accident is piercing of the needle through the fingers, particularly the right forefingers. Unsatisfactory man-machine incompatibility, work posture and fatigue, improper coordination of eye, leg and hand are the major problems of the operators. The design mis-match of the work place may be significantly improved by taking women's anthropometric dimensions in modifying the workplace, *i.e.* the seat surface, seat height, work height, backrest, *etc.*

Industrial enterprises in manufacturing garments, leather products, shoes, *etc.* employ large number of men and women sewing machine operators. The garment industry alone occupies the key position among them. The existing work practices, conditions of work and incompatible man-machine design exert varying amount of work stresses on the operators (SINGLETON, 1959, 1960). Sewing operation requires repetitive, coordinated use of the trunk, the upper and lower extremities of the operators in prolonged seated posture. The resulting biomechanical stresses

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Received for publication January 20, 1992.

may result in increased rate of back pain and disability (HAGBERG, 1984). The problems of cumulative trauma diseases (CTD) are major focus of attention in sewing operation. Teno-synovitis, tendinitis, carpal tunnel syndrome, low back pain, cervical spine injuries, *etc.* are the typical problems prevailing in this work process. The musculo-skeletal complaints associated with the postural problems in apparel sewing were examined by KEYSERLING *et al.* (1982), VIHMA *et al.* (1982) and SILLANPPA (1984). KEYSERLING *et al.* (1982) noted that 25% of the female sewing machine operators had persistent back pain. YU *et al.* (1988) investigated the sitting posture for industrial sewing operations, using a pneumatic chair which allowed adjustment of seven parameters—seat height, seat angle, seat angle rocking, seat swivel, backrest distance, backrest height and backrest angle. Further, they developed a new work seat for sewing operation and compared with the traditional work seat to evaluate the effectiveness of various chair design features (YU and KEYSERLING, 1989). The change in posture due to adaptation in a sewing workstation was studied by WICK and DRURY (1985).

Musculo-skeletal strains have implications on work safety and productivity. These have been examined in women sewing machine operators in unorganized small enterprises of Indian garment-manufacturing sectors. This contribution elucidates the work-related postural stresses and prevalence of work accidents among women sewing machine operators.

GARMENT INDUSTRY IN INDIA

The garment industry is basically a cottage-based industry comprising a large number of small units, spread all over the country. Each industrial shed or unit has as few as 5 sewing machines to as many as 1,000 to 1,200 machines. It is estimated that about 40,000 units are operating in the country, with 0.7 million sewing machines and almost equal number of other ancillary machines. The industry employs about 1.5 million workers, and women represent the major work-force (PANTHAKI, 1990).

Under the umbrella of the garment industry, there are other ancillary small-scale industries for manufacturing buttons, buckles, zippers, metal plates, paper board, shoulder pads and wadding for making finished apparel. The employment in these ancillary industries is about 1.0 million workers. That means, the total work force covered under the garment industry is about 2.5 million workers. The annual production of the industry is estimated to be around 2,000 million pieces utilizing 3,000 million of fabrics. These figures, however, do not include machine operators of the countless number of small tailoring shops at every hook and corner of the country.

METHODS

Only 107 women sewing machine operators from a few garment-manufacturing units were selected at random. The women spend about 6 to 10 hr working with the machine. The average work cycle duration of sewing operation was recorded for these women. A detailed questionnaire was filled in by interviewer-administered questionnaire technique about the household and job characteristics, socio-economic status and general health condition. Anthropometric characteristics of the women were measured with reference to man-machine complex. The postural discomfort/pain scale developed by CORLETT and BISHOP (1976) was administered at approximately every 3 hr intervals for 3 days.

A retrospective accident record was taken by introducing a separate detailed interview regarding the accident behavior among women due to machine operation.

RESULTS AND DISCUSSION

The women included in the study had minimum of 5 years experience in the profession. The number of women in the 20–29, 30–39, 40–49 and 50–59 yr age range were 42, 39, 20 and 6 respectively. The older women (50–59 yr group) were comparatively fewer in the profession. As large as 80% of the women had primary level of education or were illiterate. About 95% of the women were married and had 3–5 children. Most of the sewing operators work on a piece rate contract basis. In general, they belonged to poor socio-economic group.

The job and the machine

Three types of sewing machines are commonly used, namely motor-operated, full shuttle and half shuttle machines. Full shuttle and half shuttle machines are foot-operated and depending on the rotation of the shuttle its nomenclatures have been made. The percentage distribution of motor-operated, half shuttle and full shuttle foot-operated machines covered under the study were 26, 44 and 30% respectively. That is, among the foot-operated machines, about 60% were half shuttle machine and the remaining were full shuttle sewing machine.

Sewing machine operation involves coordination of feet, hand and eye. Despite that the work-related stresses may vary with the type of machine operations, it was not possible in this study to group the workers by the type of sewing machines being used. As observed, all types of machines co-exist in a manufacturing unit and the workers interchanged the machines depending on work demand and convenience.

The sewing operators were required to maintain a constant sitting on a stool without any backrest and the body inclining forward. The motor-operated machines were faster than the other machines. The operation with half shuttle sewing machines was considered more strenuous, requiring exertional forces. Throttle action of the lower limb was required to move the shuttle of the machine, *i.e.*, the operator's right foot manipulated the pedal to control the machine speed, whereas, the upper extremities were used to manipulate sewing fabric that may be large and/or heavy. Abducted and elevated elbow position was required during work. The hand operation was involved in manipulating the fabric, and also to raise or lower the needle foot.

The work cycles of sewing machine were of short duration, varying from 7 to 35 sec. The sewing time for one piece of garment varied from 15–18 min of which the effective time of sewing was only about 8 min. The total sewing length of each piece of garment was about 24 m, *i.e.*, the rate of work was approximately 3 m/min. Only a small part of the remaining time was spent in refixing the bobbins, inserting thread in the needle and fixing the needle foot. About 30% time were unproductive, which could be avoided by proper maintenance of the machines.

Work desk and anthropometric dimensions of operators

The anthropometric characteristics of the women operators are given in Table 1. The body weight and height of these workers are 47.0±0.9 kg and 149.8±6.2 cm (mean and S.D.) respectively.

As measured, the work surface heights of different types of machines were similar, *i.e.*, 75.2±1.1 cm. The average work seat height (*i.e.*, stool height) was 48.3±3.7 cm. In most cases, women used some form of cushion (which were usually folded fabrics or a cotton pillow) on the seat surface. The effective seat height with cushion came to about 51.5±3.0 cm.

The seat height is a major determinant of comfort, *i.e.*, the soft underside of

Table 1. Anthropometric characteristics of the women sewing machine operators ($n = 107$).

Parameters (cm)	Mean	S.D.	Median
Body height	149.8	6.2	149.5
Arm length	68.5	4.3	69.0
Body height (sitting)	78.1	4.0	77.9
Acromial height (sitting)	53.7	3.8	52.0
Elbow rest height (sitting)	20.3	3.2	19.7
Thigh clearance height (sitting)	12.4	2.7	12.0
Knee height (sitting)	45.5	3.0	45.6
Popliteal height (sitting)	38.0	3.2	38.4
Buttock-knee length (sitting)	50.3	3.7	49.9
Buttock-popliteal length	42.0	2.5	41.9
Hand length	16.4	1.4	16.1
Bi-acromial breadth	28.5	2.3	28.2
Bi-deltoid breadth	35.8	2.8	35.5
Chest depth	17.3	1.9	17.1
Elbow-to-elbow breadth	31.2	4.4	30.5
Knee-to-knee breadth	17.0	2.4	16.5
Hip breadth	31.7	2.8	31.3

the thighs is not compressed and the pressure from the front edge of the seat surface is minimum. This is possible when the knees are at right angle with feet flat on the ground. Generally, popliteal height, including shoe height, measures the seat height of a work chair. For the majority of the sewing machine operators the stool height was relatively high, since the popliteal height was only 38.0±3.2 cm. The women had to slide forward to attain a reasonable work height, *i.e.*, the height of the seat surface was 24–25 cm below the working surface.

Work-related stress

The sewing machine operations as such resulted in awkward body position, because of work nature and man-machine dimensional incompatibility. The operator inclined forward while operating the shuttle and sewing the clothes. In the case of motor-operated machines the operators exerted a sustained leg pressure on foot control for frequent turn on and off of the motor. For full shuttle and half shuttle operation the leg operation was rhythmic in nature. There were, however, significant individual variations in the pattern of leg actions and also in sitting habits. While the right leg was more used in work, the sliding tendency of the upper body was resisted by the left leg. Although sewing operation is very difficult with a trunk-thigh angle of greater than 90°, it was commonly observed in most cases of the women operators.

When a person slides forward to the front edge of the seat surface, even if there is a seat backrest, this leaves the trunk unsupported resulting in forward slumping of the torso in order to minimize the muscle activity (KENDALL *et al.*, 1967). This may be harmful for the reason that the slumped posture is attained by tension on the posterior annulus and apophyseal ligaments (ADAMS and HUTTON, 1983). In addition, in forward sitting position, seat surface support for the thighs is also minimized. It was generally observed that the sewing work was strainful to the musculo-skeletal structures, including the vertebral column. Figure 1 depicts

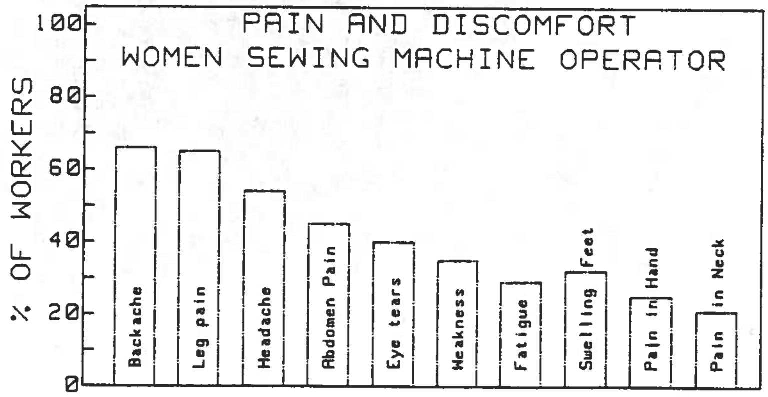

Fig. 1. Prevalence of work-related stresses.

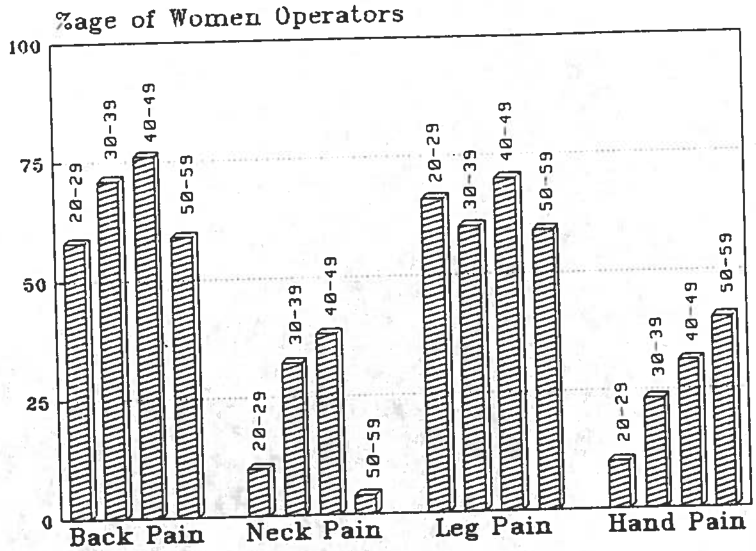

Fig. 2. Age-wise distribution of pain and discomfort among women sewing machine operators.

prevalence of work-related stresses, reflected as pain and discomfort in different parts of the body. Backache and leg pain were found to be the most prevalent complaints. As large as 68% of the women complained of back pain, among whom 35% reported a persistent and unbearable low back pain. Other common complaints were headache, abdominal muscle discomfort, eye strains, swelling of feet due to accumulation of body fluid, *etc.* Figure 2 shows the age-wise breakdown of prevalence of backache, neck pain, leg and hand pain. The 30–39 and 40–49 yr age groups had the largest number of complaints, *i.e.*, about 70–75% women of these two groups had backache. For stresses, *i.e.*, leg and hand pain, were also high with advancing age. In contrast, KEYSERLING *et al.* (1982) reported only 25% of the women sewing operators had persistent back pain.

A detailed questionnaire analysis of pain and discomfort revealed many features, as given in Table 2. A cumulative load on the musculo-skeletal structures reflected in the form of high prevalence of discomfort and pain in neck, shoulder, lower back and lower limb regions. Since the work cycle in sewing operation was short and repetitive in nature, along with more intensive prolonged inclined forward seated posture, the static muscular load particularly in the trunk region tended to be very high. VIHMA and VAIHEOMPELIJAN (1978) and VANECKOVA *et al.* (1977) noted that the short work cycle in sewing work diminishes the duration of bending posture. VIHMA *et al.* (1982) also related the increased occurrences of musculo-skeletal complaints to the mental work load associated with short work cycle. The experiences of the present authors are that despite short work cycle in sewing operation, the bent postures could not be minimized since the present

Table 2. Questionnaire analysis of pain and discomfort.

Elements	Affirmative response of the workers
1. Types of pain: spasm	88% workers
continuous	12% workers
2. Pain influences work output	53% workers
3. Changes in work output for different age groups:	
20–29 yr	2–3 hr
30–39 yr	2–3 hr
40–49 yr	4 hr
4. Initiation of pain	gradual
5. No change in pain pattern, since when it was first experienced	90% workers
6. Recollect the period of work experience when pain was first experienced	6–12 months
7. Relief from pain after rest	64% workers
8. Pain sustains even after night rest	35% workers
9. Household job influences pain	22% workers
10. Menstruation has additional effect on pain	52% workers

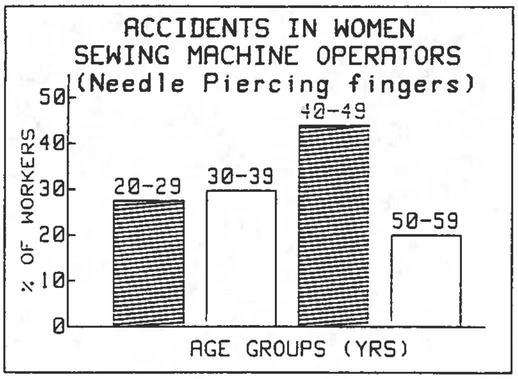

Fig. 3. Accidents among women sewing machine operators.

women had no option of backrest to relax from their incline forward posture. Moreover, the shorter cycles increased the speed of work and the duration between the two cycles was not enough to relax the muscles. This may also explain such a large prevalence of back-related complaints. The ensuing condition of discomfort, pain, edema and soreness was caused by localized muscle tension and accumulation of acidic metabolites or a result from the reactions of the connective tissue.

There is also a frequent minor accident like piercing of the needle through the finger, which was reported by 31% of the sewing operators. In most of the cases the right hand forefinger was the affected part. The accident was relatively high among the 40–49 yr women (Fig. 3). Unsatisfactory man-machine complex, work posture and fatigue, improper coordination of eye, leg and hand, less illumination and high thermal stress at the workplace were the likely contributory factors to the occurrence of this type of accidents among the women.

As such, the problems of the present sewing machine operators were associated with the operator-sewing machine mis-match, the size and shape of the seat surface, the seat height, the work height and the non-availability of backrest. As suggested by YU *et al.* (1988), the preferred sitting posture may be to maintain the trunk erect while keeping the thighs at 15° angle below the horizontal, resulting in a 105° trunk-thigh angle. Looking at the anthropometric dimensions of the present women, the seat height should be adjustable between 40–45 cm to allow women of different stature to attain the 105° trunk-thigh angle in operating the sewing pedal. The seat length/depth, measured from the front to the rear edge of the seat surface, should not be deeper than the buttock-popliteal length of a person, *i.e.*, about 40–43 cm. The seat width, as measured from the maximal width of the hip, of about 40 cm may accommodate the largest of the women operators. The armrest height and the inside distance between the armrests are the critical measurements where an operator uses fine and precise finger and wrist movements unhampered by the arm weight. The present work seat should be replaced by a seat with a backrest, that should not extend beyond the shoulder, in order to facilitate mobility of the arms and shoulders. Considering bi-deltoid breadth, the backrest width may be around 38–42 cm. The lumbar support of 20 cm high with an open space of about 15 cm high between the seat surface and the back of the lumbar support is necessary for protrusion of the buttocks. A 110–120° inclination of the backrest from the horizontal seat surface may be satisfactory for minimum stress on the back muscles. An optimal operator-sewing machine functional compatibility may significantly minimize work stresses in the long run.

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Application of Corbusier's Human-Scale to the Layout of Work Space for Typewriting

A. CHATTERJEE
CHITTRANJAN N. DAFTUAR
Indian Institute of Technology
Kharagpur, India

Reprinted from
JOURNAL OF ENGINEERING PSYCHOLOGY
Volume 5 / Number 2 / 1966 (54–62)
(Printed with the permission of the editor)

Journal of Engineering Psychology
Vol. 5, No. 2. 1966

Application of Corbusier's Human-Scale to the Layout of Work Space for Typewriting[1]

A. CHATTERJEE
CHITTRANJAN N. DAFTUAR
Indian Institute of Technology
Kharagpur, India

The study was designed to verify Corbusier's concept of a "human-scale" with reference to the design of work layout. The scale was constructed by measuring the human body at different points. Fifteen professional typists acted as Ss. The results supported the concept of human-scale, and indicated that the most efficient performance occurred when the layout of the work place followed the dimensions dictated by the human-scale.

