Defence Life Science Journal, Vol. 7, No. 3, July 2022, pp.169-178, DOI : 10.14429/dlsj.7.17841

Quantification of Mental and Physiological Workload Associated with two Specialised Military Running Events on Different Terrains

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ABSTRACT

Intense training regimes are practiced across military facilities to develop soldiers' mental and physical abilities to meet the demands of modern-day warfare. Two short-duration military runs through the jungle and flat natural tracks were selected to quantify their mental and physiological workloads and explore track-specific differences. Two groups of healthy Indian soldiers (n=43 and 30; similar age, height, and weight) participated in time-bound 2.4 km runs on the jungle and flat natural tracks. Physiological variables, speed, and elevation with environmental parameters like temperature and humidity were recorded throughout the exercises. Subjective responses through NASA-TLX questionnaires were collected after the exercises. Mann-Whitney 'U' test was applied to find out the level of significance between groups.Physiological demands of runs on the jungle and flat natural track were similar (heart rate- 178.9 and 178.4 b/min; breathing rate- 42.0 and 46.6 breaths/min respectively; body temperature- 37.6°C for both groups). The run on the jungle track needed a lower peak acceleration of 2.5 g (2.9 g on the flat track) and a higher variation in speed (4-16 knots). Participants expressed significantly high responses after the run on the jungle track. Run on the jungle track was physically intense, required adjustments in speed and acceleration to negotiate with the natural obstacles like uneven terrain and slippery surfaces. Besides this, environmental heat and higher humidity probably led to an increase in mental workload. The run on the flat natural track needed steady physical effort, fewer mechanical adjustments, and showed lower subjective responses.

Keywords: Mental workload; Subjective response; Mechanical adjustments; Jungle terrain

1. INTRODUCTION

Conventional battle practices have been replaced by modern-day warfare due to changes in overall demographics. The foot soldiers need to face volatile, uncertain, complex, and ambiguous situations. Apart from protecting the country's border, the troops need to encounter Low-Intensity Conflicts (LIC) and Counter-Insurgency (CI) operations. A vast country like India offers difficult terrain and environmental conditions ranging from high mountains of the Himalayas to the rain forests of the central, southern, and north-eastern parts; the desert areas of the western part; and the plains of northern India. The diverse climatic conditions of Indian terrains make it more difficult to optimize physical and cognitive performance. At this juncture, battle fitness has become the most important factor for a successful mission.[1,2,3] Thus, improvised training regimes have been formed to prepare the forces to face any adverse eventuality without compromising their physical and mental abilities. Since the beginning of the service, the soldiers receive thorough physical and tactical training. The Army units across the country strictly follow exercises, mock drills, and a disciplined lifestyle to maintain the physical and mental fitness of the troops. Upgradation of physical or mental effort becomes necessary depending on the warfare situation, terrain, and nature of posting. Specific physical and tactical training is organised to prepare forces to cope with the physical and cognitive requirements and achieve greater lethality and manoeuvrability required in a special type of operations.[1,4]

A scientific assessment of the physical and mental effort requirements of such training events could provide important information to trainers and instructors. Measurement of mental workload during and after physical exercise simultaneous to physiological evaluations has been attempted successfully in the past by collecting subjective responses.[5] The subjective response of a person depends on the specific nature of a task, and their perception of actual physical and mental demands, and is also sometimes

Received : 12 January 2022, Revised : 09 June 2022
Accepted : 24 June 2022, Online published : 13 September 2022

influenced by the current goal, motives, and plans.[6] The response after the completion of a task/exercise becomes accurate with the proper understanding of the rating scale and individuals' ability to narrate their sensations to some quantitative values.[7] On the other hand, continuous monitoring of physiological as well as the mechanical responses of the wearers has been made easy with the use of cardio-pulmonary status monitors.[8] It utilises the data from an in-built Heart Rate (HR) sensor and an accelerometer with an integrated GPS. The system exploits the directly proportional relationship between the body's acceleration and muscular forces[9] to derive mechanical parameters like acceleration, velocity, and altitude-related data when used for experimental studies in the field.[10]

