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WORK ORGANIZATION OF HEAVY LOAD HANDLING IN INDIA

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The physical work rate, the energy and the cardiac costs of twenty-seven young male workers from the eastern part of India in five groups handling loads of about 30, 60, 75, 90, and 125 kg, respectively, were ascertained with the objective to rationalize the rate of work based on the physiological responses of the workers. The mean rate of usual work of the groups (I to V) was 4,715, 8,020, 7,350, 6,100, and 7,660 kg·m/min, respectively, which was considered to be extremely heavy. From the mean values of all the groups for the average work pulse rate of 143.1 beats/min, the recovery-pulse-sum of 119 beats for the first five minutes of recovery, the first and third minute recovery pulses of 127 and 114, respectively, the oxygen-pulse of 0.25 ml/pulse/kg, and the energy cost of 9.1 kcal/min, it was suggested that excepting the first group, the workers were working at a level much higher than the 50% level of their maximal working capacity. The simple and multiple linear correlation coefficients between the rate of work and the various physiological parameters were significant and different linear regression equations were suggested. In conclusion, for extremely heavy types of work in India, 1,200 kcal as the net optimal energy output in an 8-hr working day is suggested.

Studies on the energy cost during load handling have been carried out extensively in various countries (GIVONI and GOLDMAN, 1971; GLASOW and MÜLLER, 1951; GOLDMAN and IAMPIETRO, 1962; HUGHES and GOLDMAN, 1970; LEHMANN, 1958; LIND and MCNICOL, 1968; MÜLLER, 1964; ROHMERT, 1961; SOULE and GOLDMAN, 1969) and a few studies have also been reported in India (BANERJEE *et al.*, 1959; DATTA *et al.*, 1973, 1974; DATTA and RAMANATHAN, 1971; SEN and SARKAR, 1969, 1973; SEN and NAG, 1974; SEN *et al.*, 1974). On the basis of the results obtained in the above-mentioned studies, values of optimal load which the workers can handle without undue physical exertion during an 8-hr working day were suggested. However, there is a paucity of data on the energy costs of handling very heavy loads repeatedly, in different modes and speeds

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throughout the whole working day by different types of workers.

The present study was designed to ascertain the physical work rates, the energy and cardiac costs of five different types of load handling in local laborers, and to rationalize the work rates on the basis of the physiological responses observed, so that the workers can maintain productivity efficiently during their functional life.

METHODS

Workers and modes of load handling. A total of twenty-seven young male workers without apparent disease but of poor economic status, experienced in regular handling of loads for at least the last five years, were selected from the eastern part of India and divided in five different groups for participation in this study. A description of their modes of handling loads is as follows (Fig. 1).

Fig. 1. Mode of handling loads by different groups of workers.

Group I. A cane basket containing clay weighing about 30 kg was carried on the head for approximately half a minute each time and transferred by relay to another worker and both of them returned the empty basket by relay. The mean total daily working time was about 8 hr 45 min.

Group II. Eight bricks, weighing about 30 kg, stacked and attached on each side of a bamboo yoke, total weight being about 60 kg, were carried for approximately 0.7 min each time. The bricks were then removed and stacked in rows and the worker then returned to the workplace without a load. The mean value of total daily working hours was about 7 hr 40 min.

Group III. Porters carrying about 75 kg food-grains bags or other materials

divided equally on either side of a bamboo yoke walked from one place to the other for 35 min at a stretch and after taking rest for about 40 min, carried a similar load back to the starting place. The whole cycle was repeated once more in the whole working day. Before they began their usual work, they normally performed some sitting work, such as cutting and plucking vegetables and others from the field for about two hours at a stretch. The mean total daily working time was about 6 hr 35 min.

Group IV. A bamboo basket (*jhanka*) containing about 80 to 100 kg of vegetables was carried on the head for about 12 min each time from a railway station to the nearest market. Usually the workers carried this type of load 10 to 12 times in a working day. The mean of total daily working hours was about 7 hr.

Group V. About 100 to 130 kg vegetables were carried on the head for approximately 12 to 13 min each time in a manner similar to Group IV. These workers were accustomed to carry this type of load 10 to 12 times in a working day. The mean total daily working time was about 7 hr.

Experimental conditions. The observations on the different groups of workers were made during the first to second working hour in the morning from 8.00 to 12.00. Each worker sat quietly for at least 10 to 15 min before resting measurements were noted.

The thermal measurements at the different work locations during different working periods of the day were recorded and from these average values different heat stress indices were evaluated by using suitable nomograms.

During rest, work in a 'steady state' conditions, and recovery, pulse rates were recorded by a stop-watch for 10 to 30 beats, depending on the subject, at intervals of 1 to 2 min. The work-pulse-sum, the average work pulse rate, and the recovery-pulse-sum were obtained from the total number of heart beats during the corresponding time. The cardiac cost of work was calculated by dividing the work rates in kg·m/min by the total number of additional work pulses per minute above the resting value.