ALMOST INVARIABLY ALL WHO HAVE TRIED TO DEFINE HUMAN ENGINEERING implicitly or explicitly have more or less included the design and utilization of tools as an enterprise that legitimately falls within the purview of those working in this field. In recent times work has been done in design of equipment layout to fit machine to man's capabilities. However, while the working tools are slowly being perfected, one aspect of research is markedly missing in this direction; namely, the establishment of the machine's dimensions relative to 'human-scale."

Corbusier, a French architect, advanced the thesis that a scale should be evolved based entirely on the human body dimensions, and the construction of all buildings and machines be based on this scale (Corbusier, 1951). On the basis of numerous findings he concluded that: (a) There is a certain relationship between the important dimensions of the human body; (b) The relationship also exists in other natural objects; and (c) Using these relationships, a scale, which he terms *Modulor*, can be constructed which can provide critical dimensions for the construction of buildings and design of machines and equipment.

The *Modulor* is a harmonious measure of the *human-scale* which is universally applicable wherever measurement matters.He defined his Modulor

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[1] Based on a post-graduate diploma thesis by the junior author in the Indian Insitute of Technology.

"as a measuring tool based on the human body dimensions and on mathematics. A man with arms upraised provides at the determining points of occupation of space—foot, solar plexus, head, fingertips of the upraised arms—three intervals which give rise to a series of golden sections, called the Fibonacci Series. On the other hand mathematics offers the simplest and most powerful variation of value: the single unit, the double unit and the three golden sections (Corbusier, 1951)."

As Corbusier explained the *Modulor*, values can be obtained from the following relationships: (a) Man's total height with arms upraised (up to fingertips raised upward) is double the height of the solar plexus; and (b) Man's height up to his head is 1 617 times the height of the solar plexus, both measurements taken from the ground. This relationship of 1: 1. 617 is a *golden mean ratio*, which is, of course, a concept coming from antiquity and it governs all interrelationships between different parts of the body.

Thus he constructed a scale of figures which pinned down the human body at the decisive points of its occupation of space, and called them "anthrocentric."

The present study is primarily concerned with the relative height of a chair and desk for typewriting. This relationship is investigated applying the scale value of the *Modulor* concept.

It is an undeniable fact that controls and displays should be located with due regard for the operator's size, position, most efficient line of sight, and space in which he can manipulate the controls most efficiently. It is not uncommon,however, for one to find situations where one feels that his physical dimensions are at odds with those that the designer or engineer had in mind when designing the layout.

Only during the latter part of the last century sitting posture was discussed in detail in the medical literature. Staffel's observation made in 1884 that "our chairs are, almost without exception, constructed more for eyes than the back" (Akerblom, 1954), is equally true today and, due to the lack of sufficient exprimental evidence, no generalization can be made regarding the height of the work surfaces in relation to sitting or standing postures. In different experiments, there are always found controversial results regarding the optimum height of working table and sitting surface (i e. chair) taken separately as well as considered relative to each other (Akerblom, 1954; Barnes, 1949; Ellis, 1951; McCormick, 1957).

Thus the present study sought to investigate: (a) the validity of the Modulor concept in working height of table for typewriting i.e., whether its height is related to body dimensions as expressed in Modulor; (b) whether a constant relationship of ϕ (1:1.617)between the table and chair height yielded best efficiency; and (c) verification of

Corbusier's concept of the relationships of various body parts to the full human height with reference to the present example.

METHOD

Procedure

For the purpose of adjustment, specially designed tables and stools were used. The height of each could be adjusted vertically by means of two adjustable rods. The heights of the stool and table were adjustable between 9 and 25 inches, and 18 and 48 inches, respectively.

Since the study was designed to be based on *human-scale* measurements of various body dimensions were taken. These measurements were taken in the manner suggested by the Tufts College Institute for Applied Experimental Psychology (1951) and by Damon, Stoudt, and McFarland (1963). The body dimensions of the Ss were taken with their full clothing on but, because it was summer, the clothing was quite light. With minor concession, the measurements agree with measurements of nude Ss.

The Ss were instructed about the purpose and nature of the investigation. They were asked to maintain their speed and accuracy of typing as far as possible at each stage of the experimental procedure and, also, to give their opinion on the most comfortable chair and table heights.

The seating height (knees at right angles) was taken as the standard seating height for each S individually and was kept constant for him throughout the experiment; Ss reported this height as most desirable. To begin the experiment the table was adjusted to ϕ height (i. e, in ratio of 1:1 617 with the stool). The ratio of 1:1.617 was rounded to 1.6 for the practical purposes of the experiment. Taking this height of the table as the starting point, five successive trials above, and five below that height were given each S, increasing or decreasing the height by one inch in each case. Thus the maximum number of trials for each S was 11.

For each trial Ss were given a two-minute typing test. The materials were 11 different passages, one for each different height of the table. These passages remained constant for all Ss. A rest of $1/\frac{1}{2}$ minutes was allowed between successive trials in both the ascending and descending series. After the completion of one particular series S was allowed a 10-minute rest period. Ss were never allowed to know the actual variation in the height of the table to avoid the confounding of suggestion.

Scoring was done on the basis of giving one plus score for each word correctly typed. For each omission and repetition, one score was deducted from the total score. Repeated words were not taken into account while counting the number of correct words. So the Performance Score = Correct Words—(Omitted Words + Repeated Words.)

Subjects

Fifteen professional typists of the Indian Institute of Technology erew randomly selected to act as Ss. The sample may be classified broadly for speed into three groups: Six Ss below 30 words per minute (wpm); Four Ss from 30 to 40 (wpm); and Five Ss above 40 (wpm). Regarding experience, education, and other personal factors the sample was a homogeneous group for all practical purposes.

RESULTS AND DISCUSSION

As stated earlier subjects were taken randomly and so some variations in body height were expected, but it is evident from Table I that SD in different measurements are very small so we can say the variations in the sample fall within a reasonable limited range.

TABLE 1

AVERAGE AND SDS OF BODY DIMENSIONS (IN INCHES) WITH POINTS OF MEASUREMENT

Body Dimension	*Average*	*SD*	*Points of Measurement*
Full Height	65.08	2.03	**From earth surface**
Knees	20.10	0.285	**From earth surface**
Back	23.41	1.276	**From seat surface**
Elbow	8.41	1.220	**From seat surface**

Table 1 shows the average of body dimensions, SD, and points of measurement.

The rate of work (RW) for each S at the various positions was calculated with the following formula:

$$RW = \frac{ES}{SN}$$

where:

ES=Experimental Score, the raw score of each trial for each S separately.

NS=Normal Score, the average score for each individual S (NS= total score for all trials divided by the number of trials).

RW was Calculated on the basis of each S's total score in each trial. Table. 2 shows each Ss Average performance score, Average RW and RW in the ϕ position. It is evident in Table 2 that RW of each individual S at the ϕ table height is higher than his average score with the exception of one case only. The differences ranged from a minimum of 0.05 ($S \neq 11$). to a maximum of 0.31 ($S \neq 12$). This supports the basic hypothesis of the superiority of the ϕ position over any other position.

TABLE 2

RATE OF WORK (RW) FOR EACH SUBJECT

Subject	*Average Performance Score*	*Total Number of Trials*	*Average RW*	*RW at ϕ Height*
1	78.18	11	0.99	1.16
2	72.70	10	1.00	1.18
3	33.40	10	1.08	1.18
4	40.80	10	0.92	1.10
5	69.54	11	1.90	1.27
6	82.87	8	0.99	1.11
7	84.30	10	0.99	1.19
8	96.45	11	1.06	1.19
9	88.30	10	1.10	1.18
10	73.55	9	1.00	1.21
11	64.00	10	1.03	1.08
12	68.60	10	1.00	1.31
13	88.20	11	0.94	1.11
14	78.27	11	1.00	1.21
15	32.36	11	1.00	1.11

Table 3 gives the t-ratios for each variable height. As additional support for the data of Table 2, Table 3 clearly shows the supremacy of the ϕ height over and other height for work efficiency. The t-ratios obtained signify and confirm very definitely that these differences in RW at different

TABLE 3

SDD AND t-RATIOS OBTAINED WITH REGARD TO WORK EFFICIENCY AT DIFFERENT TABLE HEIGHTS COMPARED TO ϕ HEIGHT

Comparison	*EDD*	t^{a}
ϕ vs 1 H[b]	8.030	7.47
ϕ vs 2 H	10.140	6.28
ϕ vs 3 H	7.590	6.73
ϕ vs 4 H	10.520	5.49
ϕ vs 5 H	10.296	5.69
ϕ vs 1 L	7.950	6.26
ϕ vs 2 L	6.935	5.43
ϕ vs 3 L	7.471	8.08
ϕ vs 4 L	8.241	6.98

a All significant at. 01 level of confidence.

b H and L indicate successively higher and lower positions from ϕ height, respectively.

table heights are decidedly greater than chance. Sinilicance of the difference between the output at the ϕ height and 5 L was not computed because it can be taken as highly significant on the basis of the fact that, out of 15 Ss, eight refused to type on the height of 5 L. They complained that, at this position, the lower surface of the table was pressing hard against their knees thereby making work impossible. Even those who worked gave very adverse "introspective reports." They reported that when the work table was much below the point of elbows being at right angles, their fingers tended to slip and chances of error increased.

The results also suggested that the work area should be of elbow height in conformity with some previous findings (Barnes & Mundel, 1939; Murrel, 1954) This is evident from Table 4, which shows that the difference between the average table height and averge stool height for the population is only 9.59 inches The average elbow heights in parallel to the ground is 8.41 inches (see Table 1). Since the elbow heights were measured from the upper surface of the stool it is clear that the difference between the ideal (ϕ) table height where the best efficiency was obtained and the average elbow height was 1.18 inches (15.09 stool + 8.41 elbow average—24.68 table = 1.18).

TABLE 4

AVERAGE AND SD OF TABLE AND STOOL HEIGHT ABOVE GROUND AT ϕ RELATION

	Table	*Stool*
Average Height	24.68	15 09
SD	1 007	0.7702

The present experimental results also confirm the hypothesis that 1:1.617 is a ratio of aesthetic, comfort, and efficiency. The minor difference of 0.179 inches in the 1.617 ratio of the stool and working table height is negligible, and may be attributed to various chance factors or to the fact that 1.617 was rounded to 1.6. Following the procedure for calculation as advocated by Corbusier (1951) the two series of the Modulor for the present sample were calculated. Since human height up to fingertips with hands upraised was not measured, the Modulor values were calculated in the following way from the average sample height: Average head height = 65,08 inches (Table 1), and Average solar plexus height = $65.08/1.6 = 40.241$ inches, the Single Unit. Therefore, average fingertip height = $40.241 \times 2 = 80.482$ inches.

Table 5 present the Modulor of the present sample, the Red Series (measurement starting from the solar plexus) going upward and downward based on the heights of the Single Unit (40.241 inches); and the Blue Series (starting from the fingertips) going downuard towards infinity based on the Double Unit (80.282 inches).

TABLE 5

THE RED AND BLUE SERIES OF THE MODUL OR FOR THE PRESENT SAMPLE (ROUNDED VALUES INCHES)

Red Series	*Blue Series*
274.50	210.54
170.00	130.14
105.00	80.50
65.00	49.75
40.30	30.90
24.90	19.10
15.40	11.80
9.50	7.30
5.90	4.52
3.70	2 79
2.30	1.73
1.41	1.07
0.87	0.66
0.54	0.41
0.33	0.25
0.21	0.15
	0.10

Taking the solar plexus (40.24 inches) of a man 65.88 inches in height to be the single source of variaion, the following main variations are obtained as shown in Table 6. The Double Unit was obtained by doubling the value, and the other values were obtained by addition and subtraction of the "golden section" with successive unit.

TABLE 6

MAIN VARIATION OF MODULOR OF A MAN OF 65.08 INCHES

15.41		210.54
24.90		130.14
		80.48 given by subtraction
40.24 given by addition		
	65.00	49.75
	105.10	30.90
	170.00	19.10

If the Corbusian hypohesis of the scale. being a scale of aesthetic, comfort, and efficiency holds true, the presumption would be that the most comfortable stool height should be the one which rosembled one of the Modulor figures. The Red Series of Table 5 gives the value. Going only two steps downward from the solar plexus we get a value of 15.41 inches. The value obtained as the average stool height, 15.09, resembles this very closely.

For the height of the working table 'the same holds true. It is evident from the results that no other than the ϕ relationship in height between stool and table produces the best output. Since this ϕ ratio is interrelated with all Modulor dimensions in each series, obviously then the working table height for best efficiency should also fall in the Red Series. The average table height ϕ relation, 24.68 inches, is very near to a Modulor figure in the Red Series of 24.9 inches, just below the solar plexus (40.3 inches).

The minor differences cf 0.32 inches in the case of the stool and 0.22 inches for the working table can be attributed to the limitations of the present study. The sample of 15 Ss is also very small to present any general conclusion.

In the present context the measurement of knee height may also give some conclusive evidence. The knee height as a critical body dimension rouses natural curiosity which led to inspection of the Modulor series for any corresponding value or at least a value tending towards that dimensional value. The Blue Series of our Modulor in Table 5 gives a value of 19.1 inches, in the fourth setp going downward from the fingertips. Allowing one inch on the average for the shoe and clothing (to 20.1 inch knee height, Table 1) as suggested previously (Damon, Stoudt, & McFarland, 1963), the two values are exactly the same. This fourth step downward in the Blue Series indicates the absolute value for the knee height. The result is also in conformity with the recommendation of the Joint Services Steering Committee (Damon, et al., 1963) that a seat of 15.5 inches will accommodate all but the smallest five percent of the population.

CONCLUSIONS

Although because of many limitations these results cannot be taken as conclusive, it would not be unfair to say that the concept of Modulor has been verified in the present investigation, at least to a certain extent. At least three dimensions of Modulor, two in the Red Series (table and stool heights), and one in the Blue Series (knee height), definitely go along with the hypothesis.

From the present study, it is tentatively concluded that: (a) different body dimensions follow a detinite pattern or ratio which is 1:1.617· (b) this ratio may be considered as the basis of a "human-scale" derived from measurements of the human body from two critical points: solar plexus. and fingertips of upraised hand; (c) the ratio is true with other objects in the working situation of man, and *human-scale* can be applied in all situations where human beings are concerned; and (d) The best efficiency of work was achieved when the stool and working table are in the ϕ (1:1.617) relationship.

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J. Human Ergol., **10**: 35–48, 1981

RELATIONSHIP BETWEEN SEGMENTAL AND WHOLE BODY WEIGHTS AND VOLUMES OF INDIANS

G. G. RAY,* R. N. SEN, P. K. NAG,** A. DE, and S. BASU

Ergonomics Laboratory, Department of Physiology, University
Colleges of Science, Technology and Agriculture, University
of Calcutta, 92, A.P.C. Road, Calcutta 700 009, India

Segmental weights and volumes were determined for nine adult cadavers (8 males and 1 female, average age 40.5 yr) mostly of poor nutritional status. The whole body was dissected into 14 major segments at each of the primary joints across the approximate center of rotation, weights being determined by a baby weighing balance, except for the beheaded trunk which was weighed by an electrically operated servo-indicator. Weights of the individual fingers (hand) and their volumes were also determined. The relative weights of the limbs (total arm=4.5% and total leg=12.8% of the body weight) were much lower in these Indian males as compared to those of the western and Japanese studies, whereas the weight of the trunk (56.3%) was much higher in Indian males. The segmental volumes of the trunk and the limbs represented 56.81 and 30.55 % of the total body volume, respectively. Both the weights and volumes of different limbs as percentage of body weight and volume were lower in case of an Indian female cadaver than those of the Indian male cadavers. Simple and multiple linear regression equations were then constructed for the prediction of segmental weights and volumes of males from different anthropometric measurements. The faster movement of the body segments of the Indians, as compared to those of the Westerners, might be due to the lower segmental weights of Indians.

In a heterogenous structure like the human body, the mass of the body is unevenly distributed over different segments and the center of gravity (CG) of the whole body is the weighted average value of all the different segmental CGs. Carrying a load on one side of the body or amputation of any limb will shift the segmental

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Present address: * Ergonomics Laboratory, Industrial Design Centre, Indian Institute of Technology, Powai, Bombay 400 076, India.
** Physiology Division, National Institute of Occupational Health, Meghani Nagar, Ahmedabad 380 016, India.

Received for publication October 23, 1980.

CG, and as such disturbs the whole body CG causing body imbalance. To keep the body in an upright position, necessary corrections in segmental weights need to be done. The average whole body weight of Indians (SENGUPTA and SEN, 1964; SEN, 1964; SEN *et al.*, 1977) is around 45 to 50 kg, which is much lower than that of Westerners (DAMON *et al.*, 1962; LEWIN, 1969; ROSS and WILSON, 1974; SHAHNAWAZ and DAVIES, 1977). It is very likely that the segmental weights in the case of Indians would also be lower. Thus it can be assumed that to move the body segments faster, as required in the case of light repetitive tasks, the resistance offered by the segmental weights would be less in the case of lower segmental and whole body weights of individuals. Besides, from the viewpoints of bio-medical engineering, aerospace technology, prosthetics and sports medicine, it is essential to have basic data on the weights and volumes of different portions of the body. Once these are known, the densities of the respective portions are easily obtainable and can also be related to the relative work done by the segments. These data are also essential in the designing of equipment, specially to determine the minimum force required to operate a control knob, gear handle, *etc.* (MURRELL, 1965).