Specialised tactical training continues non-stop with activities for a period of six weeks to three months depending on the location of posting, i.e., jungle or urban to semi-urban areas, and conflict probabilities.[11] Such training requires efficient and fast movements through rough terrain like the jungle and hilly regions. The activities are planned in such a way that they act to improve the morale of the personnel to face the toughest of the situations.[3]

Continuous running with or without equipment has been the common practice in the combat training institutes of India and Worldwide. The importance of running to improve physical fitness and cognitive ability has been documented in the past.[12] Thus, middle to long-distance run is included in the training schedules along with other necessary short-duration exercises to give a complete feel.[13] There is little research in the literature to understand the physiological and mental demands of specialised military activities involving terrain and environment.[14]

Quantitative evaluation of selective personnel undergoing commando or guerrilla type training to operate at higher levels than typical combat soldiers under real-field conditions could provide scientific incite and evidence-based selection of personnel in the future.[15] In that note, several military exercises practiced in Indian combat training institutes were explored with respect to their intensity, physical demands, and differences in track characteristics. Two of such short-distance (2.4 km) running events were selected; one through the jungle and the other on flat natural tracks for scientific evaluation. These time-bound tasks are practiced for improvement of endurance and also to build familiarity and knowledge of the real terrain. The mental demands of such activities were neither predicted nor scientifically explored.

2. OBJECTIVE

To quantify and compare the physiological and mental workload of two military running events covering similar on jungle and flat natural tracks and establish terrain-specific differences.

3. METHODOLOGY

3.1 Participants

Forty-three and thirty soldiers from the Indian Army volunteered for two running events on jungle and flat natural tracks. Their average ages, heights, and weights were 27.1 (±1.9) and 26.9 (±1.9), respectively; 1.7 (±0.35) and 1.7 (±0.37) m; and 68.0 (±5.6) and 67.7 (±4.5) kg. The study sample was purposefully recruited from two different combat training institutes in India, fulfilling the inclusion criteria of a minimum service period of three years while maintaining 'Shape I' (category) as per Indian Army standards. Both the groups of participants were undergoing training to be inducted into Special Forces for jungle/ CI operations and LIC, respectively, for about six weeks. Participants with musculoskeletal and cardiovascular pathologies were excluded from the study.

3.2 Ethics Clearance

A clearance from the Institutional Ethical Committee, which conforms to the recommendations of the Declaration of Helsinki (1983), was obtained before the study. Informed consent was obtained from each participant.

3.3. Environmental Parameters

A whirling psychrometer (Dimple Thermometers, Delhi, India) was used at both the study locations to measure wet bulb and dry bulb temperatures. The ambient temperature and relative humidity (RH) were derived from a standard dry bulb-wet bulb chart.

3.4 Selection of Events and Track Characteristics

The first event was a time-bound 2.4 km run without additional equipment on a jungle track consisting of vegetation, water streams, undulations of the slope, and slippery surfaces. The participants needed to cross a hillock in between the jungle track. The elevation and slopes of the jungle track (uphill and downhill gradients) were measured using an inclinometer (Bosch, India) at main elevation points. The volunteers wore a round-neck T-shirt, a pair of trousers (camouflage), and shoes suitable for running on jungle terrains. The experiment was carried out in the training area of a jungle and CI warfare training school in India. The track used for the study consisted typical characteristics of the jungle terrain. In the second event, volunteers ran for 2.4 km on a flat natural track of a commando training facility in Northern India without any equipment. They wore T-shirts, shorts, and sports/ PT shoes. Both the events were performed early in the morning (starting at 0630 hrs) considering the heat and or humidity of the summer days. The participants were motivated to finish their respective runs within the standard finishing times set by the respective institutes to retain competitiveness.

