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Heart rate variability, task load and perceived exertion associated with a long-distance military ski exercise: A pilot study

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ABSTRACT

Objectives: Skiing is practiced by the security forces posted at mountain areas for patrolling, securing borders, taking up rescue missions and sometimes as recreational activities. A study was planned to assess physiological and mental stress of a military ski activity through the measurement of heart rate (HR) variability, task load and perceived exertion.

Materials and Methods: Eleven healthy Indian soldiers, trained with skiing techniques, participated in a 15 km skiing with 22 kg equipment at a predetermined snowy mountainous track. Pre- and post-exercise HR and HR variability (HRV) were recorded (bio-harness, Zephyr, USA) and questionnaires, namely NASA task load index (NASA-TLX) and Borg's rating of perceived exertion (RPE) scale, were filled after exercise. Time and frequency domain parameters such as HR, variations between successive RR intervals (RMSSD), standard deviation of RR (SDNN) and percentage value of NN50 (pNN50), low- and high-frequency bands (LF and HF %) and LF/HF ratio were derived using Kubios software. Student's t (paired) test was applied to compare pre- and post-exercise HRV parameters and Pearson's correlation was applied to observe interdependencies between HRV and subjective scores.

Results: The findings depicted increase in post-exercise HR and decrease in overall HRV (both significant). Besides this, there was an increase in LF (significant) and LF/HF ratio (insignificant). Such response shows sympathetic dominance over parasympathetic domain of autonomic nervous system. The physical and mental stress experienced during the exercise was also expressed through high physical demand (79 out of 100) and high overall task load (total score – 77 out of 100) of the NASA-TLX and a moderately heavy RPE score (14 out of 20).

Conclusion: The pre- and post-exercise differences in physiological variables ensured the presence of physical stress along with dominance of sympathetic nervous system. Overall task load was depicted with high subjective ratings. Carrying out skiing task in an environment infested with cold, wind chill, moderate hypoxia at a snowy and mountainous track possibly has induced the observed physiological and mental stress to the participants. Such findings are important to understand exact requirements of the mountain warfare events carried out by the forces.

Keywords: Skiing activity, Heart rate variability, Physical and mental stress

INTRODUCTION

Skiing through mountainous terrains has been practiced by the armed forces, competitive and recreational skiers for years. Ski mountaineering is a demanding winter sport that requires climbing up several steep slopes as fast as possible then descend through rugged, off-piste snow completely unprepared and ungroomed.[1,2] Early research evidences show that the skiing used to be practiced by military troops in Europe.[1] In India, ski mountaineering is considered as a regular activity for mountain warfare. The troops need to overcome challenges such as high altitude, hypoxia, steep terrains, wind, snowfall and so on.[1,3] The military activities at mountains are little different from the professional ski events. The operations include patrolling, covering of posts, skiing through snowy terrains to maintain law and order and taking up avalanche rescue missions to save lives and wealth. Sometimes, the authorities organise recreational and competitive skiing to utilise the environmental conditions and divert the monotony of the troops.[3,4] Be it a mandatory or as recreational activity, skiing demands high level of stamina, energy, skill and motor control to generate propulsive force by the upper and lower body muscles to climb up and sliding down.[1,3] The soldiers like the professionals and amateurs need to undertake extensive training programme lasting about 16 ± 0.9 h weekly with an average ascent of 50,814 ± 3654 m to build strength, aerobic and anaerobic endurance, coordination, motor skill, balance and mobility.[3,5] They need to carry essential items such as food, water, ammunitions, communication devices and appropriate clothing during rescue operations or patrolling the area.[4] Use of ski equipment with additional load at rucksack and bulky clothing make the movement more difficult.[4] Scientific studies on training events performed at snowy and mountainous terrain are limited.[5] Thus, further studies on snow and mountaineering training events may provide more scientific information regarding physiological and mental stress.

