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Effect of Biological Rhythm on Cognitive Performance

Ravinder Yadav* and N.P. Singh

DRDO-Defence Institute of Psychological Research, Delhi - 110 054, India
**E-mail: ravinderyadav@dipr.drdo.in*

ABSTRACT

Biological rhythm has contributed in evolution process of humankind and has created certain distinct capabilities and preferences in shaping his phycho-psychological reactions. On the basis of behavioural activities, reactions, preferences and performances during the day-night cycle, individuals are classified in chronotype as morning type (M type) and evening type (E type). Such a differentiation has been hypothesised to contributing to individual differences at the cognitive, affective and conative levels. The present study was an attempt to further study such differentiation in terms of neuro cognitive performance by using the most advanced psycho-physiological measures. The participants of both chronotypes, morning and evening were classified and later subjected to cognitive testing by using the Cambridge Neuropsychological Test Automated Battery in the morning and the evening session under repeated measure design. The study revealed that performance on neuro cognitive functions; Planning and working memory, Decision-making and response control, and Motor skills get effected differently by their biological rhythm cycle and thus under performance in these functions can be attributed to maladaptation of biological rhythm termed as biological dysrhythmia. The study also highlights the role of this behavioural maladaptation in moderating operational efficiency of soldier in combat situation.

Keywords: Biological rhythms; Chronotype; Cognitive performance

1. INTRODUCTION

Biological rhythms are rhythmic biological changes in an organism, with an aim to adapt to the geo-physical cyclic variations. At times, when these rhythmic adaptations get hampered due to environmental (external) or physiological exigencies (internal), an individual enters in a non adaptive state called biological dysrhythmia. These exigencies could be due to the change of working-shift, change at work location, jet lag or personal exigencies with sleepless nights or other physiological conditions.

A comprehensive review of available literature shows that these biological rhythms create cyclic variations in human behaviour that are pervasive and occur throughout the nature. In order to understand this behavioural adaptation phenomenon, researches have classified the individuals as morning types (M-types) and others as evening types (E-types)[1] depending on their behavioural intensities. The M type individuals prefers to work in the morning time and the E type individuals prefers to work in evening time with optimal peak performance.

Basically, researches support the hypothesis that sleeplessness and alertness depends strongly on one's position within this circadian rhythm. The M type person awakes early in the morning, is full of energy and has optimised performance peak before noon whereas an E type person takes up longer time to warm up when he gets up in the morning and achieves their optimal performance post noon[2]. With this consideration it is often observed that for optimum performance in our day to day roles the biological rhythm plays a determining role in one's alertness and sustenance. Since the optimal performance in a task depends on the arousal level of the individual[3], in the morning session, the M type persons attain optimum arousal level earlier than their counterpart chronotype. Similarly, in the evening session E type chronotypes have better level of arousal which enhances their optimal peak performance. This effect of chronotype on performance has been revealed on both physical task[4] as well as cognitive functioning[5]. High alertness during optimal performance state means vasoconstriction, less heat loss, and delayed core-body temperature decline. However, during sleep-deprived situations, when a person struggles to overcome sleeplessness by blinking & fidgeting[2] tries to compensate for optimum sustained attention. Even short-term sleep deprivation produces decline in general brain activity. With respect to gender differences, morningness is more associated with female gender[6] and is also highly correlated with decreased risk of aggressive behaviour, attention problems, and delinquent behaviours but it does not mean that this aspect inoculates females from the risk of depressive symptoms. On the other hand, eveningness is associated with anxious/depressive symptoms and substance use in adolescent[7,8] and adults[9,10], without differencing the gender aspect.

Further dwelling on the pattern of sleep cycle researches have found the significance of external cues in one's sleep cycle, when human volunteers were isolated from environmental cues they manifested various forms of mental disorder such as depression[11]. Cues like the sunlight, sounds, daily routine

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of food intake exercise etc. synchronise the rhythmic cycles of the body temperature, and the sleep cycle. At times, these two circadian rhythms, patterned for M type and E type can become de-synchronised where one chronotype person has to perform the activities at his disadvantage period of day i.e. M type is required to perform in the evening and E type is forced to perform in the morning often leading to what is called dysrhythmic cycle. Disruption of cycles constitutes a stress factor that can elicit both autonomic and neuroendocrine adaption syndromes that adversely effects various motor and cognitive functioning. This disturbance in biological rhythm of an individual is considered as biological stress[12] which creates dysrhythmic conditions in certain jobs.