Nutritional status, food habits and climatic conditions have an important influence on body physique and also on body composition (COON, 1954; BANERJEE, SEN, 1958; DAMON *et al.*, 1966). Thus the prediction equations suggested by Westerners (SKERLJ, 1954; DEMPSTER 1955; BARTER, 1957; CLAUSER *et al.*, 1969) for determination of different segmental masses and volumes may not be suitable for application in the case of Indians.

The aims of this study were to determine different anthropometric measurements of Indian cadavers, to determine directly their segmental weights and volumes, and to develop prediction equations for the assessment of segmental weights and volumes from different anthropometric measurements.

MATERIALS AND METHODS

In 1976, the first attempt was made by SEN *et al.* (1976) to collect segmental data on Indian cadavers. In 1978, the present study was undertaken on 3 more cadavers and the data obtained were added to the data of the earlier study to make the results statistically more meaningful. The total left leg and left arm were further segmented at their joints into smaller portions in the follow-up study.

The samples of the present study, therefore, consisted of 9 unclaimed adult cadavers of which 1 was female and 8 were male. These 9 cadavers were selected from 15 cadavers as per the death certificates of hospital physicians indicating the cause and date of death, condition of the body, sex, age and the actual observations made before dissection. The rest of the cadavers were rejected.

Anthropometric measurements. All the cadavers were kept at a temperature of about 4°C for nearly 24 hr in the hospital morgue (LEE and NG, 1965) before the experiment could be done at night during the cooler months of January and February when the average room temperature (during experiment) was about 20°C, varying from 18°C to 22°C. The methods and techniques used in this study were in many ways similar to those used by BRAUNE and FISCHER (1889), DEMPSTER (1955) and CLAUSER *et al.* (1969). But CLAUSER *et al.* (1969) used preserved cadavers in their study. Our cadavers were totally unpreserved. Before dissecting the cadavers, altogether 63 different anthropometric measurements (excluding the nude body weight) were taken with the help of a standard Martin-type anthropometer (HERTZBERG, 1968), a steel tape and a spreading caliper, all of them being calibrated against a standard meter scale. The nude body weight of the cadavers was recorded with the help of a load cell connected to an electrically operated and properly calibrated (±10 g) servo-indicator (Technolab and Co., India). All measurements were taken in the supine position. The detailed descriptions of the anthropometric measurements are more or less the same as described by CLAUSER *et al.* (1969).

Segmental weights. Segmentations were done at each of the primary joints on a plane passing through the primary centers of rotation using the body landmarks as reference points as shown in Fig. 1. Segmentations were done at 7 primary joints of the body: hip, knee, ankle, shoulder, elbow, wrist and head-neck. The descriptions of segments are also more or less the same as described by DEMPSTER (1955) and CLAUSER *et al.* (1969). The hand was further segmented into fingers and palm following the plane passing through the metacarpal and the proximal part of first phalanges. Localized dry-ice freezing technique (CLAUSER *et al.*, 1969) to avoid fluid loss during dissection was not used in this study. Altogether the body was dissected into 14 major and 10 minor (fingers) segments and as

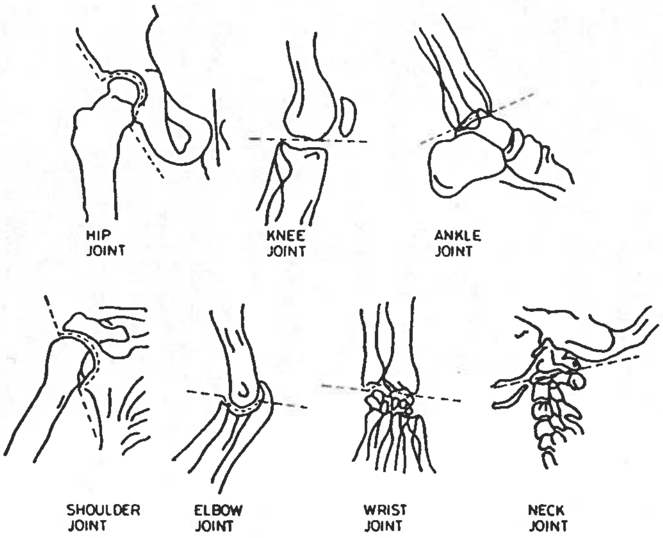

Fig. 1. Different planes of segmentation.

soon as a major segment was detached from the body, it was weighed in a calibrated (±1 g) baby weighing balance. Only the heavy beheaded trunk (including neck) was weighed, in some cases, with the help of a servo-indicator and in others, by placing it upon two baby weighing balances. The summated weight given by the individual balances gave the actual weight of the trunk. During calibration it was observed that the summated weight was very close to the value obtained by the load-cell connected with the servo-indicator. The weights of the fingers were determined with the help of a very sensitive (±0.0001 g) analytical chemical balance.

RESULTS AND DISCUSSION

From the observations of the experimenters and the written statement of the doctors, it was noted that the cadavers of the present study were of lower economic status. It was very likely that the persons in their lifetime had been suffering from undernutrition.

Table 1 gives a description of each of the cadavers selected in this study. It was observed that the average body height, weight and age of the male cadavers were 165.1 cm (SD±4.8), 37.0 kg (SD±6.2) and 40.5 yr (SD±11.5) respectively. The 75th percentile value of body height of the living population as observed by Sen *et al.* (1977) and also by Nag *et al.* (1978) was 165.7 cm whereas the 50th percentile value of the body weight of the living population (Sen *et al.*, 1977) was 45.9 kg. Thus the cadavers were of lower body weight as compared to their standard body height and weight chart. From the body height and weight when the ponderal index ($PI=(\sqrt[3]{\text{weight}}/\text{height})\times 1000$) of the individual cadavers was calculated, it was observed that the average PI of the male cadavers was 20.2 (SD± 1.0) with a range from 18.4 to 21.6. This suggests that most of the cadavers were totally ectomorphic in their physical configurations. The individual body density (Table 1) as derived from individual body volume also leads towards the same

Table 1. Particulars and description of cadavers selected in the present study.

Serial No.	Sex	Whole body length (cm)	Whole body weight (kg)	Age (yr)	Whole body volume (*l*)	Ponderal index*	Cause of death
1	M	164.0	35.6	50	32.981	20.1	Gastro-enteritis
2	F	147.2	28.2	60	25.942	20.7	Diarrhoea
3	M	162.3	39.3	50	36.340	21.6	Gastro-enteritis
4	M	172.1	36.5	29	33.523	19.3	Unknown
5	M	166.8	43.6	55	40.476	21.1	Cardiac failure
6	M	157.7	31.3	21	28.822	20.0	Tuberculosis
7	M	167.0	42.6	42	39.805	20.9	Gastro-enteritis
8	M	161.1	25.6	37	23.838	18.4	Gastro-enteritis
9	M	170.1	41.5	40	38.466	20.4	Unknown

* Ponderal index = ($\sqrt[3]{\text{weight}}/\text{height}$) × 1000.

conclusion as made for the ectomorphic physical configurations of the cadavers. The poor nutritional status might be the underlying reason.

In India more than 33% of the total population (600 millions) are manual labourers (CENSUS, 1974) and nearly 75% percent of workers seem to be underfed (NAG *et al.*, 1978). As the cadavers used in the present study were collected from those of poor socio-economic status which represent 75% of the labour force, so the present study picturizes the physical characteristics of the labour population.

Anthropometry of cadavers

The average values of different anthropometric measurements (of males) along with their coefficients of variations are given in Table 2. In comparison to our previous study (SEN *et al.*, 1977), Table 2 suggests that though the average body length for the aged male cadavers was slightly higher than that for the living population, the other body dimensions were lower. The physical configuration of the cadavers was more ectomorphic than that of the living population, as observed previously from the lower PI value (Table 1). The ectomorphic configuration is also evident from the lower breadth and circumference measurements as given in Table 2.

The anthropometric measurements of the female cadaver ($N=1$) are given within parentheses alongside the mean male value ($N=8$).

Segmental weights of the cadavers

The segmental weights as observed in the present study, expressed as percentage of the whole body weight, are given in Table 3, with a comparison of the values for the Western and Japanese studies. The respective weights of the total right arm and the total right leg (including thigh) represent 4.65 and 12.74% of the whole body weight, whereas the values for total left arm and total left leg were 4.40 and 12.89%, respectively. It was noted that the weight for both the upper and lower limbs was lower in Indian cadavers as compared to the corresponding values for Westerners. These lower segmental weights might help in rapid movement in sports or in assembly work. However, the weight of the trunk represents 56.32% of the body weight, which was much higher than the respective values obtained in Western and Japanese studies. The values obtained in the present study with regard to the segments-forearm and -handwere similar to those for the Japanese cadavers of FUJIKAWA (1963) but the weight of total right leg, thigh and calf and total left leg were very close to the values obtained by MORI and YAMAMOTO (1959). The weight of the head was similar to the value obtained by FISCHER (1906). It was also noted from this study that the weights of the right legs of Indian cadavers were slightly lower than those of the left, though in comparison to the total left arm, the weights of total right arms were slightly higher. In this study, the sum of the mean percentages of all the segmental weights was 95.6%, rather than

Table 2. Different anthropometric measurements of Indian cadavers.

Serial No.	Different anthropometric measurements	Mean ($N=8$)	±SD	C. V. (%)
1	Body length (cm)	165.1 (147.2)	4.8	2.9
2	Body weight (kg)	37.0 (28.2)	6.2	16.8
3	Age (yr)	40.5 (60.0)	11.5	28.4
4	Ponderal index	20.2 (20.7)	1.0	5.0
Top of head to :				
5	Lateral maleolus (cm)	158.9 (140.8)	4.5	2.8
6	Tibiale (cm)	118.7 (103.3)	3.2	2.7
7	Trochanteron (cm)	79.6 (68.3)	3.9	4.9
8	Illio-crestal (cm)	67.8 (56.0)	3.5	5.2
9	Penale (cm)*	77.7 (71.8)	3.1	4.0
10	Omphalion (cm)	63.2 (54.4)	2.3	3.6
11	10th rib (cm)*	54.4 (43.1)	2.3	4.2
12	Sub-sternum (cm)*	44.4 (36.8)	2.5	5.6
13	Supra-sternum (cm)*	29.4 (25.8)	0.8	2.7
14	Acromion (cm)	22.2 (21.2)	1.4	6.3
15	Neck-chin intersect (cm)	19.2 (18.1)	1.5	7.8
16	Mastoid (cm)	16.8 (13.6)	1.4	8.3
Length (cm)				
17	Head	17.5 (16.5)	0.8	4.6
18	Acromion to radiale	56.8 (48.2)	1.9	3.4
19	Acromion to olecranon	31.5 (27.6)	1.5	4.8
20	Olecranon to radiale	24.7 (22.2)	0.9	3.6
21	Radiale to metacarpal III	10.4 (7.7)	1.3	12.5
22	Metacarpal III to dactylion	8.4 (8.4)	1.1	13.1
Breadths (cm)				
23	Head	13.5 (13.3)	0.5	3.7
24	Neck	7.7 (7.4)	0.7	9.1
25	Bi-acromial	28.9 (22.8)	4.1	14.2
26	Chest	23.1 (21.1)	1.3	5.6
27	Waist (O)	20.7 (21.6)	1.8	8.7
28	Bi-crestal	25.2 (24.1)	1.4	5.6
29	Hip*	24.7 (26.2)	1.0	4.1
30	Bi-trochanteric	27.8 (27.9)	1.2	4.3
31	Knee	8.6 (8.3)	0.5	5.8
32	Elbow	6.5 (6.1)	0.5	7.7
33	Wrist	5.1 (4.5)	0.3	5.9
34	Hand breadth at thumb	8.4 (7.6)	0.7	8.3
35	Hand breadth at Metacarpal III	7.4 (6.7)	0.4	5.4
Depths (cm)				
36	Neck	9.0 (7.5)	1.7	18.9
37	Chest	17.0 (15.3)	1.4	8.2
38	Waist (O)	13.3 (10.9)	3.4	25.6
Circumferences (cm)				
39	Head	50.5 (49.5)	1.7	3.4
40	Neck	28.9 (24.4)	2.4	8.3
41	Chest	70.2 (65.7)	4.6	6.6

Table 2. (contd.)

Serial No.	Different anthropometric measurements	Mean ($N=8$)	±SD	C. V. (%)
42	Waist (O)	56.2 (49.4)	8.3	14.8
43	Buttock**	70.9 (69.4)	7.2	10.2
44	Upper thigh (Rt)	28.7 (26.7)	5.7	19.9
45	Lower thigh (Rt)	22.4 (21.2)	3.4	15.2
46	Mid-calf (Rt)	19.9 (16.4)	3.2	16.1
47	Ankle (Rt)	17.3 (15.2)	3.5	20.2
48	Arch of foot (Rt)	21.3 (19.8)	0.9	4.2
49	Axillary arm (Rt)	18.0 (16.6)	1.6	8.9
50	Mid biceps-extended (Rt)	15.5 (14.4)	2.9	18.7
51	Elbow (Rt)	20.0 (18.0)	1.5	7.5
52	Mid-forearm (Rt)	15.8 (13.6)	4.1	26.0
53	Wrist (Rt)	14.7 (12.2)	0.6	4.1
54	Hand-metacarpal III (Rt)	19.5 (18.1)	1.9	9.7
Finger lengths (cm)				
55	Thumb (Rt)**	5.9	0.3	5.1
56	Thumb (Lt)**	5.7	0.3	5.3
57	1st finger (Rt)**	7.6	1.1	14.5
58	1st finger (Lt)**	7.6	1.0	13.2
59	2nd finger (Rt)**	8.5	1.2	14.1
60	2nd finger (Lt)**	8.7	1.2	13.8
61	3rd finger (Rt)**	8.0	1.3	16.3
62	3rd finger (Lt)**	8.0	1.6	20.0
63	4th finger (Rt)**	6.3	1.1	17.5
64	4th finger (Lt)**	6.6	1.3	19.7

N, Number of subjects; * $N=5$; ** $N=3$; Rt, Right side; Lt, Left side; SD, Standard deviation of mean; C.V., Coefficient of variation. Figures within parentheses indicate the value for the female cadaver. O, At omphalion level.

100%. This reduction of 4.4% of the body weight was due to the detachment of fluid and tissues during segmentation on the polythene sheet. Later on, the weight of the fluid and tissues on the polythene sheet was addep to the segmental weights in respective proportions, the corrected values being given in Table 3. Dempster (1955) and Clauser *et al.* (1969) respectively noted a loss of 6.4 and 1.4% of body weight. The lower value of loss of body weight in the study of Clauser *et al.* (1969) was possibly due to the use of localized dry ice in the regions of dissecting. Table 3 also gives the weights of different hand-fingers of the cadavers. As no such data on fingers had hitherto been reported, it was not possible to compare the values obtained with others.

All the segmental weights in Table 3 are based on 8 adult male cadavers only, excluding the female one. In the case of the female cadaver, the weight of head, trunk (including neck) and total right arm was 2.80 kg (8.89%), 19.80 kg (62.86%) and 1.13 kg (3·58%) respectively. These values suggested that the percentage distribution of head weight in relation to the total body weight is more or

Table 3. Average segmental weights expressed as percentage of the whole body weight of the male cadavers compared to those observed by other workers.

Different body segments	The present study	Clauser *et al.* (1969)	Fujikawa (1963)	Mori and Yamamoto (1959)	Dempster (1955)	Fischer (1906)	Braune and Fischer (1889)	Harless (1860)
Sample size	8	13	6	6	8	1	3	2
Segments:								
Head	9.00	7.30	8.20	11.70	7.10	8.80	6.90	7.60
Trunk (including neck)	56.32	50.70	53.60	53.50	45.40	45.20	46.10	44.20
Total arm (Right)	4.65	4.90	4.80	4.70	4.90	5.40	6.30	5.80
Upper arm	2.40	2.60	2.60	2.70	2.70	2.80	3.30	3.20
Fore arm	1.47	1.60	1.40	1.30	1.60	—	2.10	1.80
Hand	0.79	0.70	0.80	0.60	0.60	—	0.90	0.80
Tumb	0.04*							
1st finger	0.06*							
2nd finger	0.07*							
3rd finger	0.05*							
4th finger	0.04*							
Total arm (Left)	4.40	4.90	4.60	4.60	4.80	5.60	6.10	5.40
Upper arm	2.45*							
Forearm	1.52*							
Hand	0.92*							
Thumb	0.04							
1st finger	0.06							
2nd finger	0.07*							
3rd finger	0.06*							
4th finger	0.03*							
Total Leg (Right)	12.74	16.10	14.40	12.60	15.70	17.80	17.30	18.50
Thigh	7.08	10.30	9.40	7.20	9.60	11.00	10.70	11.90
Calf	3.71	4.30	3.30	3.50	4.50	4.70	4.80	4.60
Foot	1.97	1.50	1.70	1.60	1.40	2.10	1.70	1.90
Total Leg (Left)	12.89	16.10	14.50	12.60	15.70	17.30	17.30	19.30
Thigh	8.71*							
Calf	4.18*							
Foot	2.22*							
Total	100.00	100.00	100.10	99.70	93.60	100.10	100.00	100.80

* $N=3$.

less similar in both sexes whereas the value for the trunk is higher for females. The weights of total left arm, total right leg and total left leg were 1.10 kg (3.51%), 3.31 kg (10.492%) and 3.36 kg (10.67%), respectively. When these values were compared with those given in Table 3, the percentage distribution for both the upper and lower limbs was lower in the female than for the male. It was found that the weights of upper arm, forearm and hand were 0.63 kg (1.98%), 0.36 kg (1.16%) and 0.14 kg (0.44%), respectively. The respective values for thigh, calf and foot were 1.81 kg (5.73%), 1.01 kg (3.23%) and 0.49 kg (1.54%). From these observations it might be expected that Indians can move their body segments faster than can Westerners which might also apply for very fast light repetitive tasks usually done by female workers.

