Defence Science Journal, Vol. 70, No. 2, March 2020, pp. 131-139, DOI : 10.14429/dsj.70.14539

Cognitive Workload Analysis of Fighter Aircraft Pilots in Flight Simulator Environment

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ABSTRACT

Maintaining and balancing an optimal level of workload is essential for completing the task productively. Fighter aircraft is one such example, where the pilot is loaded heavily both physically (due to G manoeuvering) and cognitively (handling multiple sensors, perceiving, processing and multi-tasking including communications and handling weapons) to fulfill the combat mission requirements. This cognitive demand needs to be analysed to understand the workload of fighter pilot. Objective of this study is to analyse dynamic workload of fighter pilots in a realistic high-fidelity flight simulator environment during different flying workload conditions. The various workload conditions are (a) normal visibility, (b) low visibility, (c) normal visibility with secondary task, and (d) low visibility with secondary task. Though, pilot's flying performance score was good, the physiological measure like heart rate variability (HRV) features and subjective assessment (NASA-TLX) components are found to be statistically significant ($p<0.05$) between tasks. HRV features such as SD2, SDNN, VLF and total power are found to be significant at all task load conditions. The features LFnu and HFnu are able to differentiate the effect of low visibility and secondary cognitive task, which was imposed as increased task in this study. This result benefits to understand the pilot's task and performance at each flying phase and their cognitive demands during dynamic workload using HRV, which could assist pilot's training schedule in optimal way on simulators as well as in actual flight conditions.

Keywords: Pilot cognitive workload; HRV; NASA-TLX; Fighter pilots; Flight simulator

1. INTRODUCTION

Over many decades, statistics on aircraft crash reveals[1,2] that the human error, particularly mental stress and loss of situational awareness experienced by pilots are the cause for plane crash. Though technology growth has contributed towards enhancement in aviation safety, the pilot's workload requirements are superseded by the combat mission requirements. Pilots have to be trained efficiently to match with advancements in fighter aircrafts, handling weapons, communication systems in coordination with other pilots and ground control systems in increased tactical battlefield environments. In-field pilots were exposed to counter G forces (acceleration), which demands extreme physical and cognitive loading, if not countered properly, the pilot will enter into grey out, blackout zone and G-induced loss of consciousness[3] (G-LOC). As an effect, pilots may also experience various neurological symptoms, seizure, spinal compression and hemorrhages. So, it is essential to understand pilot's cognitive workload (PCWL) during dynamic tasks and its influence towards performance.

Several researches have been contributed to understand workload assessment, for car drivers, industrial workers, whose job nature follows a set routine with little variation[4-6]. To author's knowledge, few research group have contributed to understand the cognitive role in fighter aircraft pilots, whose life is always under threat and high risk. Pilot uses past and current information to build a mental picture of the current and future events, where higher cognitive brain regions are involved for actions (top-down approach). It shall be stated that the workload of pilot is not an intrinsic attribute of a pilot's brain, but rather appears from the requirements, challenges under which a task is performed, skills/training, behaviours and perceptions of the pilot. The level of effort (cognitive and physical) and attention resources expected to accomplish a task in combat mission may induce stress and fatigue due to high PCWL.

It has been well accepted and reported in the scientific community that attention an indirect measure of performance and, could be assessed either by objective (performance score from simulator) or subjective techniques such as National Aeronautics and Space Administration Task Load Index (NASA-TLX)[7], subjective workload assessment technique,

Received : 12 May 2019, Revised : 08 August 2019
Accepted : 30 September 2019, Online published : 09 March 2020

rapid stress assessment scale, subjective workload dominance, modified cooper-harper scale, defence research agency workload scale and dundee stress state questionnaire. On the other hand, assessment of cognitive or physical performance was quantitatively assessed using physiological signals[4,8] CNS, such as electroencephalogram, electrooculogram, functional near-infrared spectroscopy and peripheral nervous system as measurement of heart rate, autonomous nervous system (ANS), heart rate variability (HRV)[9], electrodermal activity and electromyography.

Among many physiological measures, electrocardiogram (ECG) acquisition is a simple and effective, and, an unobtrusive technique for workload estimation; as it doesn't interfere with the subject's regular and high-risk operation or task. In scientific community, one of the established metrics that could explain the ANS is HRV. A wealth of literature exists on the capacity of HRV in neurological, psychiatric, and metabolic disorders and cognitive workload[10] among others. For instance, sympathetic activity increases the heart rate, constricts the blood vessels and thereby increases the blood pressure and parasympathetic activity on the other hand, it reduces heart rate and decreases the heart contractions thereby relaxing the individual. Several HRV studies conducted[11–15] were able to assess pilot's cognitive workload for cockpit display interface evaluation and pilot's workload measure both in a flight simulator and during actual fly for particular task or manouvering. Similarly, subjective assessment using NASA-TLX has been accepted and reported by various researchers[16]. The present study aimed to assess and understand the relation of dynamic workload and fighter pilot's performance, related to ANS regulation. To be specific, this study intends to empirically correlate the fighter pilot's attention (performance) and pilot's cognitive load during dynamic workload by physiological (ECG) and subjective measure (NASA-TLX), when pilots were flying in a high-fidelity fighter aircraft simulator.

2. EXPERIMENT

Pilots flew the fighter aircraft in the realistically fighter aircraft simulator facility available at Defence Institute of Psychological Research (DIPR), New Delhi as shown in Fig. 1.

2.1 Study Protocol

All pilots were advised to carry out four different workload sortie such as (a) normal visibility condition considered as normal workload (NWL), (b) low visibility condition as moderate workload (MWL), (c) normal visibility with secondary cognitive task (SCT) as high workload (HWL) and (d) low visibility with secondary cognitive task as very high workload (VHWL). Here, SCT task like adding two integers would be displayed on the cockpit display and if result of addition is odd number, pilots are instructed to press left switch else right switch in cockpit instrumentation, which is assumed as equivalent of responding to any kind of warning system. During each sortie, pilot has to undergo different segment or sub-tasks like start (60 s), take-off (approximately 60 s), cruise (approx. 300 s - 400 s), landing (60 s - 120 s) and rest after landing (60 s) as shown in Fig. 2.

Pilot's sub-task and its required actions along with avionic parameters (speed, altitude) and its corresponding physiological demands at each segment of workload task conditions are explained in as detail in Table 1. Between each workload sortie, 20 min break was provided to avoid the influence of the previous task. During each sortie, all parameters of cockpit instrumentation and