Dwelling on the nature of task performance with its effectiveness, certain roles require tasks to be performed perfectly with optimum precision, irrespective of the time of day-night cycle or at times with the predetermined group of persons irrespective of synchronised rhythmic cycle. In these roles there is no liberty to decide the time or the group to execute the task especially the military operations where soldier is required to perform at peak of his capacity. In these conditions the rhythmic cycle has significant relevance to the optimal efficiency of soldiers involved in various types of combat operations, where the day/night schedule and cycle is considered as an important aspect of operational plans. The M type soldier may be a more ideal chronotype for morning type operations wherein they are likely to perform at their optimum peak with less likely to have in attention and manifestation of the psycho-social problems at operational duty[13]. The E type soldiers strive hard to perform better in the day time and have reported more psycho-social and psychosomatic disturbances as compared to other chronotype soldiers[14] during morning time.

In military scenario where zero error syndrome lingers, efforts are required to optimise the performance based on their chronotype or the task based on the period of the day. The present study was an attempt to further explore the impact of dysrhythmic cycle on neuro cognitive functions which have significant importance for soldierly decision making process. Though the study is not conducted on the soldiers but the results will have significant relevance to the soldierly decision making process. With this consideration the study aimed to:

To study the impact of chronotype in two extreme circadian periods (early morning and late evening session) on performance on selected neuro cognitive tasks like: i) planning, ii) working memory, iii) decision making, iv) response control, and v) motor task.

The available literature guides for the following hypothesis

- H_0: In the early morning session, the E type person will perform at par with the M type person on planning and working memory, decision making and response control, and motor task
- H_0: In the late evening session, the M type person will perform at par with the E type person on planning and working memory, decision making and response control, and motor task.

2. METHOD AND PROCEDURE

2.1 Sample

450 students of graduate level from Delhi University and Bhopal selection centre were screened for chronotype classification by using Composite Scale of morningness & eveningness developed by Smith[15], *et al.* Based on their scores on the scale, a final sample pool comprised of 41 adolescents (34 as M type and 7 as E type), having age of 20 $\pm$ 2 years.

2.2 Tool Used

2.2.1 Composite Scale of Morningness & Eveningness

The scale developed by Smith[15], *et al.* with 13-item, the items with the best internal measurement properties of two published scales. Its score ranges from 13 (extreme E type) to 55 (extreme morning type). The composite scale possesses external measurement properties comparable with or slightly better than the two parent scales from which it was desired. The scoring information and raw score interval classified participants as evening, intermediate or morning type. The coefficient alpha of 0.87, of the scale, indicates that the composite scale possesses desired internal consistency reliability. The correlations between the composite scale with the Horne & Ostberg scale[16] and the Torsvall & Akerstedt scale[17] are 0.95 and 0.75, respectively, manifesting its validity index.

2.2.2 Assessment of Neuro-cognitive Performance

The neuro-cognitive functions were assessed by using Cambridge Neuropsychological Test Automated Battery (CANTAB)[18] test-battery that catered for sustained attention, vigilance, working memory, response inhibition, hyperactivity,

Table 1. Tests and measures

Task type	Test	Measure
Motor skills	Motor control task (MOT)	Mean latency
Planning and working memory	One touch stocking (OTS)	1. Mean choices to correct (6 moves) 2. Mean latency to first choice move 3. Mean latency to first choice (1 move) 4. Mean latency to first choice (2 moves) 5. Mean latency to first choice (3 moves) 6. Mean latency to first choice (4 moves) 7. Mean latency to first choice (5 moves) 8. Mean latency to first choice (6 moves) 9. Mean latency to correct (1 move)
Decision-making and response control tests	Spatial span (SST)	SSD (50%) (last half)

impulsivity etc[19]. The tests of CANTAB were already classified in testing various domains of brain functioning. The selection of 3 neuro-cognitive tests being used in present study was based on a feasibility study conducted in DRDO-Defence Institute of Psychological Research, Delhi on a sample of 12 adolescents. The final test battery consisted of following three tests selected for assessing neuro cognitive functions as shown in Table 1.