Monitoring of heart rate (HR) and its beat-to-beat modulation is applied for the prediction of effect of factors such as environment, terrain and operational strain on human physiology and behaviour. Heart rate variability (HRV) is the fluctuation in the time intervals between adjacent heartbeats.[6] Investigating the changes in HR and different HRV spectral components are associated with different branches of autonomic nervous system (ANS). The ANS is divided into two branches, namely sympathetic nervous system and parasympathetic nervous system. There are two major components of HRV data such as time domain and frequency domain.[7,8] Scientific studies on HRV have established its efficacy as tool to predict mental fatigue[9] as well as a predictive marker of cognitive functioning.[10] Physiological evaluation on professional and recreational skiers is rare apart from few case studies and studies considering group of participants.[11] These studies generally focused on protein intake, bronchoconstriction and energy cost of skiers to ultimately establish skiing as a heavy physical activity same as other endurance sports such as cross-country cycling or marathon.[11] However, few studies have mentioned that 70% of the entire workload remains above the first ventilatory threshold and more than 20% remains above second ventilatory threshold with HR exceeding 90% of maximum HR (HR_{max}) which is uncommon in many of the other physically demanding sports activities.[11,12]

Subjective questionnaires are regularly used in experimental studies to predict overall workload and perceived exertion of a physical task.[13] The subjective response of a person is influenced by current goal, motives and plans thus can be applied to scientific studies including physically intense tasks.[14] Use of National Aeronautical and Space Administration Task Load Index (NASA-TLX) and Borg's 14-point rating scale that predicts perfectly the perception of exertion are the most recurrently used subjective rating methods for experimental studies.[15,16] These subjective scores may complement the findings from real-time monitoring physiological data and autonomic responses. With this background, the present study was undertaken with the aim to understand the physical and mental stress during a military skiing activity (training) through measurement of pre- and post-exercise HR and HRV, task load and perceived exertion. The second aim of the study was to find out the association of post-exercise physiological and mental workload variables to ascertain their interdependencies. The acquired data will be helpful to find out the autonomic response of the personnel to measure physiological and mental stress while carrying out intensive cold and snowy conditions.

MATERIALS AND METHODS

Participants

The participants were trainees (soldiers) at a mountain warfare training institute in India. Seventeen soldiers volunteered for the exercise at snow terrain, among them six have failed to complete. The inclusion criteria: The participants had to fulfil a minimum service requirement of 3 years while maintaining physical category 'Shape I' as per Indian Army standards. The participants needed to complete their respective acclimatisation and declared medically fit to continue training and other activities. Exclusion criteria: Presence of any medical history of musculoskeletal or cardiovascular pathology. The volunteers were prohibited from smoking and alcohol consumption. Although their routine activities of training were not disturbed for the study, they were exempted from carrying out night duty to ensure proper sleep.

Baseline data collection

The volunteers reported to the temporary laboratory for baseline data collection 1 day before the study and were allowed to rest for half an hour. Their resting blood pressure, HR and oxygen saturation were taken at supine position using Microlife (Switzerland) blood pressure monitor and Nonin (Japan) pulse oximeter, respectively. Their height and weight were measured after that with an anthropometer (Nutriactiva, USA) and weighing balance (Prestige, India), respectively.

Body mass index (BMI) was calculated from height and weight using the formula

BMI = weight/(height)^2

Ethics approval and consent to participate

A clearance from the Ethical Committee of the author's institute, which conforms to the recommendations of the Declaration of Helsinki (1985), was obtained before the study. The ethical committee was comprised of panel of doctors, subject domain expert and followed guidelines laid out by the Indian Council of Medical Research for studies including human participants. All the volunteers were briefed about the purpose and the risks of the experimentation, then they signed an informed consent form.

Study design

The training event required skiing of 15 km with 22 kg equipment (rucksack and rifle) through pre-bitten natural snowy terrain consisting of 20% uphill, 40% plain and 40% downhill slopes. The trainees needed to finish skiing within fixed time (3 h) including additional activities such as patrolling, gathering information and vigilance. The study was carried out in the training areas consisting of snow-clad mountains of the Himalayan range within the areas of a mountain warfare training institute (altitude: 8200–8600 ft) situated in North India in the presence of certified instructors and medical practitioners.

