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# SLEEP DEPRIVATION AND HUMAN PERFORMANCE*

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# SLEEP DEPRIVATION AND HUMAN PERFORMANCE*

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Two groups of *S*s (ten each), experimental and control, served as *S*s under five different series of stimuli: (1) Red light; (2) Green light; (3) Sound of 40 db; (4) Light (R×G) and sound mixed; and (5) Light and Light (R×G) mixed to measure the impact of sleep deprivation (*SD*) on simple and complex RT (SRT and CRT). The last two series, of a simple automatic electrical reaction time apparatus was used for recording data. We started with following three hypothesis (1) RT in CRT conditions will have greater impact on *SD*; (2) under SRT condition there should not be any significantly different impact of *SD* on visual and auditory signals; and (3) of the sub-conditions of CRT, namely, light×sound and light×light, the effect of *SD* will be more pronounced in case of Light×Sound condition. The first and the third hypothesis were sustained. The causative factors behind some of the results were suspected to lie with the information processing functions of our nervous system. Results have been widely discussed and explained in light of various available theories.

Effect of sleep deprivation (*SD*) on performance is a relatively new phenomena to be studied by psychologists. There have been a few earlier studies, as far back as the later part of the 19th century, but they remained generally rare till recent years when engineering psychologists started giving their searching attention to this problem. So far just about fifty papers have appeared and they lead to varying conclusions and the stricking fact remains that they have yet to probe into the interactions of the several related variables. In India only recently some attempts have started (Daftuar, 1969, 1971a; 1971b). The impacts of *SD* have been found to vary with the nature of work being carried out, being in general more pronounced with uninteresting and/or complex tasks (Wilkinson, 1965).

The present study has been planned to study the impact of about 30 hours' *SD* on simple reaction time (SRT) and complex reaction time (CRT) both for visual (V) and auditory (A) signals independently and in combination. On the basis of the results obtained by various workers in the past we hypothesized that: (1) RT in complex variable conditions (CRT), will be affected more by *SD*; (2) there should not be any significantly different impact of *SD* on visual and auditory signals; and (3) of the two types of RTs measured —light×sound and light (Red)×light (Green)—the effect of *SD* will be more pronounced in case of light×sound condition.

## METHOD

*Subject:* Twenty undergraduate male students between the ages of 18 and 22 years volunteered to act as *S*s. The sample was devided into two groups of ten each. One group of ten (henceforth called *experimental group*) was asked to go without sleep for 30 hours i.e., from 6.00 A.M.

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*** Gaya College, Magadh University, Gaya, India.





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to 12.00 noon of the following day, the day when experiment was scheduled. The starting time of the experiment for both the groups, however, remained the same—12.00 noon (on different dates). The other group of ten (henceforth called *control group*) was allowed to take normal sleep.

The *S*s were put to simple medical check up for hearing and vision and were found to have normal auditory and visual capacity. Against Ishihara's (1920) test of color blindness *S*s were found to be normal.

*The Apparatus and Procedure:* A simple automatic electrical reaction time (RT) apparatus was used. The apparatus provided visual as well as auditory signals with a provision for automatic time and error recording. Briefly, the apparatus had four light bulbs, of a rated candle power of 0.55 of 1/2" diameter, of different colours (Red, Blue, Green and Yellow) of matching brightness—with four associated switches which required approximately 16 oz. operating force. Similarly there was, in the apparatus itself, a loudspeaker capable of producing white noise of 40 db level. The visual signals were presented at eye level within 10° left and right of the line of sight, keeping a constant distance of 28 inches from the eyes, following the standard human engineering criteria (McCormick, 1964). Other sitting arrangements were made in accordance with our previous finding (Chatterjee and Daftuar, 1966).

As per instruction (standardized for all) the *S*s were supposed to react and press the switches as soon as they saw the instructed light (i.e., R or G) for measuring the SRT in two different and independent series for each colour of light. For CRT they were asked to press the corresponding 'off' switch for the instructed colour of the light only when that particular colour of light appeared. The difference was that, while in the two light conditions of SRT only one light appeared in one series, in CRT condition any of the four coloured lights could have appeared but *S*s were supposed to press the switch only when the instructed colour appeared. In the same way RT for light and sound signals were measured. In SRT-A condition only sound was presented while in CRT-AXV condition the two variables were randomly mixed up so as to present equal number of trials for each of them. During both of the experimental conditions (SRT and CRT) *S*s were instructed to keep their fingers on the switch itself. Before the experimental trials started (in each of the condition) *S*s were given verbal warning. Interval between warning and test trials was 5 seconds.

The general pattern of the experiment was that of Latin-Square design, for different combinations, which balanced order effect (Chapanis, 1959).

The control and experimental group of *S*s were asked to perform essentially the same types of work. Each *S* had to undergo all conditions of the experiment which, in aggregate for individual subject, lasted for about 120 minutes. After each block of 50 trials *S*s were given 2 min. rest. Intervals of 2 seconds were given in between trials. Total experimental session for each *S* comprised 350 trials (SRT condition -R-50, C-50, sound-50; for CT Conditions AXV-50+50 (100), and for VXV i.e., RXG-50+50 (100)=Total 350 trials).

*Sleep Deprivation:* The *S*s of experimental group remained awake for the previous whole day and night i.e., from 6.00 A.M. to 12.00 noon of the next day, untill the experiment started. This amounted to about 30 hours without sleep. *S*s passed the intervening period walking, playing games, reading books and carrying out routine duty. Each of them was kept under constant supervision.

*Statistical Treatment:* To test the significance of means from zero, Wilcoxon's non-paramatric procedure was used, and the significance of difference between means was assessed by the Mann-Whitney U Tests (Siegel, 1956) as many of the distributions were suspected to be not normal.

Index of accuracy (IA) was derived (we may call it "proportional errors") following Wilkinson's formula (1963, p. 333).

$$IA = \frac{E \times 100}{E \times C},$$

Where, E is error or incorrect reaction, C is correct reactions.