2.2.2.1 Motor Skills

Assessed through motor control task (MOT). The purpose of this test was to identify any problems in vision, movement, eye hand coordination and comprehension of the instruction. The task pertained to the fronto-parietal cortices of the brain[20].

2.2.2.2 Planning and Working Memory

Assessed through one touch stockings (OTS). It was a test of planning and working memory. Performance on this test activates a neural network of structures including the dorso lateral prefrontal cortex[21].

2.2.2.3 Decision Making and Response Control

Assessed through stop signal task (SST). The test measured the subject's ability to inhibit a response. The test was associated with integrity of the inferior frontal gyrus[22].

2.3 Procedure

Initially a random sample of 450 participant was taken and they were given the composite scale of morningness and eveningness. Based on the obtained scores, the subjects were classified as M type with a score > 43 score and E type with a score < 23. These 41 adolescent (34 M type and 7 E type), had age range of 20 $\pm$ 2 yrs. Since the two group participants were decided through chronotype screening, therefore, nonequivalent group was used under repeated measure design.

These 41 participant were further tested on the two parallel batteries, comprised of three tests each of CANTAB, mentioned in Table 1. The complete pattern of testing followed is provided in Table 2.

Table 2. Session and chronotype

		Morning session	Evening session
Type	Morning type	34	34
	E type	7	7

Following the repeated measurement design the performance of two chronotype group was assessed on neuro cognitive tests. As shown in Table 2, the participants were tested on the battery of tests in two session, one in the early morning and other in the late evening. Each participant was tested in these two sessions. The participants were tested with at least a gap of day for the other session. They were given the tests in the morning and evening settings as per the schedule mentioned in Table 3.

As mentioned in the Table 3, if subject 'A' was tested on the morning session of day 1 then he was tested for evening session on day 3 on a parallel test battery, i.e. after at least a gap of one day. Similarly, subject 'B' is tested on the evening session of day 1 then he was tested for morning session on day 3 on a parallel test battery, i.e. at least a gap of one day.

The instructions were given as provided in the instruction-booklet of the CANTAB during the conduction of each test of the battery in every session.

Table 3. Schedule of testing

Sessions	Day 1	Day 2	Day 3	Day 4
Morning (Before Sunrise)	A	C	B	D
Evening (After dusk)	B	D	A	C

3. SCORING SND STATISTICAL ANALYSIS

The data were obtained on the CANTAB battery comprising of 3 neuro-cognitive tests from 41 participants in two settings for each individual i.e. in early morning and in late evening as per following procedure.

3.1 Test Scores 1

The scores of motor skill were pervaded by the motor control task (MOT) in terms of the mean latency period (µs) that a participant took in responding correctly.

3.2 Test Scores 2

The scores of planning and working memory were provided by one touch stocking (OTS) in the following forms

- Choices or options exhausted in responding correctly for sixth level (toughest level) i.e. mean choices to correct moves for six
- Time lapse (ms) in executing the first move as a whole i.e. mean latency to first choice move
- Time lapse (ms) in executing the first move for various level (1 to 6) i.e. mean latency to first choice move (1 to 6)
- Time lapse (ms) in rightly moving the first move i.e. mean latency to correct.

3.3 Test Scores 3

The scores for decision making and response control tests were obtained through spatial span (SST) in the form of time lapse (µs) in correct responding in the last half phase i.e. SSD (50 %) (last half).

The results of the testing were obtained by analysing comparative difference between the M type and E type individuals, on the bases of performance during the test sessions i.e. (i) Early-morning performance and (ii) Late-evening performance. To study the differences independent t-test is used separately for two setting (Tables 4 & 5). Further analysis was undertaken using Levene's test for equality of variance and independent sample t-test for equality of means.