Experimental data collection

Environmental parameters

Ambient temperature, relative humidity, barometric pressure, etc. were monitored through a portable and digital weather station (Kestrel 4500). Recording was carried out at an interval of 30 min at the time of the experiment.

Physiological status and HRV

The participants were fitted with multi-individual physiological status monitoring system (Bio-harness, PSM, Zephyr, USA), to their bare chest at the temporary laboratory before the exercises. The telemetric connectivity of the instrument was verified for each participant. They were asked to sit relax for ½ h. Then, pre-exercise HR and HRV recording was carried out for 10 min including all participants together. Seventeen bioharnesses were used in two sets (1 × 7 and 1 × 10) for the data collection and were monitored live with 'OmniSense live' software in two separate computers. After pre-exercise data recording, the bioharness was removed and the participants geared up for the ski exercise with their protective clothing, equipment and ski. The group had already received instructions about the course of the travel and the duration of the exercise. All the volunteers started the skiing together. Six of them could not complete the skiing within time thus their data were excluded from the study. The participants were instructed to report back to the temporary laboratory immediately after completion of the exercise. Their equipment was removed and was allowed to sit and relax. They were again fitted with two sets (1 × 1 and 1 × 10) of bioharness and their recovery HR and HRV parameters were recorded for 10 min. Complete recovery could not be recorded due to paucity of time and packed schedule of the trainee participants. The raw HR and HRV data of each second were exported to 'MS Excel' through 'OmniSense analysis' software.

HRV assessment and data processing

Pre- and post-exercise HRV data in terms of RR value were recorded in milliseconds. The recorded RR values were processed manually in a MS Excel sheet (MS office, Version 10), to eliminate the artefacts. After the artefact's correction, the RR interval files of each participant were processed using HRV Kubios software (Kubios, Oy, Finland). After creating the HRV plot in Kubios, 'Medium' filter was used to remove more artefacts and derive clean data. Clean data for HRV could be obtained for 11 participants for the skiing activity. Fourier transformer was used before carrying out respective time and frequency domain analyses. The time domain and frequency domain parameters obtained for the HRV analysis were further processed for statistical analysis. Time domain analysis is the simplest and consistent method to evaluate HRV, which can be derived using statistic or geometric calculation.[9] HRV parameters resulted from statistic evaluation method include: Mean RR intervals; root mean square of the variations between successive RR intervals (RMSSD); standard deviation of RR (SDNN) and percentage value of consecutive differences of RR intervals that covered more than 50 ms that is, NN50 (pNN50).[8] Percentage of low- and high-power frequencies (LF and HF%) and ratio of LF and HF (LF/HF) were taken as frequency parameters. The values were tabulated with mean and SEM and used for statistical treatment.

Mental workload evaluation and subjective rating

NASA-TLX questionnaire was applied for the evaluation of mental workload and overall task load immediately after each exercise session after finishing the HRV recording. NASA-TLX has six dimensions or sub-scales: mental demand (MD), physical demands (PD), temporal demands (TD), own performance, effort (EF) and frustration (FR).[15] Each sub-scale is presented with a scale of 0–100. The number of times each is chosen which 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' of TLX.[18] The participants were demonstrated how to fill up the questionnaire form 1 day before the events. All 17 volunteers had filled the questionnaire and data were obtained for all of them.

Rating of perceived exertion (RPE)

Borg's 14-point scale (6–20) where a score of '6' means 'no exertion at all' and a score of '20' means 'maximum exertion' was applied to each participant after completion of the event for RPE.[16]

Statistical analysis

The data were first tabulated with the mean, SD and SEM (as applicable for HRV parameters as a standard practice due to their variations in range) for all the studied variables across all events. 'The Statistical Package for the Social Sciences' (SPSS, version 16.0, IBM Corporation, New York, USA) was used for statistical analysis. Normality of all the parameters studied was verified using Shapiro–Wilk's test. Student's 't' (paired) test was applied to compare the pre- and post-exercise values of HR and HRV parameters of three snow exercise. Pearson's correlation was performed to the post-exercise values of HR, HRV (parametric) and non-parametric variables such as NASA-TLX and RPE scores to observe their interdependency. The correlation coefficients (r) were categorised as very weak (0.0–0.2), weak (0.2–0.4), moderate (0.4–0.7), strong (0.7–0.9) or very strong (0.9–1.0) in the study. For all the tests, statistical significance was accepted at $P < 0.05$.