3.5 Collection of Experimental Data

The participants were fitted with a multi-individual physiological status monitoring system, (Bio-harness-3, PSM, Zephyr, USA) before the physical exercise. The telemetric connectivity of the instrument was verified for each participant to ensure a smooth recording of the events. Physiological parameters viz. HR, breathing

rate (BR), peak acceleration (PAC), and estimated core body temp (ECT) were recorded throughout the exercises using 'Omnisense live' software.[8] Seven participants representing the first event and four from the second event, were fitted with GPS devices integrated with Bio-harness to measure the elevation changes (altitude) and speed over time. Data for the first event was collected in a phased manner using three sets of Bio-harnesses on two different days: on the first day-30 (3*10) individuals, and the second day- 13 (1*10 and 1*3) individuals. The second event was monitored on a single day using three sets of Bio-harnesses on 30 (3*10) individuals.

3.6 Data Processing and Analysis

'Omnisense analysis' software was used for data processing and analysis. The analysis software produces one excel sheet for an individual participant (test log) including all parameters with values of each second covering the entire duration the system was fitted with the participant. The recorded parameters were arranged column-wise in the sheet concerning time (sec). A one-minute average of each parameter was derived using a 'Java-based' averaging program to reduce the volume of data. Now that parameters were sequenced as per each minute; the exact duration of the experiment was identified in the main file. Separate spreadsheets were created for each parameter and the values of each minute of experimental duration were copied from the main file. Next, all the participants' data was arranged row-wise from 'start' to 'finish' for each parameter. The excel file was arranged in a one-parameter-one-sheet manner, including HR, BR, PAC, and ECT in four separate sheets. The finishing time of each participant in both the races would vary naturally. In another fresh excel sheet, the data sets were fixed at the finish points for all individuals for each parameter. The arithmetic mean from the rows of each participant was calculated, and automatically arranged into one column covering all the participants from each event. These mean values of the column were used for the statistical analysis of each parameter. Under the last mean value of the column, the average and standard deviation (SD) of all the participants' means were calculated, which were later presented in the main table of the 'result' section. The same procedure was followed for all four parameters for both the test events. Apart from that, underneath the last participant's row, every minute's average and SD from all participants were calculated. This had created a separate row of each minute's average.

Line plots were created for all parameters taking into account both events in order to better represent the data. The data concerning altitude and speed over time were retrieved from the GPS data, which was processed and analyzed following the same procedure as above. Due to a lack of variations in parameters like altitude and speed, the data were presented in terms of a range for both events separately.

3.7 Mental Workload Evaluation and Data Processing

The NASA-TLX questionnaire was applied for evaluation of mental workload and overall task load immediately after each exercise session. Each questionnaire sheet has six dimensions or sub-scales: Mental Demands (MD), Physical Demands (PD), Temporal Demands (TD), Own Performance (OP), Effort (EF), and Frustration (FR).[16] Each sub-scale is presented with a scale of 0 to 100.