4. RESULTS AND DISCUSSION

The mean scores and standard deviation obtained on the battery of three test, in the morning session and in the evening session, for each participant that is grouped in M type or E type are provided in Table 4 for both the sessions. Analysis of the results is discussed under following heads.

- Difference in the performance due to Circadian rhythm (M type and E type) in the morning session

Table 4. Group statistics

Test	Parameter	Participant type (Morning/Evening)	N	Morning time Mean	Morning time Std. deviation	Evening time Mean	Evening time Std. deviation
MOT	Mean latency	Morning type	34	888.31	336.405	971.1	270.11
		E type	7	734.21	93.458	696	139.43
OTS	Mean choices to correct (6 moves)	Morning type	34	1.5	0.491	1.7	0.82
		E type	7	2.18	0.943	1.6	1.1
	Mean latency to first choice move	Morning type	34	16555.33	9292.031	16816	6894.5
		E type	7	19478.7	7816.394	15779	7102.9
	Mean latency to first choice (1 move)	Morning type	34	5705.96	2947.383	7360	3997.8
		E type	7	8417.79	2923.782	6820	3072
	Mean latency to first choice (2 moves)	Morning type	34	5434.31	2355.123	6384	3235.9
		E type	7	7810.5	2174.222	6490	2767.3
	Mean latency to first choice (3 moves)	Morning type	34	6698.79	2653.545	7741	3846.5
		E type	7	7846.11	969.757	7349	2408.5
	Mean latency to first choice (4 moves)	Morning type	34	11348	4411.424	13092	6258.2
		E type	7	13258.5	2946.62	9041	3238.7
	Mean latency to first choice (5 moves)	Morning type	34	25665.71	15045.642	31299	16443.6
		E type	7	41604.32	31263.682	28832	13370.4
	Mean latency to first choice (6 moves)	Morning type	34	45367.57	33062.369	36330	18415.2
		E type	7	37935	20976.348	36141	20502.6
	Mean latency to correct (1 move)	Morning type	34	6162.85	2619.56	8002	3762.7
		E type	7	8417.79	2923.782	6820	3072
SST	SSD (50%) (last half)	Morning type	34	162.02	107.892	145.1	152.41
		E type	7	268.84	129.451	166.8	70.96

- Difference in the performance due to Circadian rhythm (M type and E type) in the evening session.

4.1 Morning Session

The performance of both the chronotype were compared using the independent samples t test where an alpha level of 0.05 is used for all the tests. The performance on the motor skills measured through the motor control task (MOT) revealed that the M type participants (M= 888.31, SD= 336.4, N= 34) (Table 4) took slightly more latency period (i.e. low performance on motor skills) in responding than the E type participants (M=734.21, SD= 93.45, N= 7), t (39) =1.19, p= .241, two tailed (Fig. 1, Table 5). The difference of 154.1 points was not significant enough to have the 95 per cent confidence interval around difference between the group means. Therefore, the results support one aspect of the hypothesis no. 1, that in the early morning session, the E type person will perform at par with the M type person on motor task.

The results of the independent sample *t* test on the performance of test battery of morning session revealed that there exists significant difference between M and E type of participants in Planning & working memory measured through the test of One Touch Stocking (OTS) and in decision making and response control measured through Stop Signal Task (SST).

In morning session, M and E type participants showed significant difference in the performance on five measures of planning and working memory (OTS) testing (Tables 4, 5).