Segmental volumes of cadavers

The average segmental volumes of Indian males, expressed as percentage of the whole body volume, are given in Table 4. The mean total body volume of the males of the present study was 33.692 *l*. The mean volume of the trunk was 19.141*l* (56.812% of the total body volume). The limbs (total arm, and total leg including thigh) represent only 30.554% of the total body volume. The mean volumes of thumb, 1st, 2nd, 3rd and 4th fingers in the case of Indian males ($N=3$) were

Table 4. Average segmental volumes (*l*) of male cadavers expressed as percentage of whole body volumes as compared to other studies.

Names of the segments	Present study		CLAUSER *et al.* (1969)		DRILLIS and CONTINI (1966)		HARLESS (1860)*
	Mean (*l*)	% of TB	Mean (*l*)	% of TB	Mean (*l*)	% of TB	Mean (*l*)
Sample size	8		13		12		
Total body (TB)	33.692	100.000	62.989	100.000	—	100.000	
Head	2.840	8.429	4.418	7.014	—	—	3.453
Neck and trunk	19.141	56.812	32.691	51.900	—	—	—
Total arm	1.463	4.342	2.978	4.728	3.971	5.730	—
Upper arm	0.810	2.404	1.638	2.601	2.412	3.495	1.492
Forearm	0.547	1.624	0.961	1.526	1.175	1.702	0.747
Hand	0.280	0.831	0.384	0.610	0.384	0.566	0.393
Fingers (cc)**							
Thumb	14.009	0.046	—	—	—	—	—
1st	19.732	0.059	—	—	—	—	—
2nd	23.421	0.070	—	—	—	—	—
3rd	18.629	0.055	—	—	—	—	—
4th	12.814	0.038	—	—	—	—	—
Total leg	4.337	12.873	9.955	15.804	10.091	14.620	
Thigh	2.728	8.097	6.462	10.259	6.378	9.241	5.442
Calf	1.338	3.971	2.620	4.159	2.818	4.083	2.037
Foot	0.688	2.042	0.885	1.405	0.895	1.297	0.918

* Segments are not from same cadaver. ** Sample size = 3.

14.009 ml (0.046%), 19.732 ml (0.059%), 23.421 ml (0.070%), 18.629 ml (0.055%) and 12.814 ml (0.039%), respectively. When these values were compared with those of the Western studies (CLAUSER *et al.*, 1969; DRILLIS and CONTINI, 1966; HARLESS, 1860), it was found that the percentage distribution of most of the segmental volumes, except for the trunk, hands and feet, was lower in the case of Indians.

As with Table 3, the values given in Table 4 are also based upon the data obtained from 8 adult male cadavers. In the case of the female cadaver the volumes of whole body, head, trunk (including neck) and total right arm were 28.98 *l*, 2.44 *l*, 18.41 *l* and 1.03 *l*, respectively, whereas the respective volumes of total left arm, total right leg and total left leg were 1.10 *l*, 3.02 *l* and 3.07 *l*. When the total arm and total leg of the right side of the body were further segmented it was observed that the volumes of upper arm, forearm and head were 0.57 *l*, 0.33 *l* and 0.13 *l* and the values of thigh, calf and foot were 1.66 *l*, 0.93 *l* and 0.44 *l*, respectively. In comparison to the male cadaver the whole body volume of the female cadaver was lower, but the percentage distribution of the volume of the trunk (63.52%) was greater in the female than in the male. The data also suggest that the percentage distribution of volumes of limbs (total arm, 3.56% and total leg, 10.42%) are lower in case of the female in comparison to the male.

Prediction of segmental weights from different anthropometric measurements

To predict the segmental weights from the whole body weight, simple linear regression equations were evolved as given in Table 5. This table presents the intercepts and regression coefficients along with their respective standard errors of estimates. The highest correlation coefficient was obtained for the trunk ($r=0.7983$). The poor correlation coefficient of the fingers might be due to the very small number ($N=3$) of observations. Hence to strengthen the prediction equations, stepwise linear multiple correlations were obtained. The multiple correlation coefficients were computed up to a maximum of five steps, of which the first three steps were whole body height, weight and age of the cadavers. The geometric configurations of the individual segments were considered as those of a frustum of a cone and hence either circumferences or breadths of both ends of the respective segments were considered (SKERLJ, 1954) for the other two steps. In the case of the foot, the highest multiple correlation coefficient ($r=0.9156$) was obtained when the body weight was considered along with body height and age. In the case of total arms, the multiple correlation coefficient ($r=0.9869$) obtained from the combination of body height, weight, age and wrist breadth was equal to that obtained from height, weight, age, elbow breadth and wrist breadth. Hence a four-step combination (height, weight, age and wrist breadth) was selected for the prediction of total arm weight. In the case of other segments the highest multiple correlations were obtained by the five-step method. The selected prediction equations for the assessment of segmental weights are given in Table 6. This table also shows the

Table 5. Prediction of different segmental weights* from whole body weight (kg) in Indian cadavers.

Dependent variables (body segments)	Correlation coefficients	Intercepts	Regression values	Standard errors of estimate
Head (9)[†]	0.5566	1.804	0.0360	±0.27
Trunk (including neck) (9)	0.7983	1.272	0.5093	1.50
Total right arm (8)	0.7560	−0.229	0.0515	0.19
Upper arm (8)	0.7032	−0.310	0.0302	0.14
Forearm (8)	0.6686	−0.182	0.0184	0.09
Hand (8)	0.5048	−0.034	0.0082	0.07
Thumb (3)*	0.3466	10.929	0.1461	2.28
1st finger (3)*	0.4690	13.751	0.2178	2.09
2nd finger (3)*	0.5519	16.313	0.2938	1.89
3rd finger (3)*	0.4068	14.416	0.1749	2.15
4th finger (3)*	0.6203	5.364	0.2554	0.95
Total left arm (8)	0.7511	−0.234	0.0495	0.18
Upper arm (3)	0.6273	0.160	0.0189	0.06
Forearm (3)	0.6117	0.169	0.0097	0.03
Hand (3)	0.2996	0.183	0.0036	0.06
Thumb (3)*	0.2822	10.104	0.1297	2.64
1st finger (3)*	0.3594	16.331	0.1596	2.37
2nd finger (3)*	0.3989	18.996	0.1751	2.22
3rd finger (3)*	0.4267	13.885	0.1858	2.11
4th finger (3)*	0.4454	4.167	0.2584	2.73
Total right leg (8)	0.7389	−1.785	0.1738	0.70
Thigh (8)	0.6842	−1.782	0.1165	0.58
Calf (8)	0.7804	−1.393	0.0458	0.15
Foot (8)	0.5616	0.192	0.0130	0.09
Total left leg (8)	0.7440	−2.019	0.1817	0.71
Thigh (3)	0.6422	−1.453	0.1270	0.33
Calf (3)	0.6633	−0.321	0.0502	0.04
Foot (3)	0.6349	0.263	0.0140	0.04

[†] Figures within parentheses indicate the number of observations.

* Only finger weights, except for the weights of major segments (kg) are in g.

standard errors of the estimates for each of the prediction equations. For a quicker prediction of segmental weights, where high precision is not required, the simple prediction equations as given in Table 5 can be used, but where high precision is important, the selected multiple prediction equations given in Table 6 should be used.

Prediction of segmental volumes from different anthropometric measurements

For the prediction of different segmental volumes from the whole body volume, attempts were made to find the intercepts and the regression coefficients for the individual segments. But as the individual simple correlation coefficients between the whole body volume and the segmental volumes were not very high, further at-

Table 6. Selected regression equations for the prediction of segmental weights from different anthropometric measurements.

Dependent variables (segments)	Equations	Standard errors of estimate
Head	$0.0102x_1+0.0283x_2-0.0094x_3+0.0803x_4+0.2820x_5-5.0902$	±0.1671
Trunk including neck	$0.7518x_2-0.0047x_1-0.0057x_3-1.0236x_6-0.3237x_7+24.1094$	2.3286
Total arm	$0.0565x_2-0.0109x_1-0.0011x_3-0.2786x_{11}+3.3243$	0.0768
Upper arm	$0.0125x_1+0.0677x_2-0.0101x_3-0.2325x_8+0.0702x_9-0.0396$	0.4592
Forearm	$0.0107x_1+0.0238x_2+0.0139x_3-0.1938x_{12}-0.0815x_{13}+2.3135$	0.1951
Hand	$0.0075x_3-0.0241x_1-0.0222x_2+0.4679x_{13}-0.0127x_{14}-1.7994$	0.1372
Total leg	$0.0386x_1+0.0675x_2-0.0156x_3+0.1594x_{15}-0.0489x_{18}-7.0786$	0.3016
Thigh	$0.0055x_1+0.0076x_2-0.0095x_3+0.1267x_{15}+0.0531x_{16}-2.9103$	0.1736
Calf	$0.0131x_1+0.0299x_2-0.0010x_3+0.0382x_{17}-0.0171x_{18}-2.2935$	0.1558
Foot	$0.0207x_1+0.0023x_2-0.0017x_3-2.6954$	0.0603

x_1, body length (cm); x_2, body weight (kg); x_3, age (yr); x_4, head breadth (cm); x_5, head length (cm); x_6, chest breadth (cm); x_7, waist breadth (cm); x_8, axillary arm circumference (cm); x_9, biceps circumference (cm); x_{10}, elbow breadth (cm); x_{11}, wrist breadth (cm); x_{12}, elbow circumference (cm); x_{13}, wrist circumference (cm); x_{14}, hand circumference at metacarpal (cm); x_{15}, upper thigh circumference (cm); x_{16}, lower thigh circumference (cm); x_{17}, calf circumference (cm); x_{18}, ankle circumference (cm).

Table 7. Selected regression equations for the prediction of segmental volumes from different anthropometric measurements.

Dependent variables (segments)	Equations	Standard errors of estimate
Head (*l*)	$0.0220x_1+0.0154x_2+0.009x_3+0.2100x_4+0.1404x_5-4.2427$	±0.1652
Trunk including neck (*l*)	$0.6934x_2-0.0109x_1-0.9224x_6-0.2853x_7+22.6197$	1.5957
Total arm (*l*)	$0.0097x_1-0.0167x_2-0.0143x_3+0.0434x_{10}+0.2971x_{11}-0.5691$	0.1192
Upper arm (ml)	$2.6025x_1+1.4128x_2-1.0897x_3+0.4173x_8+53.3433x_9-438.9270$	36.4582
Forearm (ml)	$5.4043x_3-10.2268x_1-6.1910x_2+43.8224x_{12}+145.1548x_{13}-797.1717$	5.5254
Hand (ml)	$5.2906x_3-14.8780x_1-12.4757x_2+243.9516x_{13}+1.6628x_{14}-631.3687$	35.1152
Total leg (*l*)	$0.0342x_1+0.0611x_2-0.0151x_3+0.1542x_{15}-0.0473x_{18}-6.3893$	0.2928
Thigh (*l*)	$0.0043x_1+0.0034x_2-0.0087x_3+0.1171x_{15}+0.0600x_{16}-2.6687$	0.1661
Calf (*l*)	$0.0113x_1+0.0274x_2-0.0009x_3+0.0387x_{17}-0.0172x_{18}-2.0269$	0.1402
Foot (ml)	$18.7996x_1+2.2299x_2-1.5078x_3-2444.7662$	54.2814
Whole body (*l*)	$0.9482x_2-0.0245x_1+0.0053x_{19}-0.0142x_{18}+3.2572$	0.1484

x_1, body length (cm); x_2, body weight (kg); x_3, age (yr); x_4, head breadth (cm); x_5, head length (cm); x_6, chest breadth (cm); x_7, waist breadth (cm); x_8, axillary arm circumference (cm); x_9, biceps circumference (cm); x_{10}, elbow breadth (cm); x_{11}, wrist breadth (cm); x_{12}, elbow circumference (cm); x_{13}, wrist circumference (cm); x_{14}, hand circumference at metacarpal (cm); x_{15}, upper thigh circumference (cm); x_{16}, lower thigh circumference (cm); x_{17}, calf circumference (cm); x_{18}, ankle circumference (cm); x_{19}, chest circumference (cm).

tempts were undertaken to strengthen the prediction equations by the process of the stepwise multiple correlation coefficient technique for the prediction of whole body and different segmental volumes from different anthropometric measurements (height, weight, age and 2 different circumferences of the respective segment) as used in the case of segmental weights (Table 6). It was observed that in the case of the foot, the highest multiple correlation was obtained when the body weight was combined with the body height and age. In the case of the trunk, no improvement in multiple correlation coefficient (r=0.9532) was observed when the age factor was incorporated with data on body height, weight, chest breadth and waist breadth. Thus for the trunk, a four-step multiple prediction equation was selected. It was observed that, for the whole body volume, the multiple correlation coefficient (r=0.9999) obtained from the combination of body height, weight, age and chest circumference was the same as that obtained from the combination in which age was replaced by the ankle circumference. As the correct chronological age is very important and very difficult to obtain, for practical application, the combined measurements of height, weight, chest and ankle circumferences are suggested for predicting the trunk volume. In the case of other body segments, the highest multiple correlations were obtained at the fifth-step level. All the selected equations for the assessment of whole body volumes are given in Table 7.

The authors express their heart-felt gratitude to the Head of the Department of physiology, University of Calcutta, where the study was undertaken and also to the following persons of Calcutta Corporation for kindly providing facilities in the cadaver studies at the Mysore Garden Crematorium, Calcutta:– Dr. G. C. Das, The Health Officer; Mr. A. B. Datta Gupta, Assistant Engineer of the Lighting Department; Dr. T. N. Bhowmik and Dr. B. G. Datta, Subregistrars; Mr. B. Sen, Lighting Inspector; and other workers of the Crematorium. Our special thanks go to Mr. A. Ghosh, crematorium Electrician, for his ceaseless co-operation and assistance throughout the study and also to the Computer Centre of the University of Calcutta.

The partial financial assistance of the Indian Council of Medical Research for this study is gratefully acknowledged.

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Reprint from Ind. Jour. Physiol and Allied Sc., 1968, Vol. XXII No. 1 & 2 from page 1—3

STUDY ON IONIC CONCENTRATIONS DURING MINIMAL, SUB-MAXIMAL AND MAXIMAL EXERCISE

S. R. Maitra, S. Chatterjee and S. Das †

(*Department of Physiology, University of Calcutta 92, Acharya Prafulla Ch. Road, Calcutta-9.*)

Margaria and co-worker (1), Keys and Adelson (2), De Lanne *et al* (3) have studied already the changes in ionic concentration of plasma during muscular exercise. It has been suggested by De Lanne *et al* (3) that the changes are not entirely due to haemoconcentration resulting from the fiuid transfer into the muscles. But there is no mention in the literature regarding the changes in ionic concentrations at various work loads e.g. 100, 600 and 1200 kgm/min., in our country.

The present investigation was therefore, undertaken to study the resting values of sodium, potassium, chloride and phosphate ions, and also their changes during the minimal, submaximal and maximal work on 20 male students who are born and brought up both in tropical climate and extreme climate i.e., high humidity and temperature for considerable part of the year and for the few months temperate climate .The experiments have been performed only with the people of Eastern region of India.

METHODOLOGY

The experimental procedures have been discussed in detail in our previous papers (4 & 5). Na+ and K+ concentrations in plasma have been estimated by EEL Flame Photometer (6). Plasma chloride and phosphate have been estimated by titrating with mercuric nitrate (7) and by microcolorimetric method (8, 9) respectively. Lactic acid concentration has been determined according to the method of Barker and Summerson (10, modified by Storm (11).

RESULTS

Sodium, potassium, chloride, phosphate and lactic acid concentrations increased with increasing work load gradient (vide table 1). Starting from rest to the minimal work (100 kgm/min.) the change is usually very little (not significant), but the changes are significant during submaximal (600 kgm/min.) and maximal work (1200 kgm./min.). The rate of change is not always proportional to the changes occuring during submaximal work from the minimal work loads. But lactic acid concentration increases during exercise and the rate of increment is proportional to the intensity of work load, which is now an established fact.

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† Present address—Inspector of Physiology, Central Regional Labour Institute, Sion Bombay.

DISCUSSION

The increase in ionic concentrations of plasma following exercise as noted in the present investigation are in agreement with the findings of De Lanne *et al* (3). During submaximal and maximal exercise plasma osmolality rises significantly because of increase of Na^+, K^+, PO_4^-, Cl^- and lactic acid. This is presumed to be a reflection in plasma following transference of water from the blood into the muscle where osmotic pressure rises during exercise due to accumulation of lower metabolites (12).

The increment of potassium ions following exercise (13) is found to be more than that of sodium ions. De Lanne *et al* (3) have suggested that the K^+ comes out of the muscles as phosphate and not as lactate, and the transference of K^+ is responsible for the increase of plasma phosphate. The rise of chloride ions is less than that of other ions e.g., phosphate, lactate which are considered as the mobile ions (3).

All the ions do not change proportionately (table 1); percentage increase varies from each other. Pressumably it is not due only to the transference of water from plasma to the muscle. These differential changes might be related to the endocrine factors. In terms of proportionality maximum changes in the case of Cl- and PO_4 are occuring during submaximal work. It might indicate that there is a limit of change, major portion of which is occuring during submaximal work, leaving only a small remainder which is attained during maximal work.