Pulmonary ventilation during work and, in some cases during rest, was determined with the help of a KM Respirometer, the expired air samples being collected in a rubber bladder for 4 to 5 min; the expired air was transferred immediately into a modified Bailey's gas sample bottle from the bladder and stored over mercury under pressure. Expired air was analysed, in duplicate, in a Scholander's micro-gas-analyser and the energy cost of the work in kcal was computed from the oxygen consumption value in liters, multiplied by 5.

From the time record (BANERJEE *et al.*, 1959) of the different activities of these workers, the work-day energy expenditure was calculated using the following mean values (SEN *et al.*, 1964b) in kcal/hr/kg: sitting resting, 1.1; standing resting, 1.4; standing working, 1.85; and walking on level, 3.5.

RESULTS AND DISCUSSION

The different characteristics including body height, body weight, age, load handled, and economic status of the workers are given in Table 1. The heat stress indices of the environmental conditions are given in Table 2. The mean rates of usual work of the Groups I to V were 4,715, 8,020, 7,350, 6,100, and 7,660 kg·m/min, respectively, which are considered to be extremely heavy. The workers' speed of walking was self-paced and all had the usual monetary incentive for carrying as much load and as many times as possible without any harmful physical effects. The mean usual walking rate of the groups varied from 46.4 to 76.0 meters per minute and, in these five groups of workers, there were three different types of

Table 1. Mean values plus or minus standard error of physical and other characteristics of the groups of workers handling heavy load.

Characteristics	Group I	Group II	Group III	Group IV	Group V
Number of workers	5	9	2	7	4
Mode of carrying	Head	Yoke	Yoke	Head	Head
Age (years)	24.4	30.3	22.5	27.4	28.2
Body height (cm)	164.6	154.7	165.8	159.5	167.7
	±1.9	±2.9	±1.1	±1.6	±2.0
Body weight (kg)	49.9	45.2	40.3	48.8	46.9
	±2.5	±1.2	±1.3	±2.5	±2.1
Ponderal Index	45.1	43.5	48.5	43.8	46.5
	±0.4	±2.1	±0.1	±1.3	±1.1
Load Handled (kg)	30.2	61.3	75.0	92.1	125.0
	±1.4	±1.1		±8.6	±4.1
Rate of walk (m/min)	58.9	76.0	63.8	46.4	46.7
	±11.6	±16.0	±6.6	±5.3	±6.1
Rate of work (kg·m/min)	4715	8020	7350	6100	7660
	±510	±636	±675	±274	±645
Total work done (10^6 kg·m/day)	1.62	1.20	1.03	1.36	1.67
	±0.15	±0.10	±0.09	±0.07	±0.13
Money earned for the work (rupees/day)	3.0	5.0	5.0	9.0	12.0

Table 2. Average heat stress indices of the working environment of the groups of workers.

Group	Effective Temperature (Basic)	Corrected Effective Temperature (Basic)	Wet-Bulb-Globe-Temperature Index	Predicted 4-hr Sweat Rate	Belding-Hatch Index
	(°C)	(°C)	(°C)	(l)	
Group I	28.7	31.0	30.8	3.37	190
Group II	30.8	31.8	32.5	6.69	200
Group III	28.5	31.2	31.0	5.45	200
Group IV	26.9	28.8	28.4	2.86	140
Group V	27.0	28.7	28.0	3.89	195

work; short period, prolonged, and intermediate period of loads carrying. In the mode of carrying by yoke, the walking speed was little faster when compared to other groups. It was observed that the high rate of work (force multiplied by the speed) in cases of Groups I, II, and III was due mostly to the walking speed and partly to the force required, whereas in the other two groups, the high rate of work was mostly due to the force and partly due to the walking speed. When the whole day's work was taken into consideration, it was found that Group V had the maximum (1.67×10^6 kg·m) and Group III the minimum (1.03×10^6 kg·m) total work done.

The mean values of the average work-pulse-rate, the peak work-pulse-rate, the first minute recovery pulses, the third minute recovery pulses, the recovery-pulse-sum, the oxygen-pulse per kg body weight, the energy cost of the usual work (kcal/min/50 kg body weight), and the corresponding cardiac cost of work (kg·m/pulse) of these five groups are shown in Table 3. It was observed that when extremely heavy work was performed, the working pulse rate differed in a characteristic manner in the different groups.

Table 3. Mean values plus or minus standard errors of the physiological responses of different groups of workers during their usual work.

Group (Mode of work)	Rest pulses (beats /min)	Average work-pulse-rate (beats /min)	Peak work-pulse-rate (beats /min)	Recovery-pulse-sum (beats)	First minute recovery pulses (beats)	Third minute recovery pulses (beats)	Energy cost (kcal /min /50kg)	O_2-pulse per kg (ml /pulse /kg)	Cardiac cost (kg·m /pulse)
				From average recovery curve					
Group I	96.2	127.6	137.8	38	116	104	6.2	0.19	156.1
(Head)	±1.7	±3.6	±2.9				±0.33	±0.01	
Group II	87.5	152.4	169.8	153	127	115	7.7	0.19	121.7
(Yoke)	±2.0	±1.9	±1.9				±0.49	±0.03	
Group III	92.5	143.0	154.5	151	128	117	10.1	0.28	121.6
(Yoke)	±0.0	±0.0	±6.4				±0.34	±0.00	
Group IV	87.0	141.4	155.7	125	130	117	8.4	0.24	100.5
(Head)	±3.6	±3.2	±4.5				±0.84	±0.06	
Group V	89.8	151.0	170.5	129	133	119	12.9	0.34	115.0
(Head)	±8.1	±3.3	±8.0				±0.82	±0.05	