- Mean choices to 6 moves, emerged significant at 0.01 level, where M type took lesser choices to respond correctly (M= 1.5, SD= 0.491, N= 34) than the E type participants (M= 2.18, SD= 0.943, N= 7), t (39) = -2.82, p = 0.008, two tailed. But the Levene's test**,** F (39) = 7. 20, p = 0.011 shows that there exists a significant difference at .01 level, in the homogeneity of the two samples. Hence these two samples are not comparable for mean differences.
- Mean latency to first choice (1 move), emerged significant at .03 level, where M type (M= 5705.96, SD= 2947.38, N= 34) took lesser latency period to respond correctly than the E type participants (M= 8417.79, SD= 2923.782, N= 7), t (39) = -2.22, p = 0.032, two tailed. Also, the Levene's test, F (39) =0.008, p = 0.93 shows that there exists a

Table 5. Independent samples test

Test	Parameters	Morning session						Evening session					
		Levene's test		t-test for equality of means				Levene's Test		t-test for equality of means			
		F	Sig.	*t*	*df*	Sig. (2-tailed)	Mean Diff	F	Sig.	*t*	*df*	Sig. (2-tailed)	Mean Diff
MOT	Mean latency1mor	7.093	0.011	1.191	39	0.241	154.1	2.223	0.144	2.605	39	0.013	275.1
	Mean choices to correct (6 moves)	7.202	0.011	-2.82	39	0.008	-0.68	1.744	0.194	0.035	39	0.972	0.01
	Mean latency to first choice	0.02	0.887	-0.78	39	0.443	-2923	0.001	0.975	0.361	39	0.72	1038
	Mean latency to first choice (1 move)	0.008	0.93	-2.22	39	0.032	-2712	0.287	0.595	0.336	39	0.738	540.4
	Mean latency to first choice (2 move)	0.215	0.645	-2.46	39	0.018	-2376	0.001	0.974	-0.08	39	0.936	-105
OTS	Mean latency to first choice (3 moves)	1.583	0.216	-1.12	39	0.27	-1147	2.02	0.163	0.258	39	0.798	392.6
	Mean latency to first choice (4 moves)	1.069	0.307	-1.09	39	0.282	-1911	3.759	0.06	1.655	39	0.106	4051
	Mean latency to first choice (5 move)	15.91	0.0	-2.08	39	0.044	-15939	0.442	0.51	0.371	39	0.712	2468
	Mean latency to first choice (6 moves)	0.918	0.344	0.568	39	0.573	7433	0.203	0.655	0.024	39	0.981	189.3
	Mean latency to correct (1 move)	0.008	0.929	-2.04	39	0.049	-2255	0.154	0.697	0.777	39	0.442	1182
SST	SSD (50%) (last half)	0.657	0.422	-2.31	39	0.026	-107	2.956	0.093	-0.37	39	0.717	-21.7