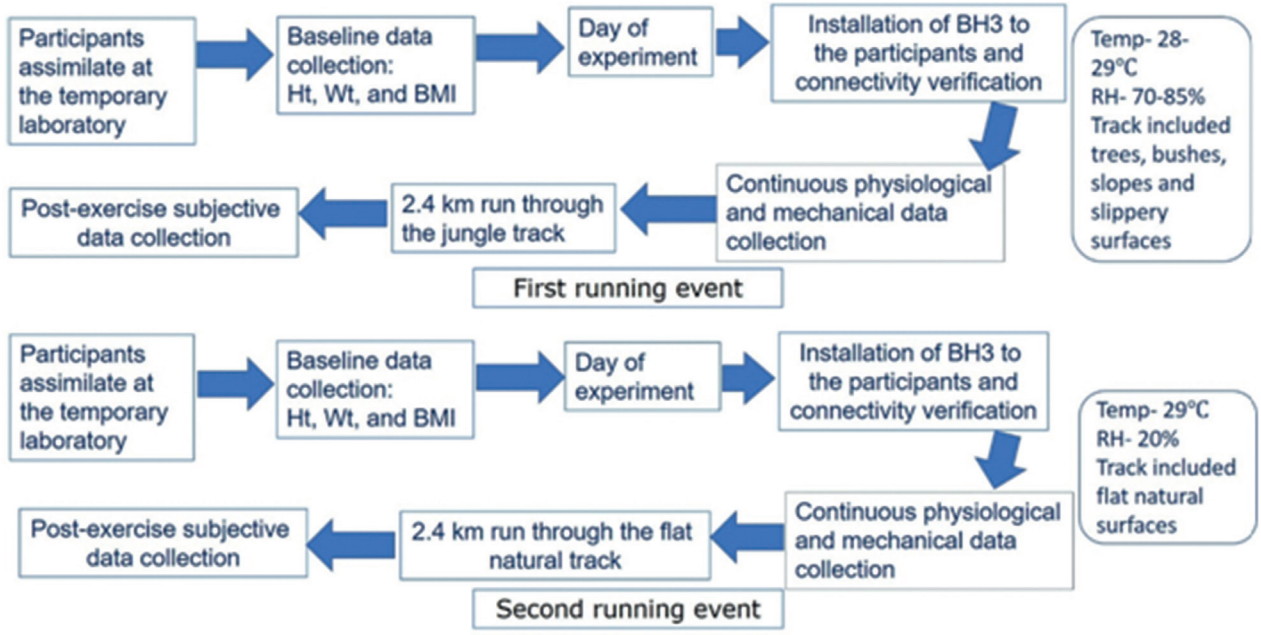

Figure 1. Sequence of events for conducting the experiments, e.g., baseline data collection, running through natural tracks, and collection subjective response including the environmental data.

The number of times each sub-scale is chosen is the weighted score.[17] This is multiplied by the scale score for each dimension and then divided by 15 to get a workload score from 0 to 100, the 'total score' (TS) of TLX17. The participants from both the groups had received demonstrations and instruction on how to fill up the questionnaire in the presence of the respective battle school instructors one day before the events. The flow of events for conducting the experiments, including baseline data collection, running through natural tracks, and subjective workload description, is presented with two flow charts in figure 1.

3.8 Statistical Analysis

The Statistical Package for Social Sciences (SPSS, version 16.0, IBM Corporation, New York, USA) was used for statistical analysis. The normality of all the parameters studied was verified using Shapiro-Wilk's test. Homogeneity tests were also performed as two different groups of participants were used in the study. Four out of seven subjective scores and only one out of four objective variables (physiological parameters) the distribution pattern of the variables and address

Table 1. Temperature, humidity and other physical actors at both the study locations

Physical factors	Run through jungle track	Run through flat natural track
Temperature	28-29 ℃	29 ℃
Relative humidity	70-85 %	20 %
Change in altitude/ elevation	200 m approx	None
Average uphill gradient	7-8°	None
Average downhill gradient	5-6°	None
Running speed	4-16 knots	7-8 knots

Table 2. The average values (± SD) of the physiological parameters and NASA-TLX scores along with percentage change 'U' scores and 'p' values between two extreme training events

Parameter	Jungle (1st) running event	Running event (2nd) on flat natural track	% Change between jungle and flat track	U score	p value	Effect size
Heart Rate (beats/min)	178.9 (± 8.1)	178.4 (± 9.3)	0.2	565.0	0.458	0.103175
Breathing Rate (breaths/min)	42.0 (± 6.0)	46.6 (± 4.9)	9.8	330.0	0.001	0.47619
Estimated Core Temperature (°C)	37.6 (± .4)	37.6 (± .1)	-	259.0	-	0.588889
Peak Acceleration (g)	2.5 (± .4)	2.9 (± .4)	13.8	240.0	0.000	0.619048
Mental Demand	61.8 (± 19.2)	55.0 (± 17.0)	11.0	502.5	0.142	0.202381
Physical Demand	77.5 (± 18.4)	66.5 (± 12.3)	14.2	351.0	0.001	0.442857
Temporal Demand	75.4 (± 24.9)	61.5 (± 16.0)	18.4	339.5	0.001	0.461111
Performance	44.0 (± 24.4)	82.0 (± 15.0)	86.3	130.5	0.000	0.792857
Effort	70.2 (± 17.0)	34.8 (± 17.0)	50.4	144.0	0.000	0.771429
Frustration	63.0 (± 22.4)	40.2 (± 16.4)	36.2	289.0	0.000	0.54127
Total Score	77.8 (± 24.2)	71.4 (± 17.5)	8.2	401.5	0.013	0.362698

the issue of comparing two different groups. The effect size of each parameter difference was verified using the following formula-

1-2U/ (n1*n2)

Where 'U' is a nonparametric statistical value derived from the Man Whitney test; n1 is the sample size of the jungle running event; and n2 is the sample size of a run on the flat track.[18] For all the tests, statistical significance was accepted at $p<0.05$.