## Results and Discussion

In analysis of the results we were concerned with comparing the performance of the *experimental* and *control* *Ss* in relation to different variables. Stimuli were presented in five different series: (1) Red lights; (2) Green lights; (3) Sound at 40 db; (4) Light (R+G) with sound of 40 db level, intermixed; and (5) Lights (RXG) intermixed. Table 1 gives these scores for all conditions and types of tasks. The results have been presented in three categories: (a) 'gaps' (when *Ss* took more than 1.00 second to respond) in terms of its occurance in number of trials; (B) 'correct' (the RT in millisceonds of only the correct responses); and (C) number of trials where wrong responses were made.

Table 1 presents some interesting results that have never been reported earlier. In the first instance it was observed, confirming the earlier results of Walter Reed group of workers that "the way in which sleep deprivation affects performance is by imposing periodic lapses in efficiency interspersed with periods of normal or near normal functioning. The organism falters, recovers and runs normally for a time, falters, recovers and so on" (Wilkinson, 1965, p. 411). It was also observed that effect on SRT is to lengthen the tail of of the distribution of response times, while having little effect on most of the responses at the short end of the distribution. In the beginning it appeared, for the above stated explanation (it seems), that the 'errors' were more pronounced. However, when analysed as a function of the total number of responses made, 'gaps' appeared almost as sensitive a measure as 'errors'. The effect of *SD* seems to be more pronounced with CRT tests. Under SRT conditions with visual stimuli we did not obtain any significant mean difference between the scores of *experimental* and *control* groups (i.e. 'gaps', 'correct' and 'error'). However, it appears that under ST conditions the reaction time to A-signals are more affected by *SD* than the V-signals for the 'correct' measure ($<0.02$). Though the phenomena is familier to workers studying reaction time we found ourselves in a puzzling situation. We know that from the very beginning of RT research (as far back as the time of Hirsch, 1861–1864), RT to A-stimuli have been found to be shorter. Yet, inspite of Woodworth and Schlosberg's (1954) attempted explanation it remained a puzzle for both the psychologists and the physiologists. Here also the phenomena of A-signals being more effected by *SD* poses a serious handicap before us and we feel helpless in giving any psychologically, physiologically or biochemically suitable explanation to it except that to attribute it to some qualities of our nervous system. It is surprising for one more reason also. Considering the relative speed of light and sound we would logically expect RT to V-signal to be shorter. But in the present result this is true only with the *experimental group* while in case of *control group* we find the same old familiar trend of RT to A-signals shorter than V-signals. This is again interesting and puzzling. There is nothing in the present state of knowledge either to explain the 'why' of the normal phenomena of shorter RT to A-

**Table 1.** Average Scores of Experimental and Control *Ss* in Each of the Condition

| Types of Score | Subjects | LIGHT R | LIGHT G | ound | Sound × Light | Light (R) × Light (G) |
|---|---|---|---|---|---|---|
| 'Gaps' | Experimental | 4 | 3 | 3 | 12 | 10 |
| (In nos. of trials) | Control | 3 | 4 | 3 | 4** | 5** |
| 'Correct' | Experimental | 208 | 226 | 452 | 469 | 362 |
| (Mean RT in Millsec) | Control | 182 | 197 | 145** | 205*** | 210** |
| 'Errors' | Experimental | 10 | 9 | 3 | 11* | 12* |
| (In nos. of trials) | Control | 6 | 8.5 | 0 | 7 | 8 |

*** $p<0.01$ ** $<0.02$ *$<0.05$



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stimuli or the present contradictory result of RT under *SD* being more effected in case of A-Stimuli. We do not have any knowledge of any possible biochemical or physiological changes in our body due to *SD, though we suspect there may be some thing of the sort,* which can adequately explain the phenomena. For we know that the only significant biochemical change in prolonged *SD* is in the specific activity of adenylic phosphate compounds in the blood and for its impact on physiological changes most of the results are either equivocal or contradictory (Wilkinson, 1965). It may be mentioned that Woodworth and Schlosberg (1954, pp. 18–19) tried to explain this phenomenon of A-RTs being shorter than V-RT in terms of the relative speed of nerve impuls transmission in auditory versus visual path ways. However, the explanation does not seem to be adequate one to the present authors as, in our opinion, it fails to explain the situation in an universal way. For example, we are known to see light first and then hear the sound in lightning, and so is the fact in case of supersonic jets. We feel that it would be worthwhile for the future workers to probe into the problem from this angle and meet the challange thrown out here.

When we turned to analyse the data of CRT the results obtained are expected. For all the three measures in CRT-condition, involving both V and A (mixed) signals, we found significant differences in their mean values. 'Gap' and 'Correct' measures again seemed to be important and sensitive measures ($P<0.02$ and $P<0.01$ respectively). It appears that the 'gap' tend to become predominantly effected by *SD* under CRT-conditions. The difference in matter of 'gap' between the experimental and control group is as great as three times larger for $A \times V$ stimulations and double in case of $V \times V$ ($G \times R$) stimulations, while in SRT condition none of the difference in 'gaps' was significant.

For another CRT condition involving two lights—red and green—again we found all means and number of trials significantly different ($P<0.05$ and $P<0.02$ level). This shows quite clearly that *SD* has more impact in tasks involving CRT than in case of SRT. It was rather expected inspite of certain previous findings. A few workers have reported that tasks involving complexity are less affected by *SD* because the 'arousal' phenomena sets in (see, for example, Wilkinson, 1964). However, we could not observe any such thing happening. It seems probable that the situation may be a potent intervening variable. The present experiment was designed and controlled in a way that nothing like incentive from without could have influenced the results. As far as within is concerned *S*s in this experiment probably failed to get 'aroused' except for a few spurts here and there, as mentioned earlier. Here too the interesting observation of SRT (A) was observed. While using $V \times A$ (as CRT signals) and two lights ($R \times G$) (as CRT signals) we found predominantly significantly different means in the earlier variables. The two results show one point at least for certain that *SD* seems to have more effect on the A-signals than upon the V-signals. This was an interesting phenomena. Here we may mention a relevant study (Champion and Field, 1963), though not directly comparable yet significant, where in workers found SRT to be significantly effected by as short term food deprivation as 5 hours and 10 hours with sound stimuli. The findings of Champion and Field (1963) support the present conclusion that sound may be a very (as well as better) sensitive measure of RT particularly under stress conditions. Incidently it may be pointed out that the food deprivation for both groups in the present experiment was the same. However, since Champion and Field (1963) used just one type of signals (A) we are not in a position to correlate their findings to the present one in any direct manner.