RESULTS

The ambient temperature, RH and barometric pressure during the snow and mountain climbing events were −6–−4°C, 50–65% and 570–590 mmHg. The baseline data of the participants are presented in [Table 1], which ensured appropriate acclimatisation to the environment through acceptable range of resting HR, blood pressure and oxygen saturation. Although medically cleared, the participants' oxygen saturation (about 94%) was little lower than expected (above 95% is expected below 9000 ft); was not considered as a point of concern due to their tight schedule and lack of proper rest in between activities. All the participants needed about 3 h to complete the race which was within the time limit set by the institute.

Comparison of HRV parameters of the ski activity

The results of the HRV are presented in [Table 2] including level of significance between pre- and post-exercise values. Post-exercise values of HRV parameters such as mean RR, RMSSD and pNN50 decreased significantly than the pre-exercise values as confirmed from the results of Student's '*t*'-test. The mean HR significantly increased after exercise. Among the frequency parameters, LF% and LF/HF ratio increased (significant) after the exercise. The HF% decreased after exercise (insignificant).

The result of NASA-TLX analyses and RPE is presented in [Table 3]. Based on the NASA-TLX and RPE results, the participants of the ski exercise responded with moderately heavy perceived exertion (14) and high PD (79) and high overall task load (TS- 77).

Results of correlation

Results of Pearson's correlation are presented in [Table 4] for the snow exercise. The Pearson's correlation revealed positive significant correlations between pNN50 and EF; RMSSD and EF; HF and FR and negative significant correlations between LF/HF ratio and PD. There were moderate positive correlations between TD, PF and mean RR; FR and RMSSD. Moderate negative correlations were observed between TD, PF and mean HR; MD, TD, TS and LF; TD, PF and HF; FR, TS and LF/HF.

DISCUSSION

Physiological studies have classified different types of skiing events, namely Alpine skiing, Nordic skiing, cross-country skiing and ski mountaineering. Alpine skiing is practiced in an altitude below 1800 m consisting of several short and long duration events which require climbing up and down through unbitten snow.[19] The cross-country skiing is carried out for long duration like more than 5 h to cover long distances like 50 km in well-prepared snow at less hilly terrain. The ski mountaineering is generally practiced at an altitude more than 1800 m including multiple activities like climbing up on steeper gradients (2–3 slopes). Other activities include walking without ski and sliding down through off-piste snow.[11] Research work covering ski mountaineering has categorised the physiological demand as 'heavy' while the HR reaching above 90% of the HR_{max} for major parts of the exercises same as 50–60 km cross-country cycling or long-distance running as marathons.[11] The ski

Table 1: Baseline data of the participants of the extreme training events (mean±SD).

Age (years)	Height (cm)	Weight (kg)	Body mass index	SBP (mmHg)	DBP (mmHg)	SpO_2 (%)	Baseline HR (beats/min)
24.9 (±2.0)	170.3 (±4.1)	63.3 (±4.3)	21.8 (±1.4)	122.8 (±3.6)	76.1 (±4.1)	93.9 (±4.3)	64.4 (±5.1)

SBP: Systolic blood pressure, DBP: Diastolic blood pressure, SpO_2: Oxygen saturation, Baseline HR: Heart rate taken during baseline data collection

Table 2: Mean (±SEM) values of HRV parameters obtained before and after the exercise and results of Student's '*t*' test for determining level of significance between pre- and post-exercise values (*n*=11).