The average working pulse rate of these groups varied from 127 to 154 per minute. These values were presumably beyond the reasonable upper limit of 120 to 130 for an 8-hr working day, as suggested by ÅSTRAND (1960). Of course, for older individuals, she emphasized that a pulse rate of 100 to 110 may represent the maximum allowable cardiac load for an 8-hr working day. If a pulse rate of 130 per minute is taken as a level corresponding to about 50% of the maximal work capacity (ÅSTRAND and RYHMING, 1954; BRODY, 1968; CHRISTENSEN, 1962), excepting the first group of workers whose average work-pulse-rate was 127.6, all the other groups were working at a level much higher than such a level. For the present types of jobs with intermittent work and high peak loads, very commonly observed in industrial situations, it is suggested that 50% of the individual's aerobic capacity should not be exceeded (ÅSTRAND and RHYMING, 1954). The average recovery-pulse-sum of the groups, 5 min after cessation of work, ranged from 39 to 153 beats, which shows that apart from the Group I workers, all the others were beyond the permissible endurance limit (MÜLLER, 1964). For more rational organization of the work load, it has been suggested by MÜLLER (1964) that when it is not possible "to bring every work period within the endurance limit, an attempt should be made to maintain the endurance limit of the individual work period at a low level by as many interruptions as possible." The first minute recovery pulses of 116 to 133 beats in these groups were beyond 110, which was above the safety limit of BROUHA (1960), and the difference in the first and the third minute recovery of the pulses obtained from the average continuous recovery pulse rate curves of the five different groups also showed that such stress might not be sustained throughout the shift in a physiological steady state (BROUHA, 1960; BROUHA and MAXFIELD, 1962). While BROUHA (1960) considered the recovery pulses mainly at normal temperature conditions, the recovery curves of the present study indicate that they were produced by the combined effect of the work and the thermal stress. The oxygen-pulse per kg body weight of these workers varied from 0.19 to 0.34 ml. Comparing the values with those of the other studies (0.10 to 0.18 ml/pulse/kg) on Indian industrial workers by SEN *et al.* (1964a; 1964b), the workers used in the present study had a better work capacity. The oxygen-pulse as an indicator of one's oxygen transporting capacity of these five groups of workers is comparable to values obtained by HAMLEY and SEN (1968) from British skilled athletes, indicating that the workers' work capacity was probably above the average (BRODY, 1968).

The simple and multiple linear correlation coefficients between the rate of work (kg·m/min) and the various physiological responses and also between the different physiological and the heat stress indices were obtained in a stepwise manner and some of the corresponding linear regression equations evolved by the least squares method are given in Table 4. In these very heavy types of work, the pulse rate increased in a linear fashion with the rate of work (r=0.604), and the multiple linear correlation coefficient between the rate of work and the average working pulse rate and the energy expenditure was highly significant (r=0.611).

This study was conducted during the period from the end of January to the end of March, excluding the cold winter and hot summer months. The values of the heat stress indices were: Corrected Effective Temperature (Basic) 28.7 to 31.8°C; Wet-Bulb-Globe Temperature 28.0 to 32.5°C; and Predicted 4-hr Sweat Rate 2.86 to 6.69 l. Group IV had the minimum and Group II showed the maximum heat stress indices. This probably suggests that the variations of the physiological load on the workers were due to the combined effects of the heat and the work

Table 4. Different regression equations to predict the rate of work, the energy cost, and the cardiac cost.

Equations	Simple or multiple correlation coefficients
A. Rate of work: W (kg·m/min)	
$W = 26.2S + 3648.3$	0.727
$W = 96.2P_{AW} - 7054.0$	0.604
$W = 69.7E + 91.5P_{AW} - 6962.8$	0.611
$W = 488.1A + 91.3P_{AW} - 7107.8$	0.615
$W = 70.2E + 77.6P_{AW} + 11.0P_{PW} - 6726.4$	0.612
$W = 485.4A + 79.4P_{AW} + 9.5P_{PW} - 6833.7$	0.616
B. Energy cost: E (kcal/min/50 kg)	
$E = 0.3P_{FR} - 31.66$	0.647
$E = 0.03S + 5.66$	0.419
C. Cardiac cost: C (kg·m/pulse)	
$C = 160.96 - 4.2E$	−0.421

A, oxygen consumption (l/min); E, energy cost (kcal/min/50 kg); S, recovery-pulse sum (beats/5 min); P_{AW}, average work-pulse-rate; P_{PW}, peak work-pulse-rate; P_{FR}, first minute recovery pulses.

loads. As no air-conditioned room was available in the field, it was not possible to find out the physiological responses due to the work and the heat stresses separately.

The comparative values of CHRISTENSEN (1953), BROUHA (1960), SEN (1967), SEN and SARKAR (1969, 1973) for the evaluation of work loads in terms of the physiological responses of the workers are partly presented in Table 5. Considering the body size of the Indian workers, the work loads were graded from heavy (6.2 kcal/min and more) to extremely heavy (12.9 kcal/min and more), according to our classification only for Indian industrial workers.