TABLE 1

Average and standard deviation of sodium, potassium, chloride and phosphate under resting condition and the different work loads

Name of the Parameters	Before work (at resting condition)	100kgm/ min.	Percentage increase from rest	600kgm/ min.	Percentage increase from rest	1200kgm/ min.	Percentage increase from rest
Sodium (meq./lit)	142.10±2.08	142.10±2.08	0%	144.95±2.28	2%	148.00±2.36	4.15%
Potassium (meq!/lit)	4.18±0.15	4.18±0.15	0%	4.43±0.14	5.98%	4.78±0.10	14.11%
Chloride (meq/lit.)	103.21±0.57	104.17±0.52	0.93%	107.02±0.83	3.69%	107.81±0.96	4.45%
Phosphate (mg.%)	3.540±.12	3.57±0.14	0.84%	4.26±0.11	20.33%	4.67±0.17	31.92%
Lactic acid; (mg. per 100 c.c.)	10.18±1.96	15.37±2.90	50.98%	50.02±5.01	391.35%	95.81±7.19	841.15%

No. of Subjects : 20.

It might, therefore, be concluded that the increases of ionic concentration are not proportional with 100, 600, and 1200 kgm/min. work load and the results obtained for resting value and during exercise corroborate with the findings of De Lanne *et al* (3).

ACKNOWLEDGEMENT

The authors are grateful to Indian Council of Medical Research, New Delhi, for their financial help for carrying out the investigation.

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ERGONOMICS, 1986, VOL. 29, NO. 6, 791–799

Influence of heat-stress induced dehydration on mental functions

By V. M. SHARMA, K. SRIDHARAN, G. PICHAN and M. R. PANWAR
Defence Institute of Physiology and Allied Sciences,
Delhi Cantt-110010, India

Keywords: Heat-exposure; Exercise; Dehydration; Mental functions.

The effect of primary dehydration of various levels (1, 2 and 3% body-weight deficits) on mental functions of different complexities were studied in eight heat-acclimatized subjects drawn from tropical regions of India. These subjects were also studied after a bout of exercise in heat under two conditions viz., Hot Dry (45°C DB, 30% rh), and Hot Humid (39°C DB, 60% rh) at 34°C WBGT. No significant change in routine mental work was seen either under dehydration *per se* of any level or after subsequent exercise under heat when compared with the normal state. On the other hand, at 2 and 3% levels of primary dehydration a further reduction was noted in all the functions though it was not significant. Inter-variations in Hot Humid and Hot Dry conditions were not significant except for more pronounced reductions in the concentration component in Hot Humid conditions.

1. Introduction

The decline in efficiency of mental functions and physical work output as a result of increased thermal stress is well established (Pepler 1964, Henschel 1969, 1971). The minimal heat-stress level which adversely affects performance, however, is seen to depend on a complex interplay of such factors as the degree of thermal stress, duration of exposure to stressful condition, and the capabilities and limitations of the individuals relative to the task as well as on their heat acclimatization status (Pepler 1958, Wing 1965, Piwonka and Robinson 1967). A significant drop in the efficiency of mental performance of individuals drawn from the cold and temperate regions has generally been reported to manifest beyond 29·4°C Basic Effective Temperature (BET) as against 32·2°C BET in the case of heat acclimatized Indians (Sharma *et al.* 1983).

Dehydration is possibly an additional stress for most of the outdoor labour population of tropical countries. Manual work schedules may result in dehydration due to non-availability of adequate water or voluntary abstinence from drinking (Adolph 1947, Greenleaf and Sargent 1965). High levels of dehydration suffered at any time take several days for recovery of complete normalcy of hydration levels (Iampietro and Goldman 1965).

Altered work capacity along with increase physiological strain during heat stress and exercise of various degrees is reported by several workers (Buskirk *et al.* 1959, Sargent *et al.* 1964, Horstman and Horvath 1972, Joseph *et al.* 1976). In general it has been observed that performance decreases progressively with increase in dehydration and reaches abnormally low levels when more than 10% of the total body-water is lost (Ladell 1965). On the other hand, effects of dehydration alone on mental performance are not reported in the literature; the only references are for the combined effects of heat stress and dehydration. Even in these studies conclusions drawn are too general, symptomatic and subjective. For example, vague terms like 'lethargic, morose, weak, irritable, drive, morale, vigour and spirit' have been used (Strydom *et al.* 1968) to describe the effects of dehydration. To fill this gap in knowledge the present research study was undertaken as an objective investigation of the effects on mental performance of different levels of dehydration alone or together wth superimposed heat stress.

2. Materials and methods

Studies were conducted on eight medically fit males in the age group 21–24 years drawn from the tropical regions of India. These subjects had no history of heat-induced illness and had not been through heat-exposure studies previously. At the outset the subjects went through a heat-acclimatization schedule in a hot chamber for eight consecutive days at 45°C DB and rh 30%, with moderate work (Pichan *et al.* 1985). This was done to ensure the same degree of heat-acclimatization status in all subjects. Maintenance of the same levels of heart rate, oral temperature and sweat rate after 2 hours of heat exposure on the last three days was taken as the criterion for the completion of heat acclimatization. Physical characteristics of subjects are reported in table 1.

On the day following the heat-acclimatization schedule each subject reported to the laboratory an hour before the commencement of heat exposure for dehydration studies. During this period they were asked to drink water to the extent of 1% of their body-weight and then to rest for a period of 1 hour in a thermoneutral room (27°C ± 1°C, rh 50%). Under this condition, oral temperature (YSI Telethermometer in conjunction with 400 series probes) and heart rate (EKG tracing lead II) were monitored. Thereafter, the subjects emptied their bladders, changed over to nylon waistcloths and entered the climatic chamber, remaining there in this dress throughout the test period.

On entry to the climatic chamber the subjects were weighed from time to time in an Avery balance (sensitivity ± 25 gm) prior to and during continuous moderate work (15 steps per minute on a 38-cm stool) to assess the dehydration levels. The chamber was maintained at 45°C DB with rh 30% for Hot Dry and at 39°C DB with rh 60% for the Hot Humid condition. During work, water restriction was imposed on the subjects to effect planned degrees of dehydration viz., 1, 2 and 3% of their initial body-weight. On obtaining the target dehydration, the subjects once again rested in the thermoneutral condition for 90 minutes. This time was observed to effect the maintenance of plateau levels of heart rate and oral temperature.

During the rest period no intake of water was allowed, thus maintaining the

Table 1. Physical characteristics of subjects.

S. No.	Age (years)	Height (cm)	Weight (kg)	Body Surface Area* (m^2)
1	24	170·0	60·300	1·71
2	23	171·5	59·625	1·69
3	24	171·0	57·125	1·67
4	23	174·0	60·550	1·74
5	23	163·5	60·200	1·66
6	23	187·0	74·550	1·99
7	23	173·0	63·150	1·75
8	22	169·0	57·850	1·68

*Calculated with DuBois formula.

Table 2. Dehydration levels during Hot Dry and Hot Humid conditions.

	Dehydration levels (%)					
	Hot Dry			Hot Humid		
S. No.	1	2	3	1	2	3
1	1·2	2·4	3·3	1·3	2·3	3·0
2	1·5	2·4	3·0	1·1	2·0	3·0
3	1·1	2·2	3·2	1·4	2·4	3·1
4	1·6	2·5	3·4	1·3	2·3	3·7
5	1·3	2·2	3·7	1·1	2·0	3·7
6	1·5	2·1	3·0	1·4	2·5	3·2
7	1·2	2·4	3·0	1·2	2·3	3·4
8	1·6	2·1	3·6	1·6	2·1	3·4
Mean ±s.d.	1·4 ±0·20	2·3 ±0·16	3·3 ±0·27	1·3 ±0·17	2·2 ±0·18	3·3 ±0·29

dehydration levels obtained earlier. On completion of the recovery phase psychological tests, as decribed in subsequent paragraphs, were administered individually. The 1, 2 and 3% dehydration levels were effected at random on different days of the study on all the subjects who went through all the tests under various conditions. A gap of two days between dehydration studies was allowed for each subject. On completion of the psychological tests each subject was reweighed inside the climatic chamber, after obligatory emptying of the bladder, to arrive at the target levels of dehydration; the levels reached are shown in table 2.

After this determination the subjects were given a standard work heat test (40 W on a cycle ergometer) in Hot Dry or Hot Humid conditions, depending on the sequence, for a period of 40 minutes. Physiological responses were monitored during the work period every 5 minutes. On completion of the work schedule, psychological tests were once again repeated inside the hot chamber. For a reliable comparison, studies were also carried out on exactly similar lines without forced dehydration (euhydration, 0%) under both Hot Humid and Hot Dry conditions.

A brief description of the psychological tests used in the study is given below.

2.1. *Substitution test*

Each individual's efficiency in routine symbol classification work was ascertained by using a substitution test in which a subject was initially presented with a sample code in terms of ten English letters, each associated with one of a set of ten uncommon geometric designs. In the test these designs were arranged in a random order in several horizontal rows and the subject was required to write the correct letter under each design with reference to the code for 3 three minutes. The scores depended on the number of correct attempts after making deductions for wrong substitutions.

2.2. *Concentration test*

The test was designed on the pattern used by Eysenck (1952) and is taken as a measure of running memory. Ten long series of numbers were orally read out to subjects at the rate of one number per second. At unpredictable intervals each series was interrupted and the subject was required to reproduce the last five digits read out to him in the reverse order. An individual's percentage scores on running memory were computed by reference to the total number reproduced in the right order over the ten series.

2.3. *Psychomotor test*

Perceptual motor coordination was assessed by using an apparatus having a solid wooden base with a metal plate fixed on it. The plate had a groove, 0·5 cm wide, cut in an eight-cornered star design covering a distance of 42 cm. Subjects were required to move a stylus in this narrow groove without touching the edge of its boundaries. Errors of alignment were automatically recorded through a battery-operated counter which in each case produced a sound, warning the subject to bring the stylus back within the groove. The time taken to trace the entire design was recorded with a stop-watch. An individual's score was the highest when he took minimum time and committed the least number of errors.

Parallel forms of the first two tests and practice trials on all of them before the actual study were used in order to minimize familiarity and learning effects, if any.

3. Results

Data concerning effects of deydration alone were analysed with the help of two-way (repeated measures) analysis of variance and differences between dehydration levels were pin-pointed by the method of least significant difference of means. Paired t-tests were used to assess the differences in the effects of Hot Dry and Hot Humid conditions when superimposed on different levels of dehydration. A critical level of statistical significance of $P < 0{\cdot}01$ was adopted.

The actual levels of dehydration attained in this investigation on the subjects under different heat-stress conditions against the target levels of 1, 2 and 3% are shown in table 2. It will be seen that under Hot Dry conditions the mean levels of dehydration turned out to be 1·4 ± 0·20, 2·3 ± 0·16 and 3·3 ± 0·28% as against the targets of 1, 2 and 3% respectively. Under Hot Humid conditions these were 1·3 ± 0·17, 2·2 ± 0·18 and 3·3 ± 0·29%. However, for the purpose of results and discussion in this paper, the observed values have been deemed to represent the target levels.

3.1. *Effects of dehydration*

Summary statistics (means, error variances, and least significant differences) are presented in table 3 and show that different degrees of dehydration alone did not affect different mental functions to the same degree. Though there was a progressive decrease

Table 3. Comparison of psychological tests scores in thermoneutral condition with different dehydration levels.

Function	Level of dehydration (%)				Error Variance	Least significant Difference	
	0	1	2	3		1%	0·1%
Substitution	135·37	131·62	110·75	105·75	634·13	35·64	48·08
Concentration	73·20	64·00	59·50	60·00	50·19	10·02	13·02
Eye–Hand coordination	150·86	147·55	132·08	122·21	102·127	14·304	19·297

in symbol classification scores with respect to an increase in levels in dehydration, the overall effect of dehydration was not significant statistically ($F_{3,21} = 2{\cdot}763$). This suggests that in such routine mental work as symbol classification, dehydration did not have a major deleterious effect.

Mean scores on the concentration test under different levels of dehydration are also reported in table 3. The mean scores for this test at the 2 and 3% levels of dehydration were significantly lower ($P < 0{\cdot}001$) than the euhydration state. The mean scores when compared with levels other than euhydration were not statistically significant.

There was only a marginal decline in the mean scores for the coordination function – from 150·85 to 147·55 – under 1% level of dehydration in comparison with the euhydration condition (table 3), indicating that 1% dehydration did not affect this function significantly. On the other hand, at higher levels of dehydration this function deteriorated in a much more marked way.

The performance scores at 2 and 3% dehydration levels were significantly lower when compared to the euhydration and 1% dehydration levels. A higher level of significance in reduction was seen at the 3% level of dehydration ($P < 0{\cdot}001$). This indicates that 2% or more dehydration results in the most deleterious effects on running memory as well as perceptual motor coordination functions.

3.2. *Effects of superimposed heat stress and exercise*

Mean test scores when heat stress and exercise were superimposed after dehydration under the two heat-stress conditions – Hot Dry and Hot Humid – are set out in tables 4 and 5 along with error variance and least significant difference.

Under Hot Dry conditions, although symbol classification test scores decreased progressively, the differences are not statistically significant ($F_{3,21} = 1{\cdot}878$). On the other hand, the mean scores obtained for the coordination test decreased significantly at all levels of dehydration. The decrements in scores between 1 and 3% and 2 and 3% are also highly significant ($P < 0{\cdot}001$). The scores obtained in the concentration test dropped significantly at 2 and 3%. The difference between the mean scores under 1 and 3% was also significant ($P < 0{\cdot}001$), whereas it was not significant between 2 and 3%.

Under Hot Humid conditions (table 5) the symbol classification test scores decreased with higher levels of dehydration. The differences in the scores between dehydration levels were not statistically significant ($F_{3,21} = 3{\cdot}400$). The mean scores obtained in the coordination test also decreased with increase in dehydration levels. The decreased scores were statistically significant at 2 and 3% dehydration levels when compared with the values at the euhydration level ($P < 0{\cdot}001$). Further, the decrements

Table 4. Comparison of psychological tests scores in Hot Dry (WBGT 34°C) condition with different dehydration levels.

	Level of dehydration (%)					Least significant Difference	
Function	0	1	2	3	Error Variance	1%	0·1%
Substitution	125·87	121·50	111·62	103·62	425·41	29·19	39·38
Concentration	71·25	67·50	60·50	55·00	41·12	9·07	12·24
Eye–Hand coordination	143·86	131·63	124·77	107·12	60·952	11·051	14·907

Table 5. Comparison of psychological tests scores in Hot Humid condition (WBGT 34°C) with different dehydration levels.

Function	Level of dehydration (%) 0	1	2	3	Error Variance	Least significant Difference 1%	0·1%
Substitution	132·37	131·12	118·50	102·62	451·50	30·07	40·57
Concentration	59·50	56·00	50·50	47·00	18·57	6·10	8·22
Eye–Hand coordination	147·82	139·95	124·42	111·92	104·503	14·470	19·520

Table 6. Comparison of mean exercise oral temperature and heart rate in Hot Dry and Hot Humid conditions with different dehydration levels.

Parameter	Level of dehydration (%) 0	1	2	3	Error Variance	Least significant Difference 1%	0·1%
Heart rate (b.p.m.)							
Hot Dry (30% rh)	122·1	127·3	135·8	148·9	11·72	4·8410	6·5304
Hot Humid (60% rh)	118·3	125·5	131·8	143·3	12·05	4·9259	6·6450
Oral temperature (°C)							
Hot Dry (30% rh)	37·26	37·53	37·77	38·02	0·0084	0·13	0·17
Hot Humid (60% rh)	37·25	37·61	37·83	38·06	0·0113	0·15	0·20

under 2 and 3% levels were also significantly lower than that obtained under 1% dehydration level. The scores in the concentration test were also significantly lower with increased levels of dehydration. Comparisons of scores in various states reveal that they are statistically significant ($P<0{\cdot}001$) when compared to the euhydration state.

Summary data for physiological measures are presented in table 6. Both heart rate and oral temperature increased as level of dehydration increased, for both Hot Dry and Hot Humid conditions, each increment in dehydration level producing a significant increase in both physiological responses. The differences between physiological measures under Hot Dry and Hot Humid conditions, however, were small and not significantly different.

4. Discussion

The subjects of this study were put through a standard heat-acclimatization schedule prior to the commencement of dehydration trials to eliminate the differences in degree of acclimatization status. The psychological tests chosen are of a different variety of processes and skills. The symbol classification test involves assessment of routine mental work. The concentration test was selected with a view to finding out the efficiency of the running memory of the subjects throughout the study period. The perceptual motor coordination test was selected to assess psychomotor function. Our aim was to sample these aspects of performance that have relevance for a variety of industrial workers.

The chosen dehydration levels are of an order normally faced by many industrial workers in work-schedules in tropical environments. The dehydration levels were forced with a combination of physical exercise and heat stress and remained similar on all days of the trials.

A consistent and steady decrease in the scores was seen in the subjects in all the three psychological tests at each level of dehydration. In addition the degree of impairment associated with dehydration was not the same for the three tests. In the symbol classification test the scores were not found to be significantly different in a variety of situations (table 3). At this stage one may be tempted to conclude that this test may not be sufficiently sensitive to reflect the changes. But the same test in an earlier study on differential effects of Hot Humid and Hot Dry environments on mental functions without primary dehydration was highly sensitive to the Humid versus Dry difference (Sharma *et al.* 1983). On the other hand, performance on the remaining two tests was found to have decreased significantly at 2% and higher dehydration levels. As the tests were administered after recovery from the effects of the heat and exercise used to force dehydration, it may be concluded that the dehydration *per se* of the order of 2% and above results in deterioration in mental functions with respect to memory and coordination. Because of the scarcity of similar studies we are not able to compare the results of the present study with others wherein the adverse effects on mental functions are observed as a result of dehydration *per se*.