## CONCLUSIONS

On the basis of the results obtained we conclude with the following observations:

1. When V-signals and A-signals are intermixed (to create CRT condition) it is significantly more effected by *SD* than any of the SRT variables i.e., the first hypothesis of the present research is sustained.

2. When two types of V-signals (R × G) are intermixed (to create visual CRT condition) it is again more effected by *SD* than the SRT conditions when they were presented in two independent series. This again confirms our first hypothesis.

3. For SRT, *SD* has greater impact in case of A-Signals than in case of V-signals. In other words, our second hypothesis stands rejected.

4. In matter of within CRT condition also when signals have mixed variables of A × V RTs are more effected by *SD* than mixed variable signals of V × V (R × G). This confirms our third hypothesis.

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# A STUDY OF EYE AND HAND-REACH ANGLE AS A FUNCTION OF DIFFERENT BODY DIMENSIONS IN TYPEWRITING JOB*

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*Indian Institute of Technology, Kharagpur.*

The present paper reports a part of the findings of the main project conducted by the author to test the Corbusier's hypothesis (1) of Human scale. In the manipulation of any control the eye movements, eye angles and other angles made by bodily postures involving various body dimensions, are of undisputable importance. In a study (2) to test the hypothesis of Human Scale (1) it was hypothesized, following the observations of Corbusier, that each dimension of human body are symmetrically and proportionately related to each other. The proportionate relationship happened to be 1 : 1.617. Later Corbusier considered it to be a law of the nature and the present hypothesis was confirmed with regard to the relationships between different body dimensions and to their bearing on layout design for typewriting job. It was observed that the same relationship of 1 : 1.617 was also true in relation of various components of the layout corresponding to the body height of the individual working on it.

The present study is a step further in the same direction to see if the said body dimension relationship has got any bearing on the eye angles at the working point where the subject, as hypothesized should achieve the best efficiency.

*The Present study* (*Hypotheses*): None can deny the basic fact that controls and displays should be located with due regard to the operator's size, his position, the direction in which he can look most easily and the space in which he can manipulate controls best. Various studies have been reported recommending the optimum eye angle, area of eye movements and angles of other important body dimensions (4), (3).

The present study seeks to investigate—

(1) What is the average eye angle on various important points of the layout in typewriting job viz; typewriter's roller, key-board and the materials to be typed, and what should be the optimum area of eye movement.

(2) Whether these angles have any correlation with different body measures viz., body heights (standing), body heights (sitting), eye height (sitting) shoulder height (sitting)

[Explanation, See Methodology].

(3) To see the relationship of chest distance-hand-reach angles with these body-dimension-measures and the different eye angles made on roller, keyboard and typing materials and their relative importance.

The hypotheses of the study were :

(1) At the particular height of table and chair giving best efficiency the eye angles should be correlated with various body-dimension of the individual, and

(2) Angles, made by handreach-shoulder height-chest distance from Keyboard should be some way related with various important body dimensions-measurements

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(mentioned above) and different eye angles.

## METHOD

When, on the basis of the previous findings (2) the proportionate heights of chair and table were obtained (with the help of adjustable table and chair) for, the best efficiency in typewriting job relative to individual's heights we moved a step further to find out the eye angles on the three critical points (Roller, Key-board and typing material) and the angle made on Key-Board between chest distance and hand-reach.

For this purpose various measurements were taken as given below:

*Body height (Standing)*: 'a vertical distance from the floor to the top of the head, The subject stands erect and looks straight ahead.'

*Body height (Sitting)*: 'a vertical distance from the sitting surface to the top of the head, The S sits erect, looks straight ahead and his knees and ankles are at right angles to the ground'.

*Back height or Shoulder height (Sitting)*: "a vertical distance from the sitting surface to the upper most point on the lateral edge of the shoulder with the subject sitting erect."

*Eye height (Sitting)*: ' vertical distance from the sitting surface to the inner corner of the eye. The S sits erect and looks straight ahead';

*Chest-Distance-point*: The point at the chest from where chest distance from Key Board was measured.

The best efficiency was obtained when the chair and the table was in the proportion of 1 : 1.617. (ϕ) With the present sample the average height of the $S_s$ was 65.08", the heights of the table and chairs (average) at the point of best efficiency are presented in the Table-1.



Table 1

*Average height of chair and table at ϕ (1 : 1.617) relationship and their $S_D$ (in inches).*

| | Average height | $S_D$ |
|---|---|---|
| Table | 24.68 | 1.607 |
| Chair | 15.09 | .7702 |

These heights were recommended as optimum heights for the sample of average height of 65.08" and at this height following measurements were taken to get the eye angles, angular area of eye movements in working situation, and chest distance hand reach angles,

(a) Distance of eye from the roller

(b) Eye distance from Key board

(c) Eye distance from typing materials

(d) Distance of the chest (heart point) from Keyboard

(e) Distance from the chest distance (i.e. point from where chest distance to key board was measured in – 'd') to the eye.

Angles of vision on the roller, key board and typing material were obtained on the basis of the above measurements. By the different angular measurement on Roller, Key board and typing material we mean:-

∠ a — Roller (R), the vertical angle made between the horizontal plane and roller.