For the groups having very high energy expenditure, some realistic and useful

Table 5. Gradation of the degree of heaviness of the jobs according to the physiological responses.

Physiological responses	Workload				References*
	Moderate	Heavy	Very heavy	Extremely heavy	
Heart rate	100–125	125–150	150–175	>175	1, 2, 3
Oxygen consumption (l/min)	1.0–1.5	1.5–2.0	2.0–2.5	>1.5	1, 2
	0.70–1.05	1.05–1.40	1.40–1.75	>1.75	3
Energy expenditure (kcal/min)	5.0–7.5	7.5–10.0	10.0–12.5	>12.5	1, 2
	3.50–5.25	5.25–7.00	7.00–8.75	>8.75	3
Based on the energy expenditure of the present study		Group I	Groups II and IV	Groups III and V	

*, 1, BROUHA (1960); 2, CHRISTENSEN (1953); 3, SEN *et al.* (1967, 1969, 1973).

Table 6. Gross and net energy expenditure and recommended fatigue allowances for the groups of workers.

	Average energy expenditure during a working day		Average net energy expenditure (kcal/hr)	Hourly fatigue allowances in % of time of an 8-hr working day			
				Existing	Additional for		
	Gross (kcal)	Net (kcal)			1,540* kcal	1,154** kcal	1,200*** kcal
Group I	1,900	1,445	165	1.87%	−0.26%	0.27%	0.19%
Group II	2,660	2,295	298	3.12	1.72	3.33	3.08
Group III	1,725	1,430	216	4.24	0.53	2.12	1.86
Group IV	1,850	1,475	210	3.50	0.33	1.60	1.40
Group V	2,660	2,310	330	3.50	2.51	4.52	4.19

*, **; The original values of LEHMANN (1958) and BENA (1963) were modified for comparison by correcting the values of 2,000 kcal/8 hr and 1,500 kcal/8 hr to 1,540 and 1,154, respectively, for 50 kg body weight instead of 65 kg.

***; The suggested value of the optimal rate of energy expenditure in this study was 1,200 kcal/8 hr.

measures could be suggested for the rationalization of work. From the average net energy expenditure values for the whole working period of the workers given in Table 6, the work load was considered to be above the permissible level for the working day. For such a level, BENA (1963) suggested 1,500 kcal (1,200 kcal for actual work and 300 kcal for other activities), whereas LEHMANN (1958) and CHRISTENSEN (1962) suggested about 2,000 kcal energy output for the functional working day. PODLESAK (1969) suggested in a study on subtropical miners that the maximum output for one shift should not be more than 1,100 kcal, while a limit of 1,400–1,500 kcal has been suggested for an 8-hr shift for Japanese male workers (NUMAJIRI, 1974). In this regard an Indian study (SEN *et al.*, 1964b) reported that in the mixing department of a textile mill four workers in a team carried cotton bales, weighing about 180 kg, with an average 8-hr energy expenditure varying between 1,620 and 2,140 kcal. These values are very similar to those observed in the present study.

The average distributions of the work and rest periods as percentages of an 8-hr period are given in Fig. 2. In Table 6, modifications of the work and rest sequences which may be necessary to bring the working day energy expenditure to a rational level are given separately according to BENA (1963), LEHMANN (1958), and the present study, corrections being made for the average body weight (50 kg) of Indians. Certain additional rest pauses or fatigue allowances in percentages of their total working period should be included every hour to the existing allowance. With a slight increase in the total working period, it may be possible to reduce the hourly energy output to an optimal level without affecting the total daily productivity.

The suggestions of BENA (1963) and LEHMANN (1958) may not be acceptable as such for Indian workers, since the average body weight of Indians is around