In most of the studies dehydration and physiological strain are cumulative in effect and cannot strictly be considered to reflect primary dehydration. The only study pertaining to primary dehydration reported by Strydom *et al.* (1968) cannot be strictly compared with the present study as the level of dehydration of the subjects was of a very high order and was forced with a combination of water restriction and prolonged field exercise over two days. Furthermore, the studies by Buskirk *et al.* (1959), Joseph *et al.* (1976) and Sawka *et al.* (1983) often referred to in the literature do not mention anything about mental functions and in these studies, too, the level of dehydration was high (5%).

When dehydration was followed by similar levels (40 W) of exercise in the two conditions of Hot Humid and Hot Dry, there was no adverse effect on the classification test. Performance scores on the mental tasks decreased significantly at 2% dehydration and above (tables 4 and 5). Scores in the various psychological tests under Hot Dry and Hot Humid conditions were not significantly different except for the concentration test for which performance was poorer in the Hot Humid condition despite the fact that the WBGT levels were the same. This observation agrees with the earlier work of the authors (Sharma *et al.* 1983).

The changes in physiological variables (heart rate, oral temperature) as an indicator of physiological strain during exercise in Hot Dry and Hot Humid conditions were not found to be markedly different (table 6). However, an increasing level of dehydration had an increasing effect on both oral temperature and heart rate within the two treatments (Hot Dry and Hot Humid), and all measures under dehydration were higher than in the euhydration state. The values are also significantly different for any order of combination of dehydration. The increase in physiological strain and the concomitant impairment of mental functions of complex order has been reported by many workers including the present authors (Sharma *et al.* 1983, Sawka *et al.* 1983, Nadel *et al.*1980, Pandolf 1979, Claremont *et al.* 1976, Joseph *et al.* 1976, Wyndham 1973, Strydom *et al.* 1968, Sargent *et al.* 1964, Bursill 1958). The reduction in running memory scores under Hot Humid stress when it is superimposed on different levels of primary dehydration is difficult to interpret and is of interest since corresponding physiological variables did not differ significantly. More elucidation of this aspect is to be provided by subsequent studies.

In conclusion, it may be stated that a 2% as well as a 3% level of primary dehydration results in a significant reduction in mental efficiency.

Acknowledgments

The authors are grateful to Mr. R. K. Gautam, for technical assistance in the study and Mr. Ashok Kumar Ghadiok for statistical analysis of the data. Thanks are also due to Shri Omparkash for secretarial help.

L'effet d'une déshydratation primaire à divers niveaux (1%, 2% et 3% de déficit par poids corporel) sur des fonctions mentales de complexités diverses, a été étudié sur huit sujets acclimatés à la chaleur et originaires des régions tropicales de l'Inde. Ces sujets ont également été examinés après une période d'exercice á la chaleur, avec deux expositions, l'une chaude-sèche (45° globe sec, 30% d'H.R.) et l'autre chaude-humide (39°C globe sec et 60% d'H.R.) à 34°C WBGT. On n'a pas observé de modification significative dans le travail mental ordinaire, sous aucun des niveaux de déshydratation, per se, ou après l'exercice à la chaleur, en comparaison avec un condition neutre. Par ailleurs, à 2% et 3% de déshydratation primaire, on a observé des baisses significatives dans les fonctions mentales telles que la concentration et la coordination. Lorsqu'à la déshydration initiale on ajoute les facteurs de chaleur et d'exercice, on observe une détérioration accrue, quoique non significative, dans toutes les fonctions. Les interactions des conditions chaud-humide et chaud-sec n'étaient pas significatives, à part une baisse plus importante dans la composante de concentration pour les conditions chaud-humide.

Die Auswirkung von primärem Wasserentzug verschiedenen Grades (1%, 2% und 3% Gewichtsverlust) auf mentale Funktionen verschiedener Komplexität wurde an 8 hitzeakklimatisierten Personen untersucht, die aus tropischen Regionen Indiens kamen. Diese Personen wurden nach einer Arbeitsphase auch unter zwei Hitzebedingungen untersucht, nämlich trocken-heiß (45°C Trockentemperatur, 30% rel. Feuchte) und feucht-heiß (39°C, 60%) bei 34°C WBGT. Für geistige Routinearbeit wurden—verglichen mit dem Normalzustand—signifikante Änderungen weder für Wasserentzug alleine noch für darauffolgende Hitzearbeit gefunden. Andererseits wurden bei 2% und 3% primärem Wasserentzug signifikante Einbußen in mentalen Funktionen wie Konzentrations- und Koordinationsfähigkeit beobachtet. Wenn Hitze und Arbeit mit primären Wasserentzug überlagert wurden, ergab sich eine weitere, allerdings nicht signifikante, Verschlechterung aller Funktionen. Die Unterschiede zwischen den Bedingungen trocken-heiß und feucht-heiß waren nicht signifikant, außer daß die Abnahme der Konzentrationsfähigkeit unter feucht heißen Bedingungen stärker betont war.

複雑な精神機能に及ぼす一次的脱水（体重の1，2，及び3%）の影響をインドの熱帯地方で温熱環境に順応した8名の被験者を用いて調査を行った。また同じ被験者を用い，34°C WBGTで高温乾燥（45°C DB，30% RH）及び高温多湿（39°C DB，60% RH）の2条件下で一定時間の運動を行った後にも調査を行った。通常の精神作業成績は平常時に比べ，脱水時及び温熱条件下における運動後の両方において有意差は見られなかった。一方，脱水の2%及び3%レベルにおいては集中力と協応力といった精神機能に有意な低下が見られた。脱水の温熱条件と運動とが重なった時にはすべての機能において有意ではないが低下が見られた。高温多湿における集中力の顕著な減少を除き，2環境条件間の変動に有意差は見られなかった。

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Manuscript received 20 August 1984.
Final revision received and accepted 29 November 1985.

J. Human Ergol., **20**: 41–50, 1991
Center for Academic Publications Japan. Printed in Japan.

COMPARISON OF GRIP STRENGTH AND ISOMETRIC ENDURANCE BETWEEN THE RIGHT AND LEFT HANDS OF MEN AND THEIR RELATIONSHIP WITH AGE AND OTHER PHYSICAL PARAMETERS

Satipati CHATTERJEE and Bidyut Jyoti CHOWDHURI

Exercise and Cardiorespiratory Physiology Laboratory, Department of
Physiology (Calcutta University), University College of Science
and Technology, 92, Acharya Prafulla Chandra Road,
Calcutta 700009, India

Maximum handgrip strength and endurance of fatiguing isometric handgrip muscle contraction at 40% of maximum voluntary contraction of the dominant hand were assessed separately for both right and left hands of 99 right-handed men aged 7–73 years. Subjects below 10 years (n=6) could not follow up the endurance test methods and were excluded. The relationship of handgrip strength and endurance with age and other physical parameters was also assessed. Maximum grip strength and endurance of fatiguing submaximal contraction of the right hand were significantly greater than that of the left hand for most age groups. Grip strength was positively correlated with age from 7–19 years (r=0.94 for right and r=0.89 for left) and was negatively correlated with age from 20–73 years (r=−0.74 right and r=−0.69 left). Grip strength was positively correlated with the weight (r=0.86 right and r=0.87 left), height (r=0.88 right and r=0.87 left) and body surface area (r=0.9 for both) of the subjects. Endurance of contraction of both hands did not show any relationship with age, different physical parameters or grip strength of the subjects.

Isometric strength varies with the age, size and sex of the individual (FISHER and BIRREN, 1947; ASMUSSEN and HEEBÖLL-NIELSEN, 1955, 1956, 1962; ÅSTRAND and RODAHL, 1970). Studies showing no change of strength with aging in men is also available (PETROFSKY and LIND, 1975). Isometric exercise fatigues muscles rapidly whenever the contraction tension exceeds 10–15% of the muscle's maximal voluntary strength (MERTON, 1954; ROHMERT, 1960a, b; FUNDERBURK *et al.*, 1974).

Received for publication October 26, 1990.

It has been also reported that the endurance time is independent of the sex of the subjects (ROHMERT, 1968) and of previous dynamic training (HANSEN, 1967), as long as the subjects work at the same percentage of their own maximum strength.

The fact that age does not affect the capacity of muscle to sustain a contraction at a known fraction of maximum strength has been reported by MULLER (1961) and ROHMERT (1960a, b). PETROFSKY and LIND (1975) and PETROFSKY *et al.* (1975) reported that aging was associated with a significant rise in endurance in women but not in men. Although CALDWELL (1963, 1964) and START and GRAHAM (1964) suggested that no variation in the holding time among various levels of strength would occur between stronger and weaker individuals when the same relative weight load was used for each of them, TUTTLE *et al.* (1950) and CARLSON (1969) reported lower holding times in stronger individuals.

A comparison of grip strength and isometric endurance between the right and left hands of men is of interest. A survey of the literature indicates that there have been few studies of different age groups, particularly with regard to Indian subjects.

The present investigation has the following objectives:

1. To determine whether the difference in grip strength and isometric endurance between the right and left hands of right-handed men is significant.
2. To determine whether there is any relationship between maximum handgrip strength and endurance contraction with age and other physical parameters.

MATERIALS AND METHODS

Ninety-nine normal healthy male subjects of six different age groups participated in the present investigation. The lowest age group (7–9 years $n=6$) could not take part in the endurance test procedures, and its members participated only in the strength test experiment.

The subjects were sedentary. No individual was accepted as subject if he had a history of any cardiovascular or pulmonary disorder or displayed an irregular electrocardiogram or abnormal blood pressure in the pre-exercise resting state. The subjects who were unable to continue the whole series of the experiment were also excluded. All the subjects were requested to refrain from eating and in engaging in any strenuous physical work for at least 1 hr before the experiment. The purpose of the experiment was explained to them to stimulate the participants' interest and to encourage them to perform the various tasks to their utmost ability. After an initial half-hour rest, the subjects' physical characteristics, including age, height, weight and health-oriented case history, were noted. The body surface area (BSA—m^2) was estimated for each individual using the DuBois formula ($S=W^{0.425}H^{0.725}\times 0.007184$) for the weight in kilograms and height in centimeters.

Two maximal voluntary handgrip contractions (MVC) at an interval of 1 min and with a duration of less than 3 sec were performed by each subject at the start of each experiment. A simple handgrip dynamometer (INCO made in India) was utilized for the grip strength measurements. The sustained handgrip contraction involved as little shortening of the forearm flexor muscles as possible. Maximum strength was taken to be the stronger of the two contractions. The MVC was measured to the nearest 0.1 kg. During the test the subjects were in the sitting position with the upper arm dependent and the forearm held horizontally. The MVC of the left hand of the same individual was determined in the same way after resting at least half an hour. The dynamometer was standardized by another dynamometer (Clarke *et al.*, 1958) before and after the experiment. It was also standardized using the investigator's own known handgrip strength.

During the subsequent experimental phase each subject exerted a handgrip contraction on the dynamometer at a tension of 40% of the MVC of dominant hand (right) until he could no longer maintain the tension. The participants performed this static effort with their right hand on the first day and with their left hand at same tension the next time they visited the laboratory. Before and during the contraction the subjects were instructed about the importance of maintaining a steady tension and were continuously encouraged by one investigator to maintain the tension to the point of fatigue. A second observer constantly observed the subjects during the exercise and encouraged them to relax the muscles of all body parts other than the exercising forearm.

The subjects were examined in Calcutta from January, 1981 to January, 1983. The laboratory temperature was 28±1°C.

The statistical analysis primarily involved the calculation of means, standard deviations and regression lines. Comparisons were made using the F test and the unrelated t test as appropriate. The difference method was applied to determine the difference between the data achieved by the static efforts of the two hands each subject. The level indicating statistical significance was $p<0.05$.

RESULTS

The mean height, weight, body surface area (BSA), ages and grip strength of the 99 men who participated in the grip strength experiment are given in Table 1. Figure 1 shows the maximum handgrip strength of the right and left hands of the subjects.

The strength of the right handgrip was greater than that of the left hand. For age groups 7–9 years, 40–49 years and 50 and above, the difference between the two hand strengths was not statistically significant (Table 1). For the rest three age groups and for the subjects as a whole, however the difference was statistically significant.

Figure 2 shows the regression lines relating the handgrip strengths of both the

Table 1. Isometric handgrip strength of right hand and left hand of men of different age groups and their physical parameters.

Age groups	Age (yrs.) Mean±SD	Height (cm) Mean±SD	Weight (kg) Mean±SD	B. S. A. (m^2) Mean±SD	MVC of right hand (kg) Mean±SD	MVC of left hand (kg) Mean±SD	Mean of strength difference (kg)	Level of significance
10–19 years $n=41$	14.43±2.80	156.55±13.93	39.67±10.38	1.33±0.23	27.06±5.87	25.44±5.55	1.62	$p<0.001$
20–29 years $n=25$	24.56±2.32	168.38± 5.73	53.75± 6.70	1.60±0.01	34.94±2.51	33.42±2.68	1.56	$p<0.001$
30–39 years $n=8$	33.37±2.92	164.72± 5.42	51.31± 6.07	1.54±0.09	33.69±2.20	32.19±1.96	1.37	$p<0.05$
40–49 years $n=7$	44.57±1.98	163.11± 6.95	53.35± 6.75	1.50±0.10	31.36±3.31	30.36±2.78	1.00	NS
50 and above yrs. n=12	67.16±6.89	164.60± 8.72	51.20±11.19	1.54±0.18	28.58±3.12	27.46±3.12	1.12	NS
Total subjects $n=99$ including 6 members of age group 7–9 years	26.62+18	159.11+16.06	45.23+12.78	1.42+0.26	29.09+7.17	27.65+6.99	1.44	$p<0.001$

NS=not significant.

By difference method was applied to compare the difference between the strength of right hand and left hand of individual persons. The lower age group 7–9 years is too small ($n=6$) to support significancy in difference between the strength of the two hands and is excluded from determining the statistical significance separately.

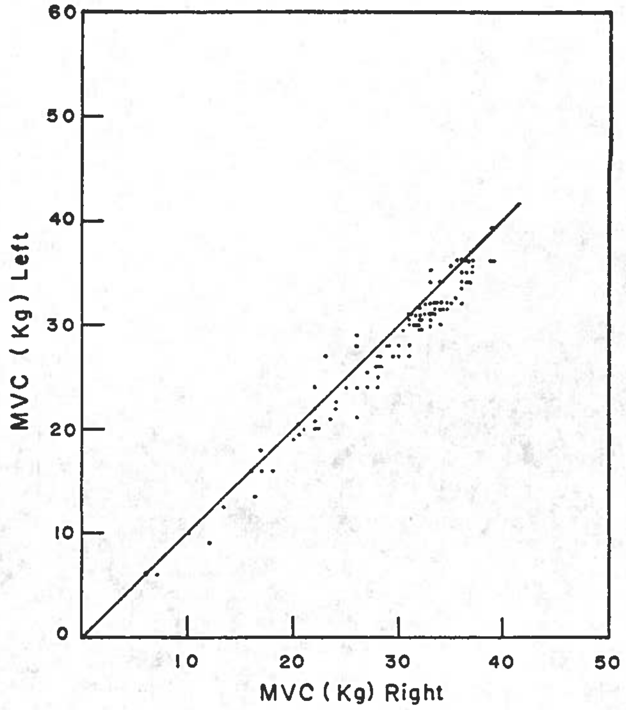

Fig. 1. Maximum handgrip strength of each of 99 men. It shows clearly that on the whole MVC (right) is somewhat greater than MVC (left) of same person.

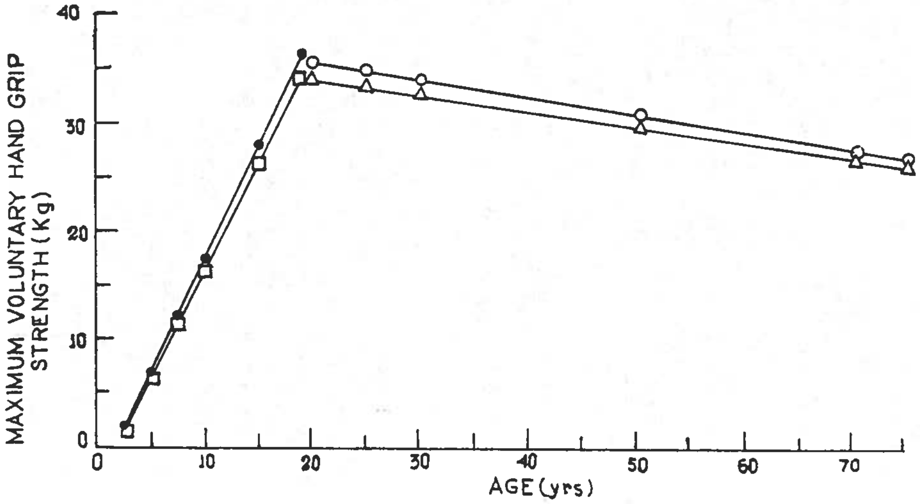

Fig. 2. Regression lines representing the relationship between grip strength of both hands and ages of 99 men. ●, MVC (right) below 20 yrs. ($y=-3.4373+2.0982x$); □, MVC (left) below 20 yrs. ($y=-3.5026+1.9892x$); ○, MVC (right) 20 yrs. and above ($y=38.8412-0.1572\,x$); △, MVC (left) 20 yrs. and above 20 *yrs.* and above ($y=36.9857-0.1442\,x$).