∠ b — Key-board (Kb), the vertical angle made between the horizontal plane and the keyboard (Both R and KB, made at the eye)

∠ c — Typing material — the vertical angle made between the KB and the typing material.

(all expressed in terms of degrees)

With various measurements of eye angles (a, b, c) the total angular area of eye movement is calculated in the following ways :

angles ∠ b — ∠ a = A′ ... Area of Eye movement between the roller and the Key board.
C ... vertical angle made between Key-board and the typing material.

A' and C are not at the same plane so the Key board height is deducted by 1" to get it on the same plane with the typing material.

So A' + C = total angular area of eye movement for each subject.

By ∠ Hand reach—Chest distance the mean angle made by the shoulder height, chest distance from KB, and distance from chest distance point to shoulder.

On obtaining angular measurements for each subjects their average and $S_D$ were worked out and then a correlational analysis was tried to find relationships between the probable related angles and body dimensions.

*Sample* : 15 professional typists of the Indian Institute of Technology, kharagpur, were selected randomly to act as Ss. The whole sample may be classified broadly for speed into 3 groups.

| *Gr.* | *Speed mt.* | *Nos. of Ss.* |
|---|---|---|
| 1. | Below 30 words | 6 |
| 2. | Between 30-40 words | 4 |
| 3. | Above 40 words | 5 |

As for other considerations such as experience, education, heights and other personal factors the sample was homogeneous group for all practical purposes.

## RESULTS AND DISCUSSION

As stated earlier Ss were taken randomly yet, variation in body height (standing) was tried to be kept within a limited reasonable range and it was expected that the mean measurements and different heights will indicate the normal trend of the population.

Table 2. gives the average different body dimensions, $S_D$ and their points of measurements and $S_E$ of chest-distance from $K_B$ of the sample.

Table 2

*Average of Different Body Dimensions, $S_D$ and points of Measurement in (inches) and $S_E$ of chest-distance from KB of the sample.*

| Body Dimension | Av. | $S_D$ | Point of Measurements |
|---|---|---|---|
| Body height (full Standing) | 65.08 | 2.063 | From earth surface |
| Back height (sitting)* | 23.41 | 1.276 | From Seat Surface |
| Eye height (sitting)* | 27.94* | 2.18 | —do— |
| Chest Distance (from KB) | 11.55 | X | From Key-Board $S_E$ .62 |

Difference between Back height and Eye height 4.53 inches.

Considering the small $S_D$ and the size of the sample the table 2 confirms the homogenetical nature of the sample, at least anthropometrically.

Table 3 shows the average and $S_D$ of eye angles made by the sample at its best efficiency producing height at three critical working points and the angular areas of eye movements between different points with the total angular area (av.) of eye movement in the job of typewriting. Table 3 (a) gives Av. and $S_D$ of chest distance-hand reach (HR) angles.

Table 3

*Average Eye angles made on Roller (R), Key board (KB), Typing materials (TM), and area of Eye movement (in terms of degrees)*

| Point of angles | Av. | $S_D$ | ≤ areas | |
|---|---|---|---|---|
| R | 26.63 | 3,86 } | ↓ | X |
| KB | 58.07 | 8.058 } | 31.44 | { 39.06 |
| TM | 39.06 | 6.21 | X | ↑ |

≤ Areas of movement = 70.50

Table 3 (a)

*Average Chest distance—hand reach (HR) angle and its $S_D$.*

| Angles | Av. | $S_D$ |
|---|---|---|
| **HR** | **47.82** | **3.008** |

It is evident from the above tables (Table-3 and 3a) that eye angles on the best working heights should be near about 30 degree. The average shift in eye angles between roller and Key-board on or the ideal height of best efficiency is found to be 31.44°. This finding is also in agreement with some of the previous findings. Baker and Grether (In 4) points out that the overall visual area should range from just below eye level down ward 60° and 30° to either side of the midplane of the body. They advocate that the line of sight to the plane of the display should never be more than 45° from the perpendicular.

While discussing the design of the panel-contour Damon and Stondt (4) suggested that the upper section should be from zero to 20 degrees from the vertical plane, with its lower edge not more than 30° below the horizontal line of sight. About the middle section they advocate for 30 to 50 degrees from the horizontal plane and extended downward to the maximum of 45° below the horizontal line of sight.

In the present investigation taking the typewriter as resembling a panel contour, the similarity in findings are obvious. The lower edge of the upper area of a contour has been suggested to be not more than 30 degrees. The average eye angles on the roller of the entire sample was found to be only 26.63 degrees.

Baker and Grether have pointed out, as stated earlier, that overall visual area should not be more than 60° from the perpendicular of the eye sight. In the present study we find average eye angle even upto Key Board, to be only 58.06 degrees. The entire area of eye movement in the present working situation happened to be only 70.50 degrees.

But from the tabulation of the complete data it was observed that in certain cases there were wide disparities on the eye angles made by individuals, for example, angle on Roller, one S made an angle as high as 34.4° while the lowest angle made by another S came to be only 20.7°. In the same way angle on KB varied between 72° and 44° and the angle made on TM ranged from 49.4° to 21°. Since, from general anthropometrical point of view the Ss form, more or less a homogeneous group curiosity was aroused to know the reason of the variations and be sure if they were actually correlated with bodily measurement as was expected. Table 4 gives the result of the findings.

Table - 4

*r and r's 't' values between various angles and body heights.***

| Angles / Measr. | | R | KB | TM | Total area of eye Mov. | HR |
|---|---|---|---|---|---|---|
| Body height (standing) | r | -.274 | -.44* | -.3075 | -.239 | .785* |
| | t | 1.03 | 1.76 | 1.16 | .48 | 4.62 |
| Back height | r | .166 | .803* | .2155 | .1954 | -.218 |
| | t | .728 | 4.81 | 1.10 | .93 | 1.10 |
| Eye height | r | .14 | .14 | .17 | .13 | -.224 |
| | t | .56 | .67 | .73 | .5135 | 1.10 |
| (HR) angle | r | -.89* | -.86* | -.76* | .-12 | x |
| | t | 4.81 | 6.18 | 4.46 | .47 | |

* Significant Coefficient of correlation.