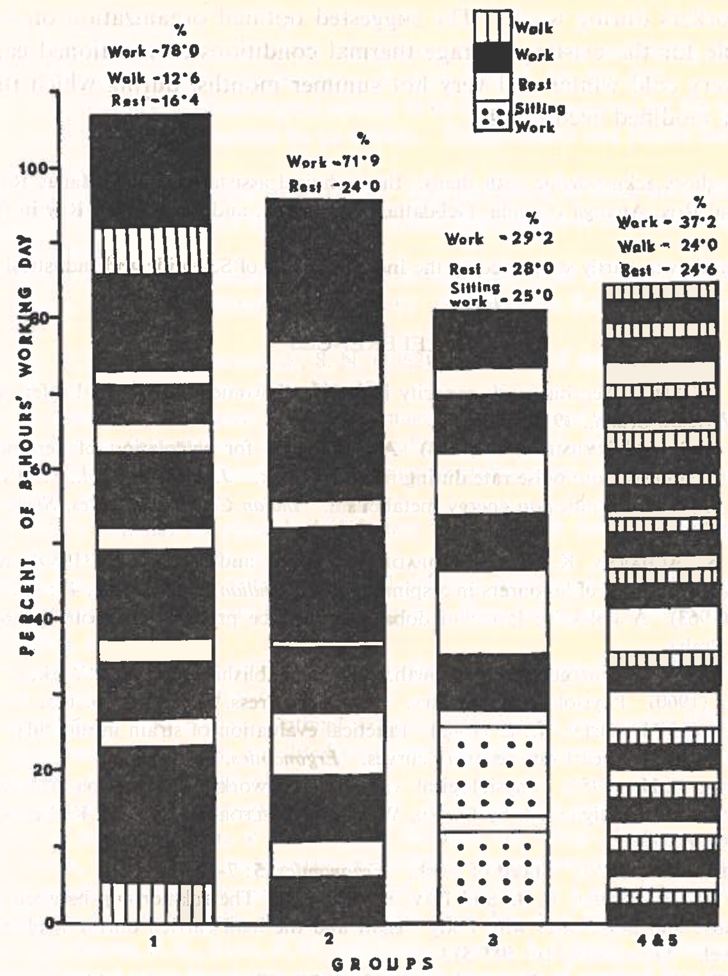

Fig. 2. Distribution of work and rest periods as percentages of time of an 8-hr working day in different groups of workers. Shaded areas indicate the periods of walking without load.

50 kg as against 65 to 75 kg for European workers, and the daily energy intake of the Indian workers does not go beyond 3,000 to 3,500 kcal (BANERJEE, 1962; PATWARDHAN and JAGANNATHAN, 1962). For extremely heavy types of jobs in India a figure of 1,200 kcal as the net optimal energy output (1,000 kcal for actual work and 200 kcal for other activities) in an 8-hr working day (*i.e.*, 150 kcal/hr) is suggested by the present study. Even the daily energy intake of these groups of workers was found to be around 2,500 kcal (NAG *et al.*, 1974).

Future study on a larger number of workers might specify, through linear regression equations, the rational rate of work based on the physiological responses of the workers during work. The suggested optimal organization of work may be suitable for the existing average thermal conditions as mentioned earlier, excluding very cold winter and very hot summer months, during which the values should be modified accordingly.

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A CONTINUOUS TIME SAMPLING PRINTING SYSTEM FOR RECORDING HEART RATE

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A new continuous time sampling digital printing system for recording heart rate is described. The system continuously prints the average heart rate per minute during a constant but short time interval (e.g., 6 seconds). It produces ten counts for every complete inter-beat-interval (I. B. I.) obtained from the successive, shaped E.C.G. pulses during the 6 seconds' period, and simultaneously generates counts as a fraction of ten pulses (representing unity ratio of the preceding I.B.I.s) for the remaining incomplete time interval between the last heart beat and the end of the 6 seconds' time interval. The simplified system, to reduce costs, uses standard logic and linear amplifier modules to form a timer, a time-to-voltage-converter, an analog-to-digital converter, a frequency doubler and an inhibitor along with a digital ENM printing counter. The accuracy of the system is about 1% when two successive I.B.I.s do not differ more than 20%.

The problem of the measurement of a slow rate of different physiological and other repetitive events, e.g., heart beats, is commonly encountered in research.

The three methods generally used for the heart rate measurement are :

(i) to determine the inter-beat-interval (I.B.I.) between successive heart beats and to express it as an "instantaneous" rate per minute from the reciprocal value of each I.B.I.

(ii) to obtain the average rate over a specified time, for example, one minute, simply by counting the events occurring during that interval. This system has an inherent error due to an incomplete interval not being taken into consideration.

(iii) to use an averaging technique by means of an integrating type of ratemeter, but this does not give a true picture of the change of heart rate, and most instruments exhibit a slow response to sudden changes in rate requiring up to 30 heart beats to reach 90% of the true rate at $\pm$ 2% accuracy (1).

Methods previously described for "instantaneous" heart rate measurement had the advantage of digital presentation but are relatively complex (2,3). McDonald and Fenelon (4) described a heart rate meter for the measurement of

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both the "instantaneous" as well as "average" time for 10 beats, but the method is also complex and the accuracy changes at different rates due to the use of a non-linear meter coupled with the difficulty of accurately reading a fluctuating pointer. A simpler method is described by Hamilton (5), but this dose not cover the high range of the heart rates, i.e., > 150 per minute, found in man during exercise.

The system presented here measures the average heart rate during a *constant* time interval similar to the method (ii) above, but any incomplete interval is taken into account. A six-seconds' interval was chosen, so that (a) short-term changes in heart rate during less than one minute are considered, but it is not too short to reflect every change in rate for each heart beat and (b) a simple multiplying factor of 10 enables the printing counter's output to be expressed in beats/min. The system may be described as a compromise between the methods (i), (ii) and (iii) mentioned above. It overcomes the disadvantages of the non-linear conversion of time to rate, the error due to missing the incomplete event and the difficulties of reading a fluctuating meter or of recording continuously on an ultraviolet (u. v.) recorder for subsequent analysis. We have found the continuously printed digital output of the present system a distinct advantage in actual use.

The instrument proved to be relatively simple to construct using standard logic and linear amplifier modules, and the cost of the components, excluding the printing counter, was less than £ 40. A photograph of the instrument is shown in Fig. 1.