Table 2. Relationship of MVC with age, weight, height and body surface area of 99 men.

Relationship		Regression equations	r-values
MVC (right) with age	$(n=47)$	$y = -3.4373+2.0982x$ (below 20 years)	+0.94
	$(n=52)$	$y = 38.8912-0.1572x$ (20 years and above)	−0.74
MVC (left) with age	$(n=47)$	$y = -3.5026+1.9892x$ (below 20 years)	+0.89
	$(n=52)$	$y = 36.9857-0.1442x$ (20 years and above)	−0.69
MVC (right) with weight	$(n=99)$	$y = 7.249+0.483x$	+0.86
MVC (left) with weight	$(n=99)$	$y = 6.031+0.478x$	+0.87
MVC (right) with height	$(n=99)$	$y = -32.958+0.39x$	+0.88
MVC (left) with height	$(n=99)$	$y = 32.652+0.379x$	+0.87
MVC (right) with B. S. A.	$(n=99)$	$y = -4.976+23.891x$	+0.9
MVC (left) with B. S. A.	$(n=99)$	$y = -5.735+23.41x$	+0.9

Note: for all r-values $p < 0.001$.

Table 3. Endurance of isometric handgrip muscle contraction of right hand and left hand of 93 men at tension of 40% of MVC of dominant hand (right).

Age groups	Endurance (sec) of right hand Mean ± S D	Endurance (sec) of left hand Mean ± S D	Mean of differences in endurances (sec) of two hands	Level of significance
10–19 years $n=41$	162.8±38.2	148.8±29.3	13.9	$p<0.001$
20–29 years $n=25$	156.2±53.0	139.6±40.2	16.6	$p<0.01$
30–39 years $n=8$	164.1±42.2	154.5±46.4	9.6	$p<0.05$
40–49 years $n=7$	161.0±41.6	131.0±33.3	30.0	$p<0.001$
50 and above ages $n=12$	162.5±42.3	144.5±41.9	18.0	$p<0.001$
*All ages	161.0±42.9	144.9±35.8	16.0	$p<0.001$
*[Mean age 27.86±17.89				
Height (cm) 161.96±11.55				
Weight (kg) 46.97±11.07				
B. S. A. (m^2) 1.46± 0.21]				

By difference method is applied to signify the difference between the endurance of two hands of individual persons.

right and left hands to the age of the subjects. Strength was positively correlated with age up to the age of 19 years and was negatively correlated with age from 20–73 years.

Table 2 illustrates the regression lines relating maximum grip strength (right and left) to the age, weight, height and body surface area of the subjects. The

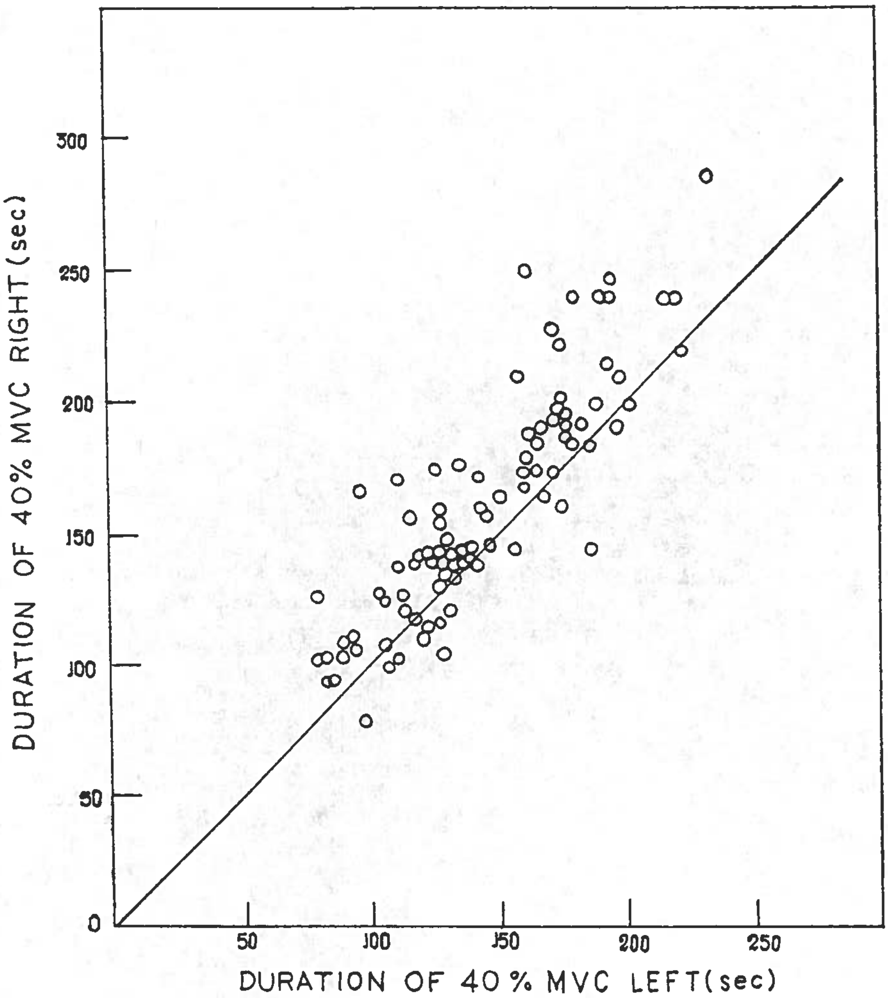

Fig. 3. Figure illustrating the individual duration of 40% MVC isometric contraction of the right and left hands of each of the 93 men.

MVC was positively correlated with the weight, height and body surface area of the subjects.

The mean endurance times of the both the right and left hand contractions at 40% of the MVC of the dominant hand (right) for 93 men belonging to five different age groups are illustrated in Table 3. There was no significant difference ($p>0.05$) in endurance for different age groups. Figure 3 represents the endurance of the right and left hands of 93 subjects. For all age groups and for the subjects as a whole the mean endurance time of the right hand contraction was significantly greater than that of the left hand contraction. For all subjects, the mean difference in the endurance of the contraction between the two hands of the individual subjects was 16 sec ($p<0.001$).

No relationship was found between the endurance of isometric contraction and the age, weight, height, body surface area or MVC of the individual subjects.

DISCUSSION

The earlier reports on the relationship between age and the maximum voluntary handgrip strength are almost unanimous that from about the age of 20 until 60 years there is a gradual decline in strength (ASMUSSEN and HEEBÖLL-NIELSEN, 1955, 1956, 1962). Our findings agree with those results. PETROFSKY and LIND (1975) reported no change in muscle strength with age in male homogenous subjects. Individual variations in MVC may be attributed to the wide differences in the mechanical advantage achieved by different hand sizes on the fixed dimension of the dynamometer. Progressive lack of training (RICHARDSON, 1953), reduced urinary excretion of testosterone (HETTINGER, 1961; SIMONSON, 1971), cell death in the brain and loss of nerve cell in the spinal cord (CRITCHLEY, 1942) and a reduction of total number of muscle fibres with aging (GUTMAN and HANZLEKOVA, 1972) could account for the reduction of muscle strength with age.

In the present study, the weight, height and body surface area of the subjects show a positive correlation with MVC. In this respect our findings agree with the findings of ASMUSSEN and HEEBÖLL-NIELSEN (1962).

In our findings the MVC values achieved by subject's right hand were significantly greater than those of the left hand. For age groups 7–9 years, 40–49 years and 50 and above, the above differences were not statistically significant. This is probably due to the small number of subjects in those groups. Because all our subjects were right handers, their right hand should be stronger than the left. The same idea also has been proposed by LIND and MCNICOL (1968). Greater utilization of the right hand in the performance of daily activities and the subsequent training effect has led to the dominance of the right hand muscles over the left hand in right-handed individuals.

The endurance of handgrip contractions in our investigation are in agreement with the results obtained by other authors (ROHMERT, 1960a, b; LIND *et al.*, 1964; BRUCE *et al.*, 1968; WILEY and LIND, 1971; FUNDERBURK *et al.*, 1974; PETROFSKY *et al.*, 1975). The balance of the evidence favors the theory that fatigue is metabolic in origin (MERTON, 1954; SIMONSON, 1971). The fact that age does not affect the capacity of muscles to sustain a contraction at a known fraction of maximum strength has been reported by MULLER (1961) and ROHMERT (1960a, b). Those findings are supported by the results of the present investigation. Reasons for the absence of any relationship between the endurance of handgrip contraction and different physical parameters and MVC should be the same as those discussed with regard to age effects.

In our findings, the endurance of right hands was greater than that of left hands. The dominance of right hand endurance over left hand endurance was statistically significant for all ages and for all age groups. As the absolute load was same for each arm, the muscles of the left arm would have to contract at a greater proportional tension in comparison with the dominant right hand. Thus the contraction at greater tension by the weaker arm caused the lower endurance during left-hand contraction in the right-handed subjects.

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Center for Academic Publications Japan. Printed in Japan.

EFFECT OF VIBRATING STEERING ON GRIP STRENGTH IN HEAVY VEHICLE DRIVERS

Satipati CHATTERJEE and Anupam BANDYOPADHYAY

Exercise, Sports and Cardiorespiratory Physiology Laboratory, Department of Physiology, University College of Science and Technology, 92, Acharya Prafulla Chandra Road, Calcutta 700009, India

The grip strength in both hands of thirty-two heavy vehicle drivers and twenty-two nondrivers ranging from 30 to 60 years of age was investigated. Blood pressure, heart rate and other physical parameters were also investigated. The subjects were drawn at random from the employees of the North Bengal State Transport Corporation and Civil Aviation. Heavy vehicle drivers perform their duties 8 hr per day with an average speed of 60–70 km per hour for 4–5 hr of continuous driving at a time. The only significant difference in the physical characteristics of heavy vehicle drivers and nondrivers was their body weight ($p<0.05$). The right and left wrist power of heavy vehicle drivers was respectively 6% and 3% higher than that of nondrivers. The mean blood pressure, heart rate and wrist width were found to be almost same in heavy vehicle drivers and nondrivers. From our studies we concluded that vibrating steering probably has no influence on the grip strength and that performing 8 hr of driving daily does not affect the blood pressure and heart rate in heavy vehicle drivers. However, further studies are needed to determine the influence of vibrating steering on grip strength.

The possible harmful effects of vibrating tools has been consistently reported over the past few years. KUROSAWA (1988) and SAMUELSON *et al.* (1989) are just two of the investigators who have made contributions in this area. From their investigations it can be concluded that vibrating tool affect grip strength and other physiological parameters. Samuelson *et al.* (1989) suggested that vibration may decrease the maximal sustained isometric muscular contraction. MUSSON *et al.* (1989) suggested that health damage due to occupational exposure to vibration is underestimated by the Dutch occupational health services. From their investigation they concluded that more investigation is needed to evaluate the

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Received for publication June 19, 1991.

precise nature of occupational exposure to vibration in order to provide a basis for its reduction or elimination.

In our country, vibrations occur in the steering of heavy vehicles when they are being driven. The vibrations occur in steering of the running vehicles at about 3 to 5 Hz, and the acceleration is 0.25 to 0.50 m/s^{-2} RMS. The present investigation was undertaken, therefore, to determine: i) whether prolonged driving has a significant effect on the grip strength of different age groups; ii) the effects of prolonged service on the grip strength of drivers; and iii) a comparative study of grip strength, blood pressure, heart rate and other physiological parameters between drivers and nondrivers.

MATERIALS AND METHODS

Thirty-two heavy vehicle drivers (HVD) and twenty-two nondrivers, varying in age from 30 to 60 years, were drawn at random from the employees of the North Bengal State Transport Corporation and the operational and ministerial staff of Civil Aviation. All the subjects were Bengali and their socioeconomic conditions were similar. The subjects were healthy and had no history of heart or lung disease. Heavy vehicle drivers performed their duties 8 hr per day at an average speed of 60–70 km per hour with 4–5 hr of continuous driving at a stretch. Nondrivers were engaged in clerical jobs.

Physical parameters like age, height, weight and BSA as well as cardiovascular parameters like resting heart rate, blood pressure while seated and the width of right and left wrist were measured using standard methods. A grip dynamometer was used to secure scores for the grip strength of each hand. The maximal voluntary strength for the handgrip contractions of both the right and the left hands of each subject were determined. Three maximal voluntary handgrip contractions at intervals of 1 min and a duration of less than 3 sec were performed by each subject at the start of each experiment. A simple handgrip dynamometer (INCO made in India) was utilized for the grip strength measurements. The sustained handgrip contractions involved as little shortening of the forearm flexor muscles as possible. The strongest of the three contractions was taken to be the maximum strength. Maximal voluntary contractions were measured to the nearest of 0.1 kg. Resting heart rate and blood pressure were measured after allowing the subjects 30 min of rest in a seated position. The wrist width of both hands was measured with an anthropometric callipers by keeping the subjects' hand straight on a plain surface.

The experiments were performed at a room temperature varying from 29–32°C with the relative humidity varying between 80–90%.

The statistical analyses used were the one-tail *t*-test, analysis of variance (ANOVA) and the correlation coefficient.

Table 1. Physical characteristics, heart rate, blood pressure, wrist width and grip strength of subjects studied in the various age groups of heavy vehicle drivers (HVD) and nondrivers (ND).

Parameters	Age group (Category)	30–60 years HVD = 32 ND = 22	30–40 years HVD = 8 ND = 9	41–50 years HVD = 18 ND = 6	51–60 years HVD = 6 ND = 7
Age (years)	HVD	45.16 ± 6.99	36.0 ± 4.75	46.06 ± 2.39	54.67 ± 2.66
	ND	44.0 ± 8.80	34.6 ± 3.53	46.67 ± 2.42	53.71 ± 1.38
	p	NS	NS	NS	NS
Height (cm)	HVD	163.66 ± 3.68	163.87 ± 5.72	163.72 ± 2.49	163.02 ± 4.22
	ND	164.03 ± 4.78	162.3 ± 5.27	167.53 ± 3.39	163.24 ± 3.96
	p	NS	NS	$p<0.01$	NS
Body weight (kg)	NVD	58.29 ± 6.50	55.6 ± 10.13	59.89 ± 4.56	57.17 ± 5.01
	ND	62.66 ± 8.72	60.67 ± 9.44	60.42 ± 6.65	67.14 ± 8.68
	p	$p<0.05$	NS	NS	$p<0.05$
Body surface area (m^2)	HVD	1.61 ± 0.09	1.57 ± 0.16	1.63 ± 0.06	1.59 ± 0.08
	ND	1.66 ± 0.11	1.62 ± 0.11	1.66 ± 0.09	1.70 ± 0.10
	p	NS	NS	NS	$p<0.05$
Normal heart rate (beats min^{-1})	HVD	78.00 ± 7.08	75.50 ± 6.82	79.67 ± 7.20	78.00 ± 7.04
	ND	77.00 ± 10.48	71.80 ± 8.63	78.00 ± 8.19	81.71 ± 12.72
	p	NS	NS	NS	NS
Systolic blood pressure (mm of Hg)	HVD	119.00 ± 15.72	112.20 ± 10.28	119.50 ± 17.67	124.67 ± 14.51
	ND	119.00 ± 17.95	116.89 ± 11.09	111.22 ± 12.18	128.28 ± 25.96
	p	NS	NS	NS	NS
Diastolic blood pressure (mm of Hg)	HVD	76.31 ± 8.24	73.25 ± 6.84	77.22 ± 8.87	77.67 ± 8.24
	ND	77.30 ± 16.46	80.00 ± 7.94	79.67 ± 5.85	84.57 ± 9.43
	p	NS	NS	NS	NS
Right wrist width (cm)	HVD	10.01 ± 0.47	9.90 ± 0.34	10.03 ± 0.47	10.10 ± 0.65
	ND	9.69 ± 0.70	9.58 ± 0.65	9.53 ± 0.68	10.00 ± 0.79
	p	NS	NS	$p<0.05$	NS
Left wrist width (cm)	HVD	9.91 ± 0.42	9.85 ± 0.41	9.96 ± 0.46	9.83 ± 0.34
	ND	9.68 ± 0.68	9.58 ± 0.65	9.50 ± 0.63	9.97 ± 0.79
	p	NS	NS	NS	NS
Right grip strength (Newton)	HVD	272.26 ± 59.96	304.41 ± 54.59	264.28 ± 47.18	253.98 ± 90.48
	ND	257.92 ± 53.52	264.60 ± 47.19	271.13 ± 46.24	238.00 ± 67.59
	p	NS	NS	NS	NS
Left grip strength (Newton)	HVD	264.91 ± 51.74	291.55 ± 49.14	264.05 ± 41.61	236.02 ± 69.19
	ND	255.69 ± 64.24	274.40 ± 65.33	260.52 ± 40.09	229.60 ± 78.57
	p	NS	NS	NS	NS
Duration of service (years)	HVD	16.62 ± 6.09	8.62 ± 4.69	18.50 ± 3.03	21.67 ± 4.76
	ND	20.91 ± 10.29	10.55 ± 6.44	24.42 ± 4.41	31.28 ± 1.49
	p	NS	NS	$p<0.01$	$p<0.001$

Values are mean ± standard deviation. *p* denotes level of significance. NS denotes mean difference is not significant.

Table 2. Correlation values of heavy vehicle drivers (HVD) and nondrivers (ND) in relation to grip strength with physical characteristics.