4. RESULTS

Both groups represented similarities in terms of age, height, and weight. The ambient temperature, RH during the first and second events, and rise in altitude and elevations (gradient) of uphill and downhill slopes of the jungle track are presented in 1. Table 2 shows the mean (standard deviation) values for the physiological and mental workload parameters, and the 'U' scores with percentage changes and p values. Figure 2 (a, b, c, and d) show overall changes (average plots) in physiological parameters, e.g., HR, BR, ECT, and PAC throughout the runs on the jungle and flat natural tracks. *Place figures 2-a, b, c, d, and tables 1 and 2 here.* There was no significant difference observed in HR and ECT between the groups. The running event at the flat natural track had significantly higher BR and PAC than the run at the jungle track. The results of the Mann-Whitney 'U' test revealed significantly higher NASA-TLX scores in the first event than in the second (MD was insignificant but higher for the first event). The effect sizes were large for ECT, PAC, PR, and EF; medium for BR, PD, TD, FR, and TS; and small for HR and MD.

The average time needed to complete the jungle running event was about 18 minutes, and about 11 minutes for the second running event. Thirty-one of the forty-three participants in the jungle running event took 16-18 minutes to finish, remaining had finished within 20 minutes. The other group on the flat natural track was more consistent; 90 per cent of them could finish the race within 10 minutes. Figures 3 and 4 show the speed and acceleration pattern of an individual participant from each group for a better understanding of the pattern of changes with the progression of runs. The running speed over time fluctuated between 4 and 16 knots (1 knot= 1.15 miles/h)[8] at the jungle track and was maintained at a steady 7-8 knots at the flat natural track. It was observed that the running speed on the jungle track increased (up to 15-16 knots for each