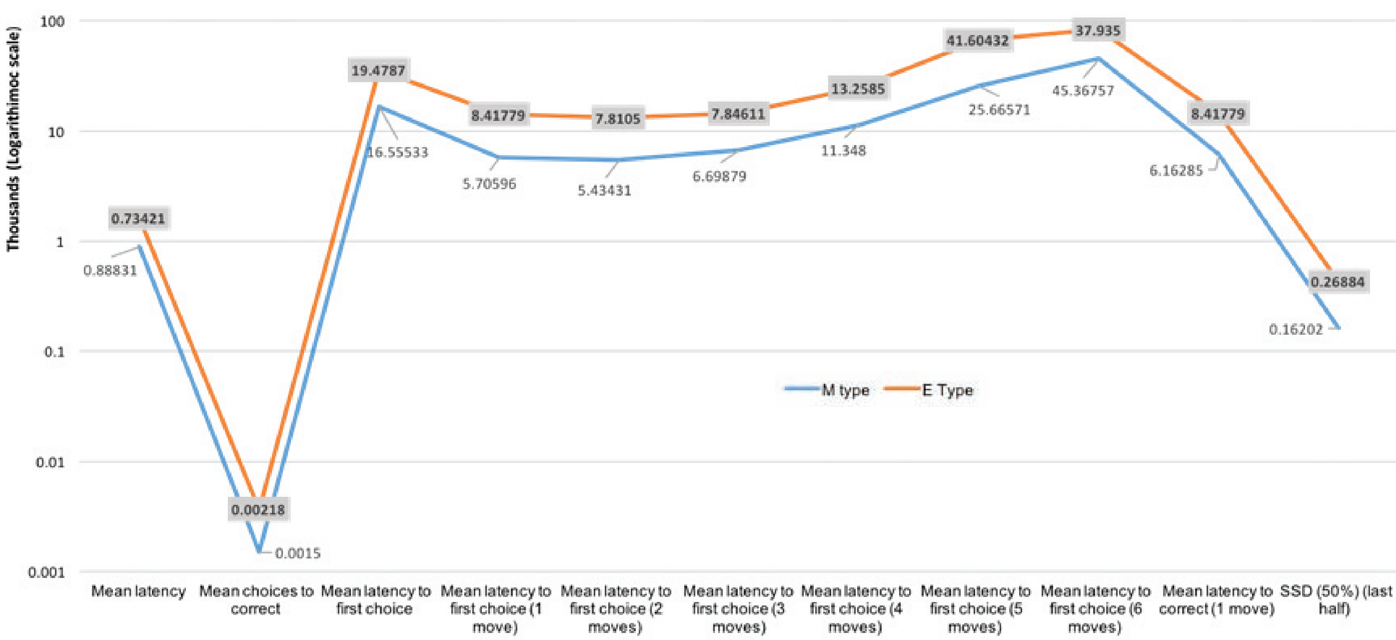

Figure 1. Morning session performance (time in micro unit).

non significant difference between the groups, as the two samples are homogeneous. Hence the significant difference exists between the two sample means is confirmed.

- Mean latency to first choice (2 move), emerged significant at .01 level, where M type (M= 5434.31, SD= 2355.123, N= 34) took lesser latency period to respond correctly than the E type participants (M= 7810.5, SD= 2174.222, N= 7), t (39) = -2.46, p = 0.018, two tailed. Also, the Levene's test, F (39) =0.215, p = 0.645 shows that there exists a non significant difference between the groups, as the two samples are homogeneous. Hence the significant difference exists between the performance of two samples is confirmed.

- Mean latency to first choice (5 move) significant at .04 level, where M type (M= 25665.71, SD= 15045.64, N= 34) took lesser latency period to respond correctly than the E type participants (M= 41604.32, SD= 31263.68, N= 7), t (39) = -2.08, p = 0.044, two tailed. But the Levene's test, F (39) =15.91, p = 0.001 shows that there exists a significant difference at .01 level, in the homogeneity of the two samples. Hence these two samples are not comparable for mean differences.
- Mean latency to correct (1 move) significant at .05 level, where M type (M= 6162.85, SD= 2619.56, N= 34) took lesser latency period to respond correctly than the E type participants (M= 8417.79, SD= 2923.782, N= 7), t (39) = -2.04, p = 0.049, two tailed. Also, the Levene's test, F (39) = 0.008, p = 0.929 shows that there exists a non significant difference between the groups, as the two sample are homogeneous. Hence the significant difference between the performance of two sample means exists.

In all the five measures (although two cases have sample homogeneity issues) related with planning and working memory, the performance of the M type superseded the performance of the E type participants, be it choosing the correct options, making prompt planning and considering best move from multiple options. In all there exist a 95 per cent confidence interval between the means of two groups in three measures, barring two measures for homogeneity issue in sample. Therefore, the results refuted one other aspect of hypothesis no.1, that in the early morning session, the E type person will perform at par with the M type person on planning and working memory. The M type person have out performed E type person on these cognitive aspects of planning and working memory.

In the task of decision making and response control (i.e. SST), the scores of SSD (stop signal delay) in last 50 per cent of the time, showed that the M type participants performed better than the E type participants by taking less delay period in making correct opting for the correct response. The score of mean delay-period of M type participants (M= 162.02, SD= 107.89, N= 34) was less than the score of mean delay period of E type participants (M= 268.84, SD= 129.451, N= 7), t (39) = -2.31, p = 0.026, two tailed. Levene's test F (39) =0.657, p = 0.422 also indicate that the two samples have no difference in their homogeneity. The mean difference of -107 has created the difference of 95 per cent confidence interval between the two groups. Therefore, the results also refuted the remaining aspect hypothesis no. 1, that in the early morning session, the E type person will perform at par with the M type person on decision making and response control. The M type participants have performed better in decision making and response control than the E type participants.