** Ceofficient of correlation significant for 28 df on .05 level to .01 level, between .361 - .463.

The table 4 presents before us some of the puzzling but interesting results. As it is obvious very few eye angles have any significant correlation with any of the body-measurements. Yet, inspite of the low correlation we get at least a definite trend of relationship viz. in positive or negative direction. From level of significance point of view, for eye angles on any point, it seems 'Human body height' (Standing) and 'Back height' (sitting) have definite advantage over the 'Eye height' (sitting) i.e., the length of the body part between the shoulder and the eye (average 4.53 inches) has relatively very inferior role to play in determining eye angles. The reason probably might be lying in the-simple fact that the length is relatively too small a variance to make any significant difference. Besides, in the typewriting job it seems KB is more potent factor and more directly related with the body heights and, as we see, even with the HR angles. More over, the HR angle differs significantly from all other eye angles in directions of its correlation with body measurements. With the full body heights (Standing) HR angles has the heighest correlation and in negative direction while the other angles are having more or less insignificant or very low significant positive correlations.

This fact naturally leads us to suppose that in the present task at least, probably the

HR angles have a greater part to decide. We come to the last column of the table - 4 (up to down) and find the hypothesis to be true. HR angle has a very high negative correlation coefficient with all eye angles as for example, with R - angle, -.80, with KB angle, -.86 and with TM-angle, -.76. But with the total area of eye movement (in terms of degree) the HR angle has almost negligible correlation since 't' value of correlation is only .47. The results lead us to suppose that in the determining Eye-angles on any point especially in the work involving manual control the HR angles is more important or we can probably go to the extent of saying that probably they decide the eye angles. In other words, we can assume that due to the previous learning and habit pattern of body postures in sitting, the individual tries to adjust himself in the working situation and if it may not create a high restrain on the visual mechanism, for manual control at least, the operator will first try to have bodily ease. The data reflect the underlying fact that according to sitting habit, the individual tries to adjust himself with the layout and these adjustment efforts affect the eye angles formation by bringing necessary changes in eye-point distance from the dispaly (here the points of observations as KB, R, etc.,). The point is more clear by the fact that HR angle has not only negative correlation with Eye angles but what-ever the direction of correlation coefficient of eye angles correlation with different body dimensions - measurements (considered in the present study) come, the HR has angle its' opposite direction of correlation with those dimensions.

The result suggests a possible generalization that for a physical comfort in system design, (as pannel design) where the operator is allowed to sit, the control system as switches, knobs, etc., should not be at a place having more than 11.55 inches distance from the operator's chest especially for a sample of an average height of 5' 6" (Table-2). The body-height is important in this case because we have seen that all parts of the body are proportionately related (2) and the arms are no exception to the rule and than the HR angles are positively correlated with human body heights (Table-4). We can assume that if controls are placed within this distance it would be easy to manipulate. However, by insisting over this limit of distance it is not meant that the distance should be as low as possible since too low a distance also can jeopardise the purpose and may put the operator's body dimensions at odds.

The negligible correlation of HR angle with the total area of Eye movement is in itself of no importance since points were on different level and it is expected that they may not have any correlation with any of these variables.

## CONCLUSIONS

From the results obtained in the present study we can tentatively conclude with certain reservations that:

(1) The working heights (displays, pannels etc,) should be adjusted to make an eye angle of about 30 degrees for the lower edge of the upper level and the area of eye-movement should be near about 70 degrees.

(2) The Eye angles are independent of any variation in the different body dimension. However, the lower edge of the pannel contour (for a generalization, in the present study KB) seems to be related with the full human heights and Back heights.

(3) In jobs of manual control (like typewriting, involving chain reaction) HR angles are more important than eye angles since they involve habit pattern of sitting postures. Due to habit pattern operator will try to adjust himself by changing the normal positions of other body dimensions such as neck, head, etc, and thus influencing formation and changes in eye angles.

Lastly, our first hypothesis that eye angles should be correlated with various body-measurement could not be sustained by the results obtained. However, second hypothesis has been confirmed. The data presented here do not pretend to be index of frequency of eye-movements. Due to experimental limitations, especially time factor, comparison of eye angles different at heights of work surface could not be made. Próbably that data could give us some more insight in man - machine system.

In the present-day knowledge of man-machine system a detailed information is lacking in this direction. No particular generalization is emphatically claimed from the present study. We can, however, conclude with fervent hope that it will throw some welcome light to the future investigation on this line - one on the other.

## SUMMRAY

The present study forms a part of an investigation carried on to find out the applicability of Corbusier's hypothesis on Human Scale in a specified work situation. Eye angles formed on different critical working points measured for 15 professional typists who acted as subjects in the investigation. The angle formed with the Key board at the shoulder point, while the subject was in working position, was also measured. The relationship between the different angular measurements themselves and also with different body dimensions were analysed following the correlational technique. The habitual sitting postures may influence changes in Eye angles. The total area of Eye movement is found to be about 70° for the job of typewriting. It is also suggested that the distance of controls should be at about 11.55 inches from the chest for more efficient operation and comfortable sitting posture, so far as task of manual control involving chain reaction (as typewriting) is concerned. Working height of the controls should be at an Eye angle of 30 degrees.

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# Optimizing System and Machine Design following Human Scale of Proportion[1]

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In our mechanized society, while working tools are being perfected day by day for the benefit of the human race one aspect of research is markedly missing in this direction by the Human Factors Engineers—the measurement of machine dimensions relative to 'human-scale'.

Le Corbusier, the French Architect, advancced the thesis that some measurements should be evolved based entirely on the human body dimensions and the construction of all buildings and machines should be based on that scale (Le Corbusier, 1951). On the basis of his numerous findings he concludes that all the beautiful monuments of ancient times of Parthnon, Indians, Egyptians and Greeks have been constructed with the help of this scale as basis of their measurement, where different human body dimensions are used as units of measurement.