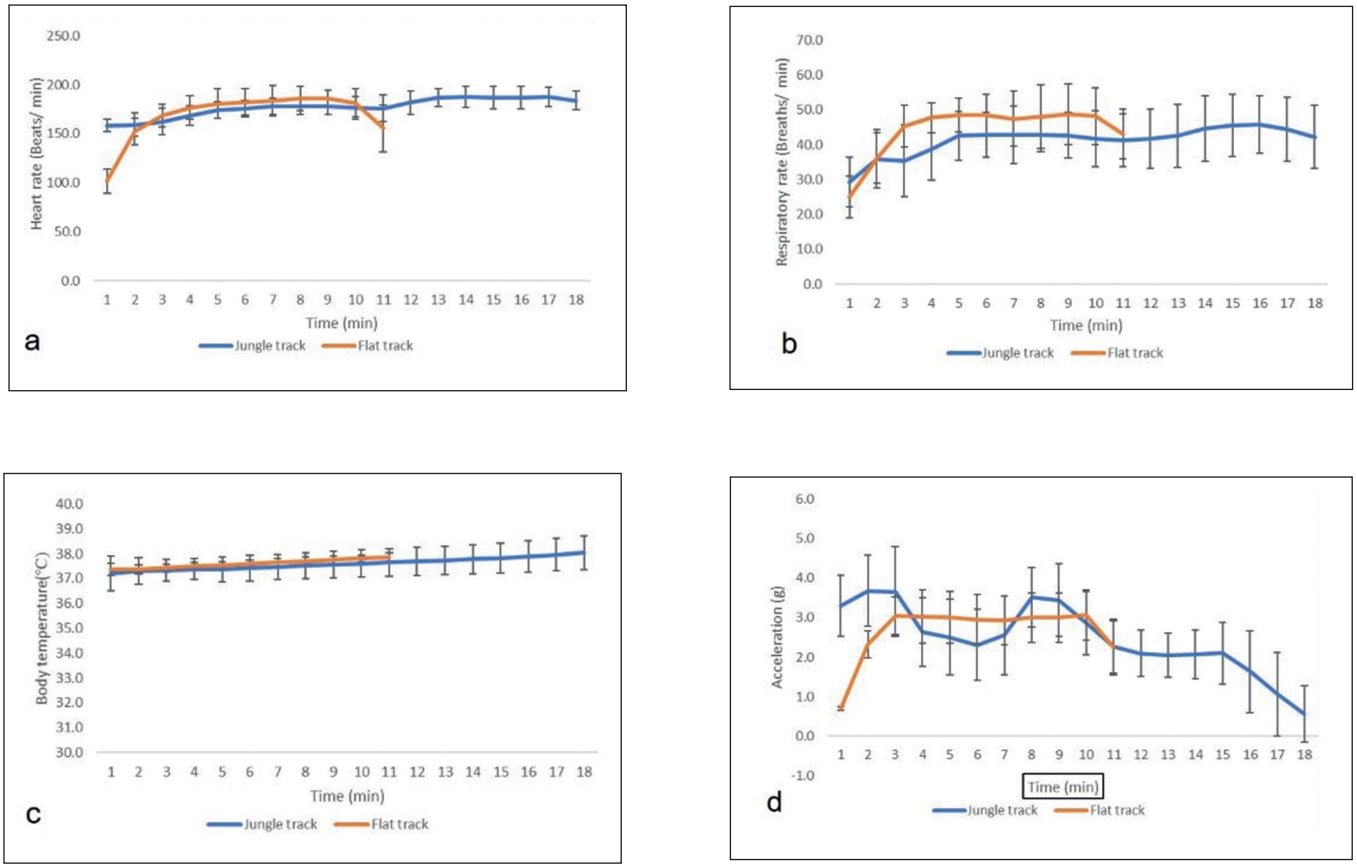

Figure 2 a, b, c, and d. Changes in physiological parameters viz. heart rate, breathing rate, estimated core temperature and peak acceleration throughout the runs on the jungle track and flat natural track. Average data from all the participants of both runs are plotted together.

individual measured) in the second minute after the start of the event and decreased after the 8th – 9th minute (4 knots for each individual measured). Whereas the PAC decreased after the first two minutes (reached 1 g) (1 g= 9.81m/sec^2), then began to increase after the fifth minute and continued until the eighth minute (reached >4 g). The participants needed regular adjustments during the rest of the run until the end. On the other hand, running on a flat natural track required a steady speed over time (7-8 knots) and a steady PAC at the rate of 3 g.

5. DISCUSSIONS

5.1 Study Justification

The first training event reported in the study is an endurance run practiced on a predetermined natural track through jungle located in the North-Eastern part of India. The purpose of practicing such a run is to gather knowledge about the terrain and develop expertise in moving faster from one spot to another, considering the probable situational requirements of the jungle. The second event is generally practiced to improve the physical proficiency of soldiers considering combat areas other than the CI and jungle warfare, for example, urban and LIC operations (as learned from the sources of combat training institutes). The participants of the present study represented two combat training institutes in India. Their basic training, diet, daily exercise pattern, level of activity on a working day, and health status were similar and strictly maintained.[1] Both groups were similar in terms of age, height, and weight, as well as years of service. Research evidence in the past has qualified the use of individuals of two different groups with similar ages, heights, and weights in experimental studies.[21,22] In that connection, the study was planned considering the similarity in demographic characteristics of the groups. Before comparing their physiological and mental workloads, the normality of the data was verified using Shapiro-Wilk's test. It was observed that the data was not normally distributed; hence, non-parametric statistical interpretation, i.e., Mann-Whitney 'U' test was applied.[19,20]