Parameters	Skiing exercise		Level of significance
	Pre	Post	
Mean HR	70.9 (±2.1)	108.8 (±6.3)*	0.000207749
Mean RR	858.4 (±25.3)	572.7 (±19.2)*	1.13952E-06
RMSSD	54.0 (±9.9)	9.8 (±1.3)*	0.004033355
pNN50	30.8 (±7.9)	0.6 (±0.2)*	0.01959801
LF%	33.2 (±5.3)	47.3 (±5.3)^{NS}	0.059528951
HF%	15.5 (±2.9)	7.6 (±2.1)^{NS}	0.096847794
LF/HF	2.7 (±0.7)	6.3 (±0.9)*	0.030825069

Mean heart rate, mean RR intervals, RMSSD: Root mean square of the variations between successive RR intervals, SDNN: Standard deviation of RR intervals, and percentage value of consecutive differences of RR intervals that covered more than 50 ms that is, NN50 (pNN50), percentage of low- and high-power frequencies (LF% and HF%) and ratio of LF and HF (LF/HF), $P<0.05$, *significant, NS: Non-significant

activity reported in the present study somehow resembled ski mountaineering due to its variations in activities carried out at moderate high altitude. The activities include: Climbing up multiple slopes with/without ski, reaching certain point, gathering valuable information like weather report and avalanche prediction. Besides this, they need to carry out patrolling certain areas to inspect presence of threat and carry out dummy rescue operations as well which play crucial role in soldiers' preparation for winter and mountain duties. Here, precision, skill and stamina play an important role to provide additional edge to the troops.[20] Thus, sometime, the physiological workload may not appear to be as hard as expected. However, the results indicated 34.8% increase in HR from pre- to post-exercise recordings. Continuous monitoring of physiological variables was beyond the scope of the present study. Hence, the physiological stress was predicted through such a significant difference in pre- and post-exercise HR.[21] The participants rated their perceived exertion 'somewhat hard' (about 14) and scored as high

Table 3: The mean (±SD) NASA task load index scores and rating of perceived exertion of the extreme ski activity (*n*=11).

Mental demand	Physical demand	Temporal demand	Performance	Effort	Frustration	Total average score	RPE
69.7 (±16.4)	78.8 (±15.0)	69.1 (±14.6)	70.9 (±19.5)	68.2 (±18.8)	43.2 (±25.4)	77.0 (±9.7)	13.8 (±1.7)

RPE: Rating of perceived exertions using Borg's 14-point scale

Table 4: Results of correlation between heart rate variability parameters, NASA task load index and rating of perceived exertion scores.

	MD	PD	TD	PF	EF	FR	TS	RPE
MEANRR								
Pearson correlation	0.245	0.291	0.523	0.443	0.354	−0.361	0.283	0.127
Significance	0.525	0.448	0.148	0.233	0.350	0.339	0.460	0.765
MEANHR								
Pearson correlation	−0.245	−0.291	−0.523	−0.443	−0.354	0.361	−0.283	−0.127
Significance	0.525	0.448	0.148	0.233	0.350	0.339	0.460	0.765
RMSSD								
Pearson correlation	−0.166	−0.017	−0.337	−0.315	−0.671*	0.487	−0.200	−0.469
Significance	0.669	0.965	0.375	0.409	0.048	0.183	0.606	0.241
PNN50								
Pearson correlation	−0.268	0.118	−0.389	−0.235	−0.695*	0.313	−0.230	−0.392
Significance	0.486	0.763	0.300	0.543	0.038	0.412	0.552	0.336
LF								
Pearson correlation	−0.656	−0.265	−0.514	−0.323	0.112	0.319	−0.400	−0.469
Significance	0.055	0.491	0.157	0.396	0.775	0.402	0.286	0.241
HF								
Pearson correlation	−0.350	0.316	−0.559	−0.630	−0.354	0.874*	−0.050	−0.279
Significance	0.356	0.407	0.118	0.069	0.350	0.002	0.898	0.503
LFHF								
Pearson correlation	−0.149	−0.752*	0.186	0.119	0.019	−0.563	−0.550	0.063
Significance	0.703	0.019	0.631	0.760	0.962	0.114	0.125	0.881

Mean heart rate; mean RR intervals, RMSSD: Root mean square of the variations between successive RR intervals, SDNN: Standard deviation of RR intervals, and percentage value of consecutive differences of RR intervals that covered more than 50 ms that is, NN50 (pNN50), percentage of low- and high-power frequencies (LF% and HF%) and ratio of LF and HF (LF/HF), MD: Mental demands, PD: Physical demands, TD: Temporal demands, OP: Own performance, EF: Effort, FR: Frustration, TS: Total score, RPE: Rating of perceived exertion, *significant, $P<0.05$

as '79' as 'PD' (NASA-TLX).[15,16] Such findings predicted presence of physical stress in the ski mountaineering event.