He (Corbusier) studied the relationship of human height with the body dimensions of different objects and again their interrelationship with each other and developed the concept of 'Le Modulor'. The 'Modulor', according to him, is "a harmonious measure to the human scale universally applicable to architecture" (Corbusier, 1951) and probably to any other field where any measurement may at all matter.

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1. The paper is based on a post-graduate thesis work conducted by the author at I. I. T., Kharagpur, India.

2. Thanks are due to the publisher of 'The Modulor', Faber and Faber, London, for their permission to reproduce the figures, to Mr. J. C. Gambhir, architect and Dr. A. Chatterjee of I.I.T., Kharagpur and Dr. Martin I. Kurke of Combat Operation Res. Group, Virginia, U.S.A. for their help.

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Le Corbusier defined the 'Modulor' as 'the measuring tool based on human body dimensions and on mathematics'. A man with arms upraised provides at the determining points of his occupation of space-foot, solarplexus, head, tips of fingers 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 values ; the 'single Unit', the 'double Unit' and the three 'golden sections'.

There are reasons to believe that this one proportionate measurement of the 'golden section' is a concept which is known to the thinkers since the days of antiquity. Pathagoras and his followers were interested in it and, as we know, theorists of the Renaissance period took it up again (especially Leonardo da Vinci), and in our days again Le Corbusier based his principle of 'Proportion', 'Le Modulor' on it. Incidently, it would not be out of place to mention that in Norway Fredrick Mecody Lund published his great work 'Ad Quadaratum' in 20S of the present century and tried, to a large extent successfully, to prove that the great historical works of architecture—both of ancient, prehistoric as well as of modern and contemporary time—were and are, knowingly or unknowingly, based on the proportion of the 'golden section'.

According to the golden section a line segment is divided 'when it is composed of two unequal parts of which the first is to the second as the second is to the whole (Corbusier, 1951) and in this way, by simply adding and subtracting, one can get an infinite series of line segments which grow according to the 'golden section'.

Le Corbu has gone much forward than the original old concept in his cultivation of the golden section The basic ideas behind his researches (for architectural designs) were :

1. There are certain definite relationships between the important dimensions of the human body.
2. The relationships exist in other natural objects also—they are universal.
3. Using the relationship a scale can be constructed which can provide critical dimensions for building, machine and equipment design and for preparation of an scale of aesthetic, comfort and efficiency.



It was probably Leonardo da Vinci who first observed an important relationship between different dimensions of the human body. He diagrammatically explained that—

a) with both hands stretched the measurement is equal to the height of man closed in a square, and,

b) putting hands stretched at angles man can be enclosed in a circle.

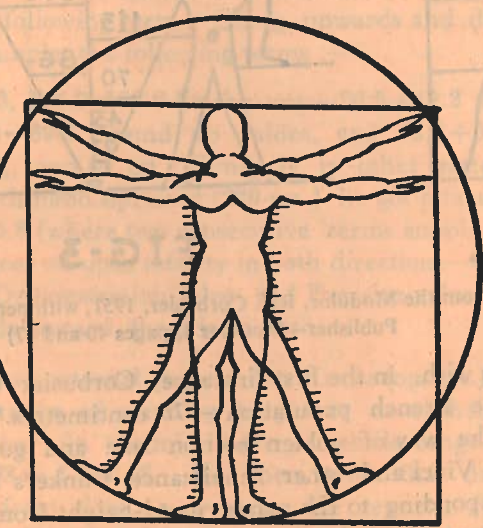

**FIG. 1.**

**(Fig. 1, based on Leonardo da Vinci's Concept)**

After Leonardo da Vinci no further serious work was done in this direction till Corbusier took up the subject for a far more elaborate study and added the following further observations—

1. The man's total height with arms raised is double the height of the man's navel (Solarplexus). (Fig. 2)
2. The dimensions of man's height upto his head is 1.617 times of the height of the solarplexus, both the measurements taken from the ground. This relation of 1 : 1.617 is the same old *golden-mean* ratio.

3. The golden mean ratio is obtained in all the different dimensions of the body in their relations between each other.

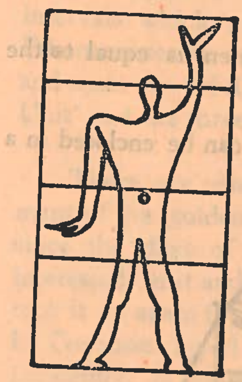

FIG-2

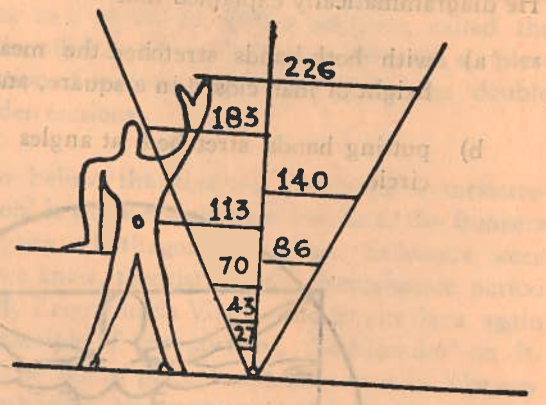


FIG-3

(Fig 2 & 3, from the Modulor, Ref. Corbusier, 1951, with permission from the Publisher—Modulor 1, pages 40 and 67)

To start with, in the first instance, Corbusier took the average height of the French population—175 centimetres.* The figure he divided in the way of golden section rule and got 108 cm. Like Leonardo da Vinci and other renaissance thinkers he observed this height corresponding to the man's navel-height from the floor. The fact, so obvious through measurement, probably carried a deeper philosophical meaning that man as nature's perfect creation, was proportioned according to this noble rule of ratio and nature was quick to display 'the point of inter-section' by neatly marking a little circle there—the navel.