5.2 Physical Workload

The aim and objectives of the study were to quantify and compare the mental and physiological efforts required for running 2.4 km on a jungle track and a flat natural track. The results confirmed similar physiological requirements for competing on both tracks. The mean HR was about 92 per cent of the age-predicted maximum HR (HR_{max}) of the respective groups, which they had maintained steadily throughout the distance. Any exercise that achieves an HR beyond 90 per cent of the HR_{max} can be considered as 'very hard'.[23] The findings reported by Pemrick[24] from his work on the 'Rangers regiment' of the US Army in the battle were found to be similar. According to them, the Military Special Forces need to undertake plenty of demanding tasks in difficult conditions infested with infiltration with a shortage of food, water, and logistic support.[25]

Likewise, the trainee soldiers who participated in the present work were deliberately exposed to physical and tactical training regimes for about 6 weeks to 3 months to build aerobic fitness and agility, with an additional focus on developing knowledge about the terrain and environment. Such wholesome training has probably helped them to accomplish the feat of maintaining HR steadily at a rate of more than 90 per cent of HR_{max} throughout the 11- or 18 minutes. The body temperature of the participants did not vary irrespective of the tracks, may be due to the short duration of the exercise. The soldier's training and adaptation processes were so effective that they could withhold the effect of the extra RH (about 60% higher than the flat natural track) of jungle terrain and stabilise the physical workload for the short duration of the run.[26] Validation studies with a larger sample in similar training environment seemed essential to establish this kind of an observation. However, the possibilities of such a longitudinal approach were beyond the scope of this study.

5.3 Mechanical Properties of the Runs

Another interesting observation of the study was the speed over time increased from 2nd-minute up-to 18 knots at jungle terrain then reduced to as low as 4 knots at about 8th minute which again increased up to 15-16 knots and followed a disoriented pattern before the finish. At the same time, exactly the opposite pattern of change was observed with PAC during the run on the jungle track. It first started decreasing at the 3rd minute (<1 g) and increased at about the 8th minute (>4 g), then continued with the fluctuations until the last moments of the race (figure 3). On the other hand, the participants maintained steady speed over time and PAC throughout the run on the flat natural track (figure 4). The explanation of different patterns of acceleration and running speed is quite complex. When a person starts gaining momentum to reach a higher speed, the required acceleration may not show larger deviations or can even decrease. On the other hand, the person may have greater changes in acceleration (in the positive direction) even while slowing down, for example during ascending toward the top of a hill or descending from it.[22,27,28] The participants had to cross a hillock (elevation of 200 m approximately), which required running uphill (7-8°) and downhill (5-6°) while competing through a jungle track. The soldiers chose to slow down during the uphill part of the run and required speed adjustments on downhill slopes. The participants had to maintain good coordination between speed and the PAC to match the requirements of the track.[29]

Uphill running involves a lot of mechanical adjustments like an increase in step frequency, decrease in step duration, increase in mechanical work of leg muscles and loss of time. The participants seemed to have gone through such modifications while crossing the hillock.[30,31,32] However, physiological output was maintained the same