The present system was developed (6) from the concept that the number of I.B.I.s in 6 seconds, if multiplied by 10, gives the average heart rate per minute during that period, with a maximum error of about 10 beats per minute too low, only when the end of the 6 seconds' period just misses a heart beat. The problem of incorporating the incomplete time interval between the last heart beat counted and the end of the 6 sec. time interval was solved in the present system by *continuously* measuring the ratio of the "instantaneous" I.B.I. with the preceding one and expressing the incomplete interval as a fraction of 10 pulses denoting unity ratio of the preceding I.B.I.s. The accuracy of the measurement is unaffected by the changes in the rate over its operating range of 40 to 200 beats per minute, since a ratio principle is used. The accuracy of the system is about 1% when two successive I.B.I.s do not differ more than 20%, a value not commonly encountered in physiological conditions.

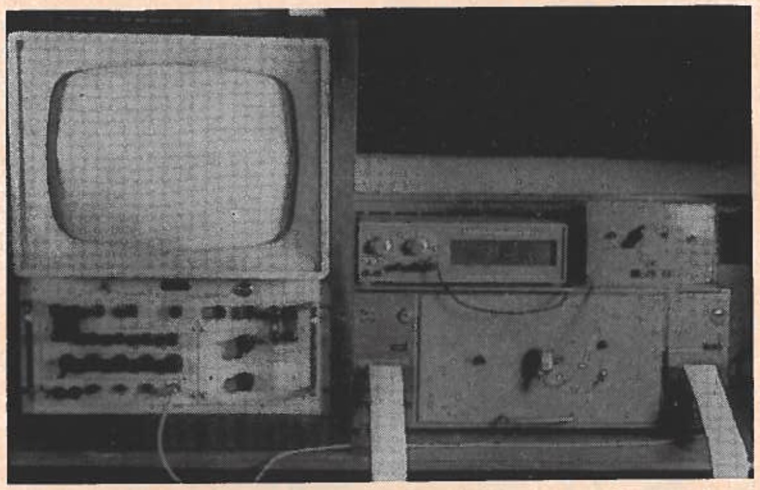

Fig. 1

The continuous time sampling printing system for recording heart rate with a cathode ray oscilloscope for displaying E.C.G. The printer at left gives the heart rate every 6 seconds and that at right gives it every minute.

2. *CIRCUIT DESCRIPTION*

The arrival of a shaped E.C.G. pulse opens a gate to a counter and keeps it open for 6 seconds for counting. The time interval between two pulses (I.B.I.) is converted into a proportional voltage which, in its turn, is converted into a number of pulses—the number being proportional to the ratio of the voltages of two successive I.B.I.s. These pulses are finally counted and the number is printed out. After 6 seconds, the entry of the pulses is blocked till the whole process is started over again after 150 ms. delay for the printing and resetting of the counter.

The circuit diagram, and the wave forms at the various points in the circuit, are presented in Fig. 2 and Fig. 3 respectively. All the three integrators (I_1, I_2 and I_3) used in this circuit are μA 741C operational amplifiers and all the comparators (C_1 to C_6 inclusive) are of the type μA 710C. The potential divider used with the comparators (C_2 to C_6) consists of a chain of six resistors each with a value of 330Ω.

The sequence begins with a filtered and shaped E.C.G. pulse ("a" in Fig. 3) arriving at the point "X" (Fig. 2) where it takes two paths : (i) to initiate a 6-sec. timer and (ii) to control a time-to-voltage-converter.

2.1 *Six-sec. Timer*

The arrival of an E.C.G. pulse passing through the 'AND' gate 1 triggers the bistable BS1. The AND1 and BS2 ensure that the 6-sec. sweep cannot be