Later on he realized that the average height of the English was about six feets (163 cm.)* and as he knew that the average height is increasing all over the world the fear was natural in him that his houses would be too small in the long run if he utilized a measuring figure derived from the average Frenchman's height. So 183 cm. was decided to be taken as definitive quantity to base for his two final series of measuring figures (initially to be called Fibonacci series).

* Dr. Martin K. Kurke of Combat Operation Research Group, Virginia, U.S.A., points out that contrary to Corbusier's assertions, for the average height of British and French about 176 cm. and 175 cm., respectively (including women), are closer figures (Kurke, 1966).



The other reason to take 6 ft. as model human height was to fit the largest percentile of the human population and to have a generalizing capacity for the concept.

Like the previous case of 175 cm., this 183 cm. was divided by middle-solarplexus and calculating the golden mean difference (1 : 1.617) from two points (Solarplexus and finger tips with arms upraised) he obtained his series of measuring figures. In this series the addition or subtraction, as the case may be, of two consecutive terms supply the following term. Going upwards and down in this way he got, for example, the following terms :—

26.5, 42.2, 69.3, 113.0, 182.9 [in the way—26.5+43.2 (26.5, being 1.6 value of 43.2)=69.8, round up values, and 43.2+69.8=113.0, 113.0+69.8=182.8], and so on. Similarly in other series, starting from finger tips with hand upraised (226 cm.) he got following values, as 139.7, 226.1, 365.8 (where two consecutive terms supply the following term). This goes on upto infinity in both directions—upward and downward. (See Demonstration value and Exercise value, Corbusier, 1951, p. 82). To downward, there is no zero.

However, on my personal request Dr. Kurke (op. cit.) calculated the golden mean ratios of standing height to navel height of the American population. In the middle 90 percentile range these ratios range from 1 : 1.63 to 1 : 1.68. He, then, adds that data on men appear to differ from data on women. He reports, for instance, standing height to elbow height ranging from 1 : 1.54 to 1 : 1.58 for men and from 1 : 1.58 to 1 : 1.6 for women. But these figures, of course, do not invalidate the basic concept if one would accept, as proposed here, a ratio with only two significant figures, *i.e.*, 1 : 1.6 as an approximation of the average person. Then again it is a working hypothesis and the way of measurement should be considered in its specific context.

In both of these series most of the values correspond to some of the critical body dimensions' height measures taken from the earth surface. Thus Corbusier drew up a scale of figures which pinned down the human body at the decisive points of occupation of space and he called them to be 'anthropocentric'.

The decisive points and calculations on the golden mean section ($\phi$ of 1.617) taking the height of man as 183 centimetres, are as follows :—

The Unit A (=113) Solarplexus.

The Double Unit B (=226) The finger tips with hands upraised.

The relationship (1 : 1.617) of A to head C=(113+70 ; *i.e.*, 113×1.617)=183 ; Head values.

The $\phi$ relationship (1 : 1.617) of B to palm with hands downwards D=(226—140 ; *i.e.*, 226/1.167 values)=86.

(all figures in centimetres ; see Fig 2).

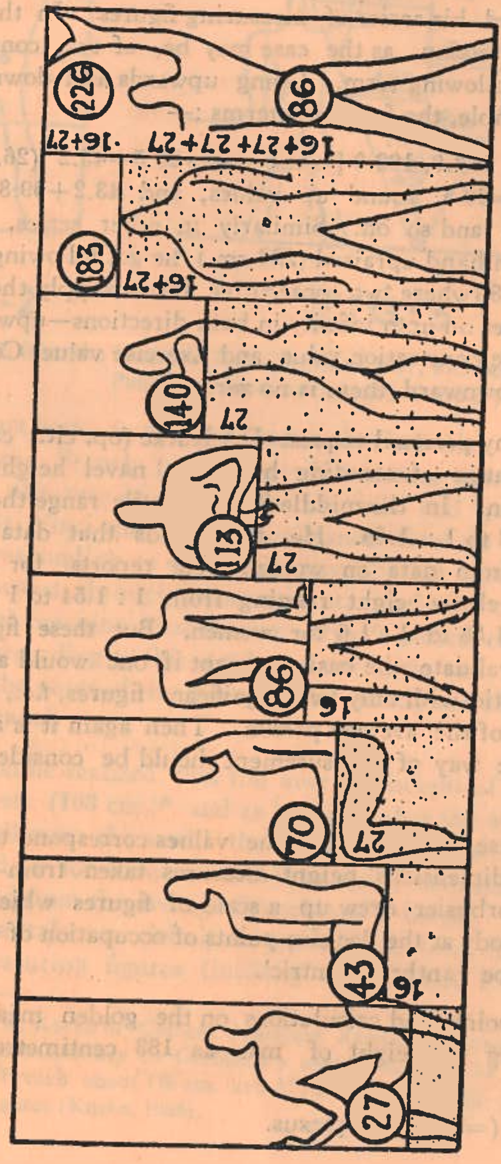


FIG-4

(Fig. 4, from the Modulor-I, p. 67, with permission of the Publisher)



So the rule essentially projects its central focus on the key points of occupation of space of human body and it represents the simplest and most fundamental mathematical progression of values, namely, the ***Unit*** (Solarplexus), the ***Double Unit*** (finger tips with hands upraised) and the golden mean added (C-183 cm. Head) and subtracted (D-86 cm. palms with hands downward).

Later on the series arising from the '***Unit***' was named '***Red series***' and the series arising from the '***Double unit***' was called '***Blue series***' and the name Fibonacci series was given up. Le Corbusier studied the golden mean ratio for decades very vigorously and observed this natural phenomena operating in mountains, plants and animals, etc. In the unity and diversity of nature he confirmed the existence of golden mean relationship. Distance between modest interrelationship of three branches was observed carrying the same relationship. Many snail shell, for example, have whorls which grow steadily larger in regular progression from the innermost to the outermost but at the same time the whorls grow in several dimensions so that they continue to keep on the same proportion.