The significant variations have been found in the morning session on one touch stocking (OTS) and Stop signal test (SST) where M type participants have performed better than the E type person. Since, OTS is a spatial planning test variant that gives a measure of dorsolateral prefrontal cortex[21], which measures the planning and working memory. The SST is a measure of decision-making and response control tests; this is associated with integrity of the inferior frontal gyrus[22]. Therefore, it can be concluded that in the morning time, the frontal lobe functioning of the M type person are relatively better than the E type person. The frontal lobe functioning is related to working memory, planning, and decision-making.

4.2 Evening Session

The results of the independent sample t test on the test battery of evening session indicate significant difference in the motor skills where an alpha level of 0.05 is used for all the tests.

It was found that performance on motor skills measured through the motor control task (MOT) the mean latency of E type participants (M= 696.0, SD= 139.43, N= 7), is significantly

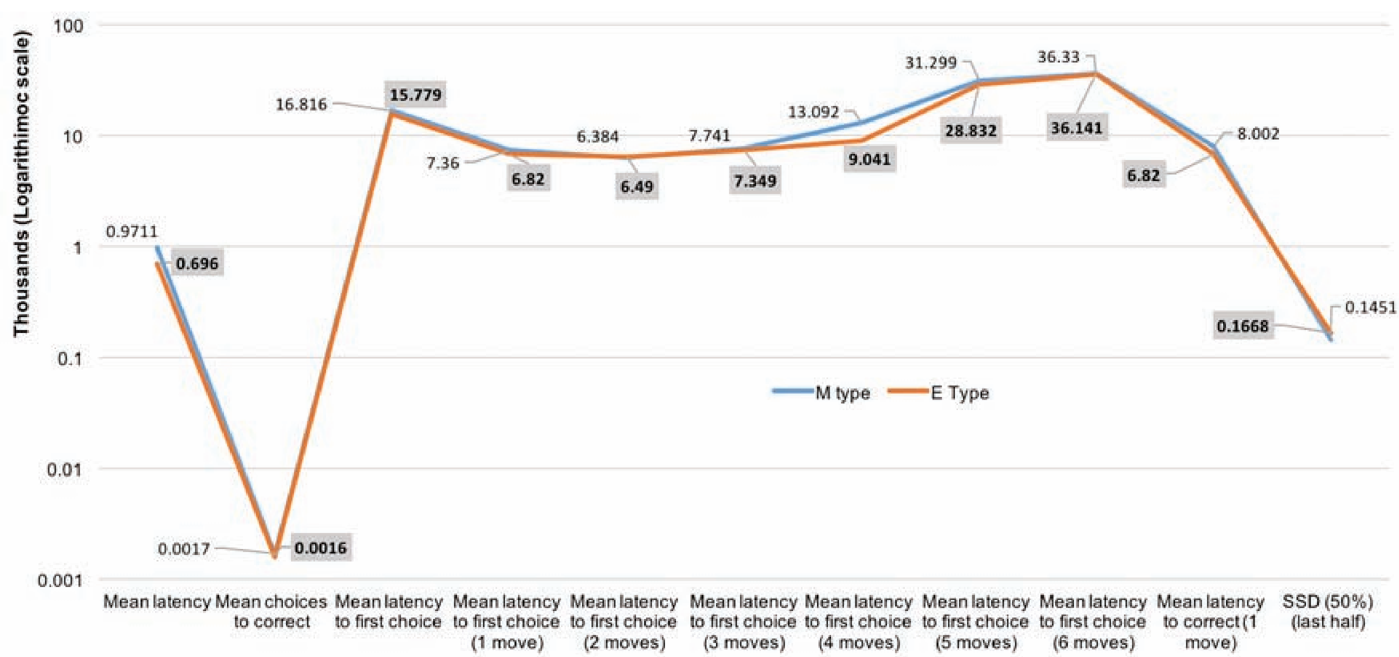

Figure 2. Evening session performance (time in micro unit)

less than that of the M type participants (M= 971.1, SD= 270.11, N= 34), t (39) = 2.605, p = 0.013, two tailed (Table 4 & Table 5). The Levene's test F (39) =2.223, p = 0.144 also indicates the homogeneity of two samples (Fig. 2). Thus the mean difference of 275.1 has created the 99 per cent confidence interval between the means of two group. Therefore, the results rejected one aspect of the null hypothesis no. 2 related with motor skills that in the evening session, the M type person will perform at par with E type person on motor task. Now, it can be concluded that E type participants perform significantly better than their counterpart by taking less time in initiating the task involving motor control in the evening session.