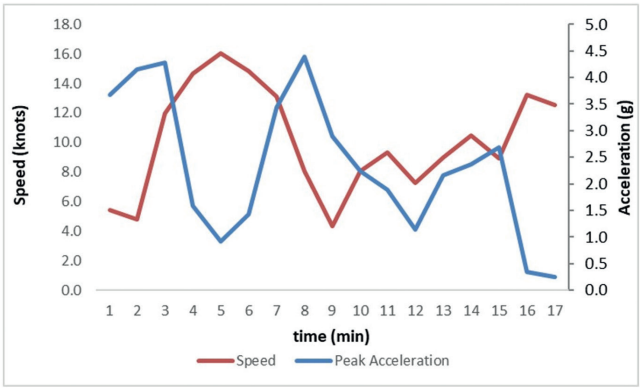

Figure 3

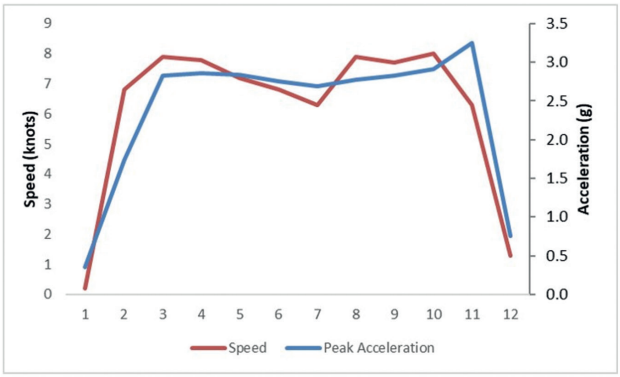

Figure 4

Figure 3 and 4. Changes in Speed and peak acceleration of one participant each from the runs on the jungle and flat natural tracks.

as the flat track at this point to make up for the energy requirements for mechanical adjustments.[33] A longer finishing time (7 minutes more than the run on a flat natural track) to cover the same distance on the jungle track could be related to such modifications in human movements.

5.4 Mental Workload

The mental workload is determined by the interaction of the task demands, the circumstances under which it is performed, the skills, behaviours, and perceptions of the individual.[5] Significantly higher PD, TD, EF, FR, and TS were observed (11.0, 14.2, 18.4, 50.4, 36.2, and 8.4% higher) for the run on the jungle track than on the flat track. The performance score was 46.3 per cent higher for the second event which eventually denoted a higher workload for the first event. Studies have been carried out (using NASA TLX) on tasks where the movement of the whole body combined with cognitive tasks complemented each other.[34,35] Such effects are typically greater when the two tasks are more challenging, requiring greater executive resources.[36] Blakely et al[37] have found that carrying out the additional mental task while running at high intensity could hamper physical performance. Research in the field has suggested that human performance is limited when performing dual tasks such as running and memorising words or climbing and verbal instructions.[38,39] On the same note, participants required adjustments in speed and acceleration to cope with undulating surfaces, avoid slips and falls, and negotiate with the vegetation present within or near the jungle track. Their perception of high humidity on the jungle track and its effect on running performance may have added to the mental effort requirements. A combination of competitiveness, physical effort, mechanical adjustments, and environmental factors needed appropriate planning, coordination, and execution of motor functions, all of which were reflected through higher subjective response and overall task load (high TS).[36]

6. LIMITATIONS

The study compared two different sample groups of individuals performing similar physically demanding tasks. The same group of individuals could not be exposed to different tasks as both the training institutes had different sets of curricula and were training for different purposes. However, the groups had similarities in physical characteristics, training, and activity level. A test of VO_{2max} as a baseline parameter was attempted in controlled environmental conditions for both the groups. However, only a few of the two groups could complete the test due to their pre-determined engagements and busy training schedules. No other controlled experimental conditions could be presented. The objective measurements of mental workload after the given tasks like reaction time and other memory function tests through computerized test batteries would require one volunteer to perform the test. The present work deals with a group of individuals together. Due to a lack of time and the prescheduled engagement of the participants after the training events, measurement of sweat loss or difference in pre- and post-exercise body composition could not be performed.

7. CONCLUSION

Competitive running of 2.4 km through the jungle and flat natural tracks demanded ‘very hard’ physical efforts. The participants needed adjustments in speed and acceleration to negotiate with track characteristics like the slope of the path, muddy and slippery surfaces, the natural obstacles such as bushes and trees, and environmental factors like heat and humidity of the jungle terrain. On the other hand, running a similar distance on a flat natural track on a hot summer day required fewer mechanical adjustments signified by higher PAC and lower but steady speed over time; and also needed higher respiratory effort. In the jungle, participants took about seven more minutes to complete the same distance and rated the overall task load significantly higher than that of the flat track. Such findings indicated the need for mechanical adjustments and extra mental

effort to overcome natural obstacles and environmental variations. The findings of this study will help the trainers, instructors, and commanders for evidence-based selection of personnel for specific events/operations. Improvement of reflexes to quickly change acceleration and focus on improving the mental steadiness of the troops besides building endurance shall be emphasized for carrying out successful operations in jungle areas.

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