Parameters		Right grip strength (Newton)	Left grip strength (Newton)
Age (years)	HVD	−0.23 NS	−0.37 $p<0.05$
	ND	−0.17 NS	−0.31 NS
Height (cm)	HVD	0.31 NS	0.15 NS
	ND	0.32 NS	0.24 NS
Weight (kg)	HVD	0.41 $p<0.02$	0.22 NS
	ND	0.51 $p<0.01$	0.41 $p<0.02$
BSA (m^2)	HVD	0.11 $p<0.02$	0.21 NS
	ND	0.57 $p<0.001$	0.44 $p<0.02$
Right wrist width (cm)	HVD	0.15 NS	0.11 NS
	ND	0.18 NS	0.07 NS
Left wrist width (cm)	HVD	0.25 NS	0.18 NS
	ND	0.20 NS	0.11 NS
Duration of service (years)	HVD	−0.21 NS	−0.32 NS
	ND	−0.13 NS	−0.38 $p<0.02$

p denotes level of significance. NS denotes correlation is not significant.

RESULTS

The mean values, standard deviation and the level of significance (*p*) of physical characteristics, heart rate, blood pressure, wrist width and grip strength of heavy vehicle drivers and nondrivers are listed in Table 1. Only the body weight of the heavy vehicle drivers was significantly lower than that of nondrivers ($p<0.05$). The heavy vehicle drivers and nondrivers were grouped according to decades. Body weight and body surface area (BSA) of heavy vehicle drivers 51–60 years old was found to be significantly lower than that of nondrivers ($p<0.05$). Significant differences were also found in height, right wrist width and duration of service in the 41–50 year age group. The grip strength, blood pressure and heart rate of the two groups did not show any significant differences.

Table 2 shows the correlation values of grip strength in relation to physical characteristics and duration of service for heavy vehicle drivers and nondrivers.

Table 3. Analysis of variation of physical characteristics, heart rate, blood pressure, wrist width and grip strength of heavy vehicle drivers.

Parameters	Sources of variation	Sum of squares	Degrees of freedom	Mean square	F
Age (years)	Between	943.01	2	471.50	23.78**
	Within	575.21	29	19.83	
	Total	1,518.22	31		
Height (cm)	Between	7.38	2	3.69	0.259
	Within	413.62	29	14.26	NS
	Total	421.00	31		
Weight (kg)	Between	69.59	2	34.79	0.813
	Within	1,241.34	29	42.80	NS
	Total	1,310.93	31		
BSA (m^2)	Between	0.01	2	0.005	0.555
	Within	0.27	29	0.009	NS
	Total	0.28	31		
Heart rate (beats min^{-1})	Between	890.10	2	445.05	19.47**
	Within	662.77	29	22.85	
	Total	1,552.87	31		
Systolic B. P.	Between	854.34	2	427.17	1.82
	Within	6,806.53	29	234.71	NS
	Total	7,660.87	31		
Diastolic B. P.	Between	94.41	2	47.20	0.681
	Within	2,010.47	29	69.33	NS
	Total	2,104.87	31		
Right wrist width (cm)	Between	0.31	2	0.15	0.704
	Within	6.52	29	0.22	NS
	Total	6.83	31		
Left wrist width (ɯɔ)	Between	0.12	2	0.06	0.333
	Within	5.39	29	0.18	NS
	Total	5.51	31		
Right grip strength (Newton)	Between	15,309.57	2	7,654.78	2.319
	Within	95,705.93	29	3,300.20	NS
	Total	111,015.50			
Left grip strength (Newton)	Between	13,753.82	2	6,876.91	2.90
	Within	68,684.56	29	2,368.43	NS
	Total	82,438.38	31		

Heavy vehicle drivers are categorized into three groups according to their duration of service; 1–10 years ($n=6$), 11–20 years ($n=20$) and 21–30 years ($n=6$). ** $p<0.01$. NS= not significant.

Nearly negative insignificant correlations of age with right and left grip strength were obtained. The height, weight and BSA of heavy vehicle drivers and non-drivers are positively correlated with the grip strength of both the right and left hands. The correlation values of weight and BSA with hand grip strength were almost statistically significant, but height did not have a significant relationship with handgrip strength. Duration of service shows a negative correlation with the grip strength of both the right and left hands, although the correlations were statistically insignificant. Positive insignificant correlations of right and left wrist width with right and left grip strength were obtained for both heavy vehicle drivers and nondrivers.

Table 3 shows the analysis of variance (ANOVA) of physical characteristics, heart rate, blood pressure, wrist width and grip strength for heavy vehicle drivers. Heavy vehicle drivers were categorized into three groups according to their duration of service, *i.e.*, 1–10 years ($n=6$), 11–20 years ($n=20$) and 21–30 years ($n=6$) of service. Age and heart rate were statistically significant ($p<0.01$). All other parameters were found to be statistically insignificant.

DISCUSSION

The present study is based on two groups of people who, except their jobs, are very similar. The general physical characteristics and environmental factors are comparable.

The difference in body weight between heavy vehicle drivers and nondrivers of 30–60 years age was readily apparent. But when the subjects of both categories were grouped by age decades, the difference persisted only in the oldest age group, *i.e.*, 51–60 years. In other age groups the body weight of nondrivers was higher than that of heavy vehicle drivers, though the differences were not statistically significant. It is presumed that the difference in body weight between heavy vehicle drivers and nondrivers aged 30–60 was significant mainly because of the weight difference in the older age group (51–60 years). It may be due to the higher weight of the older age group. Moreover, nondrivers were engaged in clerical jobs, and almost all of them were sedentary people. Therefore, their body weight was higher than the heavy vehicle drivers.

Earlier reports on the relationship between age and maximal handgrip strength are almost unanimous that there is a gradual decline in strength from the age of 20 years up to the age of 60 years (Asmussen and Heeböll, 1955, 1956, 1962). Our findings agree with these findings, except for the 41–50 year age group of nondrivers, though that discrepancy is statistically insignificant. In both sexes the rate of decline in the strength of the leg and trunk muscles with age is greater than the strength of the arm muscles (Åstrand and Rodahl, 1970). Petrofsky and Lind (1975) reported on changes in handgrip strength with age. It seems reasonable to attribute the above findings to the homogeneity of their subjects, although standardization of procedures and methods might also play a part. Arguments about cell death in the brain and loss of nerve cells in the spinal cord (Critchley, 1942) and a reduction of total number of muscle fibers with aging (Gutman and Hanzlekova, 1972) could account for the reduction of muscle strength with age. But other factors can modify the functional properties of muscle. It has been shown that continued physical activity may temporarily arrest the decline of muscle strength (ÅSTRAND and RODAHL, 1970). In our studies, the weight, height and BSA of the subjects show a positive correlation with the maximal grip strength of both the right and left hands. In this respect our findings agree with the findings of ASMUSSEN *et al.* (1962).

In order to investigate how vibration affects endurance during muscular contraction, knee joint extension efforts were performed by SAMUELSON *et al.* (1989). A vibration with a frequency of 20 Hz and an acceleration of 20 m/s^{-2} RMS was applied in the horizontal sagittal direction to the ankle. They concluded from their investigations that vibration tools might decrease the maximal isometric muscular contraction. In our investigations the frequency of the vibration was 3 to 5 Hz and the acceleration was 0.25 to 0.50 m/s^{-2} RMS, which were much lower than those used in the investigations of SAMUELSON *et al.* (1989). The experimental designs were also different. Therefore, our investigations did not corroborate the findings of SAMUELSON *et al.* (1989). From our investigations we have concluded that vibrating steering (frequency 3 to 5 Hz and acceleration 0.25 to 0.50 m/s^{-2} RMS) did not produce any significant change in the grip strength of either hand of heavy vehicle drivers. Moreover, the probable reason for the slightly higher grip strength of heavy vehicle drivers when compared to non-drivers (6% and 3% right and left hands respectively) agrees with the findings of ÅSTRAND and RODAHL (1970).

In the present investigations, we categorized heavy vehicle drivers into three groups according to the duration of service, because we tried to find out the effect of prolonged driving on grip strength and other physiological parameters. No significant differences in grip strength were found among the three groups.

From the present investigations we conclude that the vibration of steering may have no influence on grip strength and performing 8 hr of driving daily did not affect blood pressure and heart rate of our heavy vehicle drivers. However, longitudinal prospective studies are needed to determine the influence of vibrating steering on grip strength.

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J. Human Ergol., **20**: 85–88, 1991
Center for Academic Publications Japan. Printed in Japan.

Communications

Gait Patterns of Young Japanese Women

Haruhiko Sato, Hideki Sako, Hideyuki Mukae,
Akira Sato, and Tetsuro Takahashi

Department of Ergonomics, Kyushu Institute of Design,
Shiobaru, Minami-ku, Fukuoka 815, Japan

Gait patterns of 440 young Japanese women walking along a sidewalk were observed in September. Walking speed, step length and cadence were significantly greater in single walking than in group walking. Time of day, walking direction and clothes did not influence the walking patterns. Step length in heeled shoes was shorter than that in sneakers and flat shoes.

There have been very few studies on natural walking (reviewed by Yamasaki and Sato, 1990). In the previous paper (Sato and Ishizu, 1990), gait patterns of Japanese pedestrians were investigated in December, taking such variables as sex, age, accompanist, time of day and footwear into account. In the present study, walking patterns of young Japanese women were observed in September, and walking speed, step length and cadence were analyzed considering whether the subject was accompanied, time of day, direction of walking, footwear and clothes. In addition, the September and December gait patterns were compared.

METHODS

The location and the technique of the investigation were the same as those in the previous study (Sato and Ishizu, 1990). In brief, pedestrians walking along a flat, straight sidewalk in a residential area of Fukuoka-city were recorded by means of video recorder for 9 hr on clear days during September 25–29, 1989. From the measurements of the number of steps and the time required to traverse 50 m as recorded on the videotape, walking speed, step length and cadence were calculated for 440 young women (19–24 years of estimated age), most of whom were the students of a women's junior college in the neighborhood. The time of

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Received for publication August 15, 1990.

J. Human Ergol., **21**: 99–103, 1992
Center for Academic Publications Japan. Printed in Japan.

Communications

Perceived Workload and Performance of Shift Workers

Azizur RAHMAN and Shamsul HAQUE

Department of Psychology, University of Dhaka, Dhaka-1000, Bangladesh

The present paper is based on the results of a study conducted to investigate whether the relationship between perceived workload and quality of performance, if any, holds true if controlled for shift system, type of task, age, and skill level of the workers. The sample of the study comprised 279 blue-collar workers of a jute industry operating under fixed three-shift system. The subjects were all males selected by random sampling method. The method of data collection was a field study through questionnaire. The collected data were analyzed by employing zero-order and partial correlation coefficients. The results indicate that workload and performance were negatively correlated but the strength of the relationship reduced substantially when the effects of the control variables were partialled out simultaneously. It was concluded that the control variables had joint effect on the relationship between workload and performance but skill level of the employees appeared to be the variable having the greatest contaminating effect.

Various studies and reviews conducted so far have demonstrated that shift workers experience more physical, psychological, and social problems than normal day workers (MOTT *et al.*, 1965; MAURICE, 1975; CARPENTIER and CAZAMIAN, 1977; TASTO *et al.*, 1978; GORDON *et al.*, 1981; KUMASHIRO *et al.*, 1982; SMITH *et al.*, 1982). Efficiency and production of the shift workers have been shown to be dependent on the shift system, nature of work, characteristics of the employees, and the interaction of the three types of elements (FOLKARD and MONK, 1979). However, though there have been studies on the productivity of the employees, very few studies have been conducted on the perceived workload of the shift workers. And, especially in Bangladesh, there seems to be no previous effort towards ascertaining the determinants of perceived workload and performance of the shift workers. Such a study might have been helpful in proper redesigning of the work

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Received for publication September 4, 1991.

and working methods leading to better quality and quantity of output.

The present study, therefore, aims to investigate whether the relationship between perceived workload and quality of performance if any, holds true if controlled for shift system, type of task, age, and skill level of the workers.

METHODS

Sample. The sample of the study comprised 279 blue-collar workers of a jute industry operating under fixed three-shift system. But the scheduling of the three shifts was somewhat unusual. Everyday, 'A-shift' was running from 06:00–10:00 hours and again, from 14:00–18:00 hours; 'B-shift' was running from 10:00–14:00 hours and again, from 18:00–22:00 hours; while the 'C-shift' operated from 22:00–06:00 hours. The subjects were all males selected by random sampling method. Of the selected sample, 127 were working in A-shift, 43 in B-shift, and 109 were working in C-shift. Again, 108 of the sample were skilled, 82 semi-skilled, and 89 were unskilled workers. According to type of task performed, 97 of the sample were engaged in finishing (requiring visual and mental concentration, *e.g.* sewing jute bags), 36 in weaving (requiring high mental concentration, *e.g.* weaving of cloths), and 146 were engaged in batching (mainly manual labor, *e.g.* bearing raw-jute and rolling thread).

Of the total sample, 76.7% were married and 23.3% unmarried. Educational level of the subjects ranged from illiterate to higher secondary (12th class). Of them, 37.7% were illiterate, 22.6% read up to class V, 31.5% read up to class X, and 8.2% passed S-S.C. or H.S.C. examination. Age of the respondents ranged from 15–60 years, with a mean of 31.45 years. Their experience in the present job ranged from 1–26 years, with a mean of 11.10 years. Monthly income of the respondents ranged from Tk.400/- to Tk.3,000/- with a mean of Tk.1,386.90. Their family size ranged from 1–13, with about 6 members on the average.

Tools used. In order to measure workload, the RPE (ratings of perceived exertion) scale developed by BORG (1962) was used. The scale consists of numbers from 6 to 20 printed in a quarto format with descriptive phrases appearing with each odd number, ranging from 'very very light' at 7 to 'very very hard' at 19. The values of the scale were chosen to be as close as possible to one-tenth of the corresponding heart rate. The RPE scale has been reported to be reliable and valid due to the fact that individuals are capable of adequately reproducing ratings and, RPE strongly correlates with heart rate during work (BORG, 1962; SKINNER *et al.* 1973; STAMFORD, 1976).

For assessing quality of performance, supervisory ratings of performance were collected by using a checklist (prepared after BLUM and NAYLOR, 1968).

Design. This was a field study through questionnaire using the scale and checklist mentioned above. However, in the questionnaire, there were provisions to record some relevant sociodemographic information.

RESULTS AND DISCUSSION

The collected data were processed through computer using the SPSSX program. And, to address the problem under consideration, both zero-order and partial correlation coefficients were computed (Tables 1 and 2 respectively).

An inspection of the figures in Table 1 reveals that there is a significant negative correlation between perceived workload and quality of performance ($r = -0.13$). However, performance also covaries with age and skill level of the respondents ($r = 0.30$ and 0.63 respectively). These latter relationships are, no doubt, stronger than the relationship between workload and performance. Similarly, perceived workload correlates with shift system ($r = -0.16$) which, in turn, correlates with type of task and age of the respondents ($r = -0.66$ and 0.19 respectively). Now the question is, whether perceived workload will have any effect on performance if the effects of age, skill level, shift system, and type of task are removed.

To answer the above question, five partial-correlation coefficients (four first-order partials and one fourth-order partial) were computed. As may be observed from Table 2, the strength of the relationship between workload and performance remained the same when controlled for type of task (partial $r = -0.13$). That means, the effect of workload on performance was independent of type of task.

Table 1. Zero-order correlation matrix.

Variables	Performance	Type of task	Age	Skill level	Shift system
Type of task	0.09				
Age	0.30*	−0.16*			
Skill level	0.63*	0.07	0.35*		
Shift system	0.07	−0.66*	0.19*	0.02	
Workload	−0.13*	0.02	−0.09	−0.09	−0.16*

* $p < 0.03$ (for $df = 277$).

Table 2. Partial correlation between workload and performance when controlled for some selected variables.

Variables controlled	Partial r	df
Type of task	−0.13*	276
Shift system	−0.12	276
Age of the respondents	−0.11	276
Skill level	−0.09	276
Simultaneously controlled for type of task, shift system, age, and skill level of the respondents	−0.06	273

* $p < 0.03$.

Table 3. Mean workload and performance scores according to skill level.

Skill level	$\bar{X}$ workload	$\bar{X}$ performance
Unskilled (89)	14.63	3.19
Semi-skilled (82)	15.51	4.30
Skilled (108)	14.01	8.98

Nevertheless, with the computation of the other three first-order partials, the strength of the relationship between workload and performance reduced somewhat (partial $r=-0.12$, -0.11, -0.09 respectively for controlling shift system, age, and skill level), the reduction being highest for controlling the effect of skill level. On the other hand, when the effects of all four controll variables were simultaneously partialled out, the strength of the relationship between perceived workload and quality of performance reduced drastically (partial $r=-0.06$). This fact implies that type of task, shift system, age, and skill level of the respondents independently did not have much effect on the relationship between workload and performance but the said control variables jointly acted to contaminate the relationship between the latter two variables. These findings, therefore, were in line with the findings of FOLKARD and MONK (1979).

It needs to be mentioned, however, that of all the four control variables, skill level of the employees had the greatest contaminating effect on the relationship between workload and performance. So, an attempt was made to have a bird's-eye view of the distribution of workload and performance scores according to skill level (Table 3).

It appears from the figures in Table 3 that perceived workload was highest for the semi-skilled workers and lowest for the skilled workers. On the other hand, performance quality was highest for the skilled workers and lowest for the unskilled workers. This fact indicates that by improving the skill level of the employees, feeling of workload can be minimized and performance increased.

In conclusion, the variables of type of task, shift system, age and skill level of the respondents seem to have joint effect on the relationship between workload and performance but skill level of the employees is the variable having the greatest contaminating effect. The findings, however, need to be reaffirmed by further studies in this direction.

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