The simple wish of the author here in introducing the concept of Modulor is to present this wonderful idea of human dimensional-scale values for the attention of Design Engineers and Engineering Psychologist. In spite of advance researches in the human factors science it was felt that probably many of the conflicting findings through researches (so far measurements are concerned) might be primarily due to the simple fact that our measuring tools are artificial and that we are overlooking nature's law. The Modulor gives us a possibility of evolving a new scale based on human-body dimension and golden mean ratio (entirely just on 'Modulor' line or somewhat different with experimental support) which would be true to the nature's law. The Modulor, we feel, is another attestation of the view that not only sensory-motor-psychic areas to date so common fields of study in Psychology are of sole importance. But if we are careful enough to note the nature's law about measurements, the very concepts of our contemporary measuring tools prevalent in our society have to be tested and probably changed. Our inches or metres must be based on these natural human dimensions if they are to be used for man's benefit. To this effect supporting experimental evidences are not entirely lacking. Unknowingly, of course, many architects, design engineers and even human engineers have indirectly supported the concept on the basis of their experimental findings. Quite innocently they have arrived at results which add testimony to the concept of 'Modulor'.

The famous architect, to begin with, Kaare Klint believed that many kinds of furniture have standard dimensions based on the proportions of human body. In fact as early as in 1918 he designed a whole series of commercial furniture adapted to human measurements and human needs (Ramussen, 1964). It would not be out of place to mention agreeing with Corbusier himself, that the various measurements, from man's height down, can be employed for different purposes and functions, such as the height of desk or platform, table heights, various seat heights, etc.

In Ergonomics field also Akerblom's finding suggests that maximum male $S_s$ can adjust on 44 cm. While women round about 40 cm. only (Akerblom, 1954). Hooten recommended that seat height for railways should be between 42 to 43 cm. in order to accommodate the largest percentile of the population except the shortest 5 percent of the travellers (In McCormick, 1957).

Here, we may mention a recent Indian study by Prof. P.V. Krishna Iyer and M.N. Bhattacharyya on body measurements in relation to Cockpit design. On the basis of measurements of various body dimensions (all 22) of 691 Indian airmen they found a linear relationship among different body dimensions. All the partial regression coefficients were significant at 1 per cent level. They have reported the regression equation of total length ($X_1$) on knee height ($X_2$) and thigh ($X_3$) as—

$X_1 = 108.58 + 1.17\ (X_2 - 54.77) + 0.68\ (X_3 - 58.24)$, where the partial regression coefficient was highly significant (Iyer & Bhattacharyya, 1966).

These findings suggest at least partially that the concept of Modulor carries some truth. These two measures so near among themselves are clearly in direct correspondence with a definite value (of 43.2 cm.) in the *Red series* of Modulor (Corbusier, 1951, Table, p. 82). In the same way it may well be hypothesized that if a working table height would be under study and Modulor holds good, a most comfortable seat and working table adjustment would be in interrelation of the 1 : 1.617 ratio. In other words it is expected that the most desirable heights of both the working table and the seat should be in correspondence to some of the critical human body dimensions while



their own interrelationship should be proportionate and carry the same ratio of 1 : 1.617.

In the same way the concept can be useful and tested in several aspects of Engineering Psychology, for example, besides layout design, length and breadth of letter or traffic signs for better visibility, size of hammers for more efficient handling, design of machine for more human touch and comfort, etc., to mention a few.

In author's won studies the concept was put to test of experimental verification (Daftuar, 1964, 1966 and Chatterjee and Daftuar, 1966). The study was conducted to determine the relative height of the stool and working table with reference to human (5) height in the job of typewriting. On the basis of results obtained it was tentatively concluded with certain reservations that, (a) different body dimensions follow a definite pattern of ratio which is 1 : 1.617, (b) the relationship of 1 : 1.617 is true with other objects also particularly the working situations of man (the conclusion suggests that probably the human scale value can be applied in all situations, where human beings are concerned), (c) the best efficiency can be achieved (here in term of typing materials) when the stool and working tables are in the $\phi$ (1 : 1.617) relationship, and besides efficiency and (d) taking the ideal heights of stool and chairs (1 : 1.616 relation) the total area of eye-movement too, in terms of degrees, remained near about 70 degrees even when the materials were on two different levels (Daftuar, 1966).

In the context it may be claimed that Modulor's concept of rule of law is intimately tied to a rule of life. It is a beautiful expression of what it means. It is nothing like a system of repetitive identical dimensions of dreary short, rather it is a system of related proportion based upon the ancient "Golden Section" and the human figure that reflects that "Section". This rule of law which the French Architect has tried to bring into his art may some day be considered as one of the most outstanding contribution that has ever been made to the human culture.

However, the claims are yet to be verified and, in spite of verification of the concept by the present author (op. cit.), the writer refrains himself from any generalized comment at the moment. The concept is well now open for further study-test and retest—till a generalized valued answer is established. However, the present writer feels, with a specialized knowledge of man's capabilities—sensory, motor or intellectual—and advantages of research techniques in our disposal, we—the human factors engineers—are better equipped to test the Corbusier concept's validity. Of course, an extensive research programme needs to be executed because we know, the human body, its structural and mechanical function, occupies a central place in man-machine system. If the designer fails to provide a few centimetres critical for the operator it will not only jeopardize the performance but may even ruin the health and life of both man and machine.

**Summary**

The 'Modulor' concept has been dealt with as an introductory attempt. The 'Modulor' has been defined as a 'harmonious measure to the human scale'. The scale is based on human-body dimensions, its golden-mean ratio and simple mathematics of addition and subtraction of its definite proportionate values. The scale is proposed to be used by Human Engineers to give a natural and human touch in their construction. It is hypothesized that the scale will produce more beauty and comfort in man-machine system. Some previous results have been mentioned along with those of the present author in support of its purposive value. Some areas of applicability in Human Engineering have also been pointed out.

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