In rest of the six tests no significant difference was found, related to the performance of M type and E type participants, in the evening session. Therefore, the results support the remaining two aspect of hypotheses no. 2. that in the evening session, the M type person will perform at par with E type person on planning and working memory, and decision making and response control.

The significant difference in the mean latency of the motor control task, which provides measures of both speed and accuracy. Calculated through the index of the subjects' motor skill, revealed the difference in the speed of motor skills in the M typeand E type persons. Hence in the evening session, E type persons performed better than the M type persons on motor skills that pertains to fronto-parietal cortices of the brain[20].

5. CONCLUSIONS

Hence the results revealed that the variation arousal level does not hamper the performance on various neuro cognitive tasks uniformly, with respect to the day-night cycle certain cognitive functions are more vulnerable. In the early morning session, M type person have edge over their counter chronotype (i.e. E type) only on the planning and working memory, and decision making and response control but not over the motor skills; whereas in evening session, E type person perform better on motor skills and not on the other two neuro cognitive functions than M type person. The differential performance can be attributed to mental load generated by the biological *dysrhythmia* that impedes the neuro cognitive brain region, differently, for both the chronotypes. In the morning session, the M type person performed better than E type person in planning, working memory, decision-making and response control but not in motor skills. Whereas, on motor skills E type person performed better than M type person in the evening session, but not on the other two cognitive functions. Therefore, following higher order neuro cognitive functions.

- Planning and working memory
- Decision-making and response control,
- Motor skills get effected differently by biological dysrhythmia and these functions can also be treated as the markers of biological dysrhythmia.

6. IMPLICATIONS

The findings of the study suggest the need for in-depth studies to investigate chronotype and their relationship with various cognitive functions. Results of the study leads one to suggest the significance of biological rhythm and impact of dysrhythmia on certain neuro cognitive functions involved in decision making process. In situations where decision making is incremental towards life saving, like soldierly role, the understanding of soldier's rhythmic functions vis-à-vis his operational deployments and engagements have a significant relevance for the human resource manager or commanders at the helm of affairs. Though the study was not conducted on participants having soldierly roles but the need for differentiating the role specific neuro cognitive functions in their decision making engagements draw significant attention as an out come of the study. It leads us to suggest that soldier engagement in morning will have better performance levels. However, the observation need further analysis by a study having soldier subjects.

7. LIMITATIONS

The study was conducted on non equivalent group size because of restricted screening of E type of participants, more representative sample could have been taken.

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CONTRIBUTORS

Dr Ravinder Yadav, obtained his PhD (Psychology) from JNV University, Jodhpur. Presently working as Scientist 'D' at DRDO-Defence Institute of Psychological Research, Delhi. He is a trained cognitive drill therapist. He has experience of other classified R&D Projects and has published research papers in national and international journals of repute.
In the current study he identified the suitable tools and done the liaison with the sample for on field data collection. Administered the tests and subsequently analyzed data using suitable statistical techniques. Finally, the results were interpreted in consultation with coauthor.

Mr N. P. Singh obtained MA and MPhil in Psychology from Guru Nanak Dev University, Amritsar, Punjab. Presently working as Scientist 'G' & Head of the Strategic Behaviour Division at DRDO-Defence Institute of Psychological Research, Delhi. He has more than 54 publications to his credit and has attended various national and International conferences. He has also been associated with various academic association like National Academy of Psychology, National Academy of Applied Psychology.
He is contributed in the conceptual design of the study and defining the implications of the study in military settings. Although the data was collected by the first author, the analysis and interpretation of results was carried out in consultation with the second author.