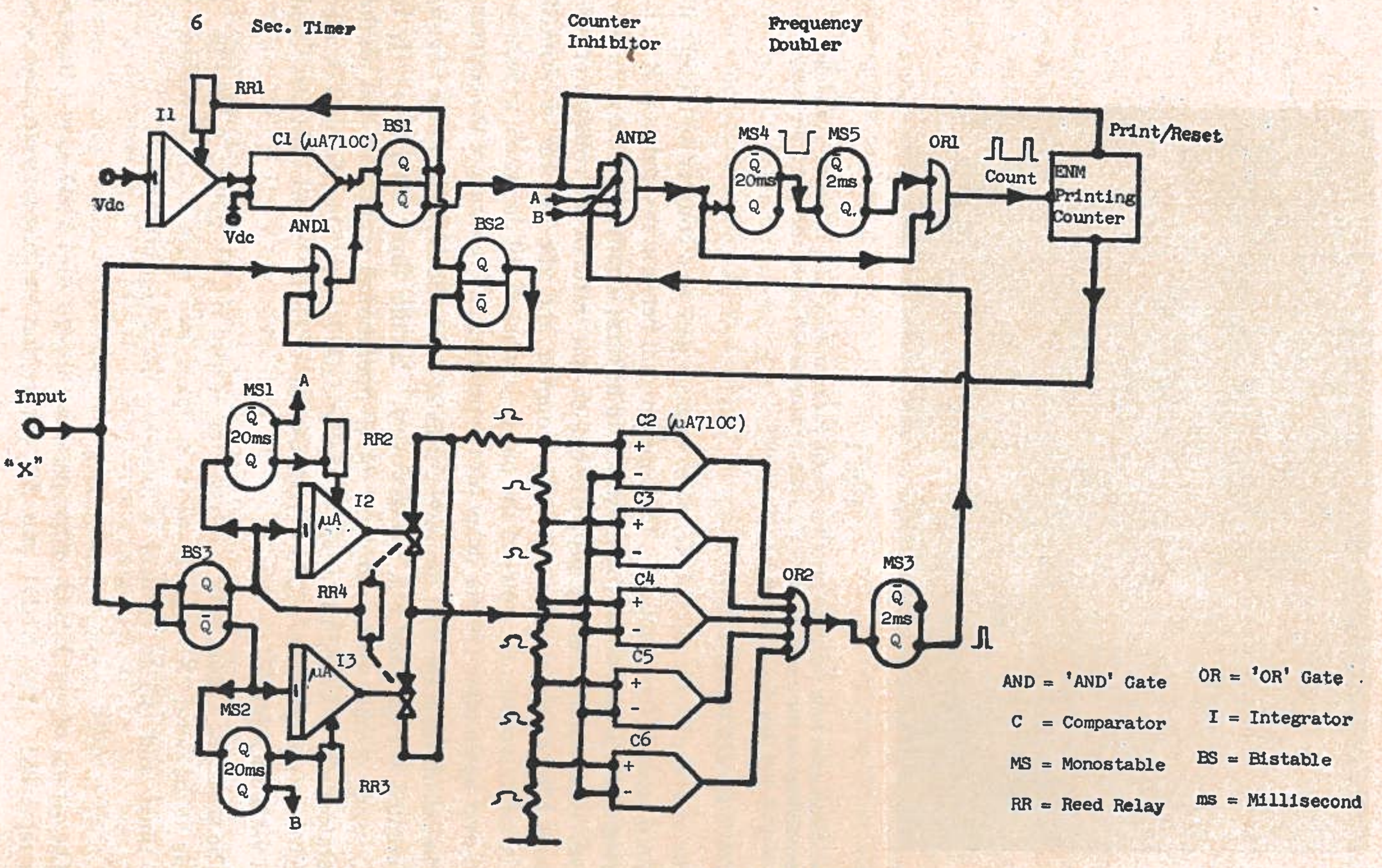

Fig. 2

Circuit diagram of the continuous time sampling printing system for recording heart rate.