The results of HRV analyses showed post-exercise decrease in the time domain parameters such as mean RR, RMSSD and pNN50 compared to the pre-exercise values. Whereas, the frequency domain parameters showed increase in LF% and LF/HF ratio and decrease in HF% after the exercise. Reduction of the time domain parameters generally occurs after any heavy physical activity mainly due to withdrawal or diminished functions of the parasympathetic domain followed by delayed onset of recovery due to the exertion.[21] Increase in LF% and LF/HF ratio indicates central modulation of sympathetic tone through cardiovascular active neurons in the lower brainstem by adrenergic dominance during physical exercise.[22] Such responses can also be linked to additional mental efforts needed to execute various physical tasks in the ski mountaineering event.[23,24] The sympathetic hyperactivity during the beginning of the recovery could be attributed to exercising in freezing cold and hypoxic conditions.[25,26] Cold stimulus affecting physical performance in skiers has been published in past and proved that the autonomic responses of the participants of the current work have occurred as normal consequences of skiing at sub-zero temperatures.[19] In a study on cross-country skiers, the researchers have established that recording of HR recovery play a crucial role in predicting their physical performance and also their ability to tolerate stress.[27] These evidences point out the utility of recording of post-exercise recovery to understand the overall requirement of physical and mental efforts to carry out ski mountaineering with equipment at moderately high-altitude areas for 3 h.

The total average score (NASA-TLX) of the military ski mountaineering event was '77' which depicted expression of a heavy overall task load. Studies in the area of exercise physiology in the past have proved that exercising outdoor puts extra burden on human system with additional requirements of planning, coordinating sensory and motor activities, avoiding injuries or accidents, etc.[28,29] The subjective responses of the participants: MD – 69.7, PD – 78.8, TD – 69.1, PF – 70.9, EF – 68.2, FR – 43.2, TS – 77.0 and RPE – 13.8 provided logical and acceptable insight into the perception of physical and mental effort requirements. They had to utilize their technical and tactical adaptability to overcome challenges like the variations in quality and the texture of the snow and encounter sudden slopes and turns that could affect the interaction of the equipment.[2,30] Positive significant correlations between EF and pNN50 and RMSSD and negative significant correlations between LF/HF ratio and PD partially supported the notion that the 15 km skiing-induced physical and mental burden on the participants. However, more accurate prediction of the physical stress, autonomic response to it and associated mental stress could be established with a larger sample size.

CONCLUSION

The significant increase in post-exercise 'mean HR' than pre-exercise values could identify presence of physical stress due to 15 km ski mountaineering event. This finding was supported by 'somewhat hard' perceived exertion (about 14 out of 20) and 'high' PD (79 out of 100) expressed through NASA-TLX score. Recordings of pre- and post-exercise HRV indicated withdrawal of parasympathetic control and subsequent delayed onset of recovery after exercise as well as dominance of sympathetic system. The sympathetic hyperactivity could also be linked to extra mental effort requirements of the ski mountaineering with overall high task load expressed through NASA-TLX scores (especially total score – 77). Overcoming the natural adversities such as snow, freezing temperatures, hypoxia, upward and downward slopes, turns and control of speed of movement and other task demands can be attributed to the above-mentioned findings. Such results are important to understand exact requirements of the mountain warfare events carried out by the forces. The results could be utilised by the instructors, commanders for training and real-time operation purposes.

Study limitations

Continuous monitoring of HRV during the exercise was not permitted due to official restrictions. No. of participants were limited and clean HRV data were not available for all the participants. That may be the reason behind improper correlation between HRV and the subjective parameters. Profiling of complete recovery HRV could prove fruitful to portray full image of autonomic control of the recovery from the stress induced by the exercise at snowy mountains.

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Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent.

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Conflicts of interest

There are no conflicts of interest.

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