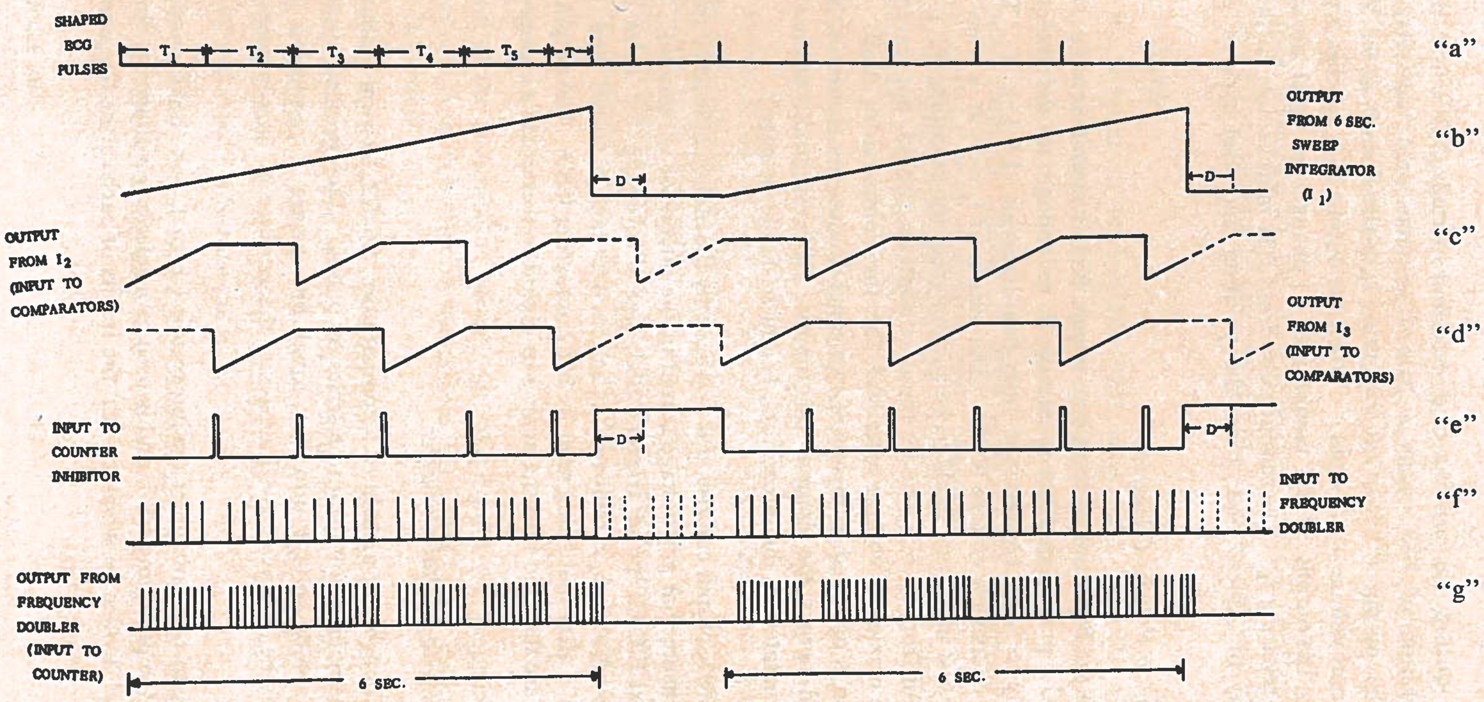

Fig. 3

Diagram showing wave forms at various points in the circuit.

initiated during the printing and resetting period ("D"=150 ms. in "b"). The operation of BS1 opens a pair of contacts on a reed-relay RR1 which allows the output ("b") of the integrator I_1 to rise linearly at 0·5 V/sec. due to the constant voltage at its input. When the output of I_1 reaches 3 volts, i.e., in 6 seconds, the output of the comparator C1 changes its level abruptly, setting BS1 and resetting I_1. The output pulse from BS1 inhibits any further counting by means of AND2 and starts the printing and reset cycle of the printing counter.

2.2 *Time-to-Voltage-Converter*

With the beginning of the 6-sec. sweep, BS3 is simultaneously triggered by an E.C.G. pulse, applying a steady d. c. voltage to the integrator I_2 or alternately to I_3 to convert the inter-beat-intervals (I.B.I.s), T_1, $T_2, \dots\dots T_5$, ("a"), to equivalent voltage levels. The output of I_2 rises at a rate determined by the lowest input rate likely to be encountered, for example, 40 beats/minute. The output from I_2 (or I_3) under these conditions should not exceed 5V, this being the maximum voltage permitted for the comparators used. Additional protection is provided by means of two zener diodes (not shown in the diagram), connected across the comparator inputs. It is essential that the slopes of the ramps generated by the integrators, I_2 and I_3 should be equal.

Before I_2 output can rise, it is first reset by the monostable MS1 and reed-relay RR2 to ensure that any voltage stored in the integrator is removed. The arrival of the next E.C.G. pulse triggers BS3, again reversing the roles of I_2 and I_3. When the input to I_2 is removed, its acquired voltage is stored and I_3 starts to ramp ("d") after first being reset by MS2 actuating RR3. The outputs from both I_2 and I_3 are then fed into the analog-to-digital converter via a change-over switch RR4.

2.3 *Analog-to-Digital Converter*

This consists of a chain of 5 comparators, C6–C2, to form a simple converter for changing a voltage into a series of pulses. The present system proportions the analog voltage into five equal bits giving a resolution of 2 beats, which may be improved by increasing the number of comparators used in the chain.

The constant voltage of the integrators (I_2 or I_3) in 'hold' mode is proportional to the preceding I.B.I. and is used as a reference voltage by connecting to a potential divider, to which one of the inputs of each of the five comparators is

connected. The other inputs of the comparators are connected together and taken to the integrator with the increasing ramp voltage, which fires the comparators C6–C2 in turn as the threshold of each comparator is exceeded, to give a total of 5 pulses for each complete I.B.I.

The 5 pulses generated at the output ("f") of OR2 are then simply frequency-doubled before passing to the counter, thus giving 10 pulses for each E. C. G. pulse.

2.4 *Frequency-Doubler*

The circuit comprising of monostables MS3, MS4, MS5 and OR1 produces two pulses ("g") to be counted every time a comparator fires. This technique was introduced to save on the number of comparators required.

A 2 ms pulse from the output of MS3 triggers MS4 and appears at the output of OR1. After a delay of 20 ms, MS4 triggers MS5 ; thus two pulses, 20 ms apart, are available at the output of OR1, thereby effectively achieving a doubling of frequency.

The process continues with I_2 and I_3 interchanging their roles on the arrival of each E.C.G. pulse an dten pulses being counted for each complete I.B.I.

In order to distinguish between a rate of say, 150 beats/min, and 159 beats/min during the 6 seconds' period, the least significant figure, i.e., the last figure 9, must be obtained from the incomplete I.B.I. ("T"). Since a complete I.B.I. with unity ratio will always produce 10 pulses, an incomplete interval ("T") will produce pulses proportional to the ratio of this interval and the previous complete I.B.I.

2.5 *Inhibitor*

At the end of the 6 seconds' period, an inhibit-pulse ("e") appearing on AND2 ensures that no pulses after an incomplete I.B.I. ("T") are counted till another cycle starts again.

Additional inhibit-pulses ("e") (derived from 'A' of MS1 and 'B' of MS2 during the change-over of I_2 and I_3) prevent any spurious counts occurring due to the switching transients of RR4. The counter also remains inhibited until the arrival of the next E.C.G. pulse following a delay of about 150 ms necessary for the printing and resetting to take place.

The system may also be used for other time intervals, e.g., 3 secs, 10 secs, etc., which would only necessitate changing the reference voltage of the timer and the number of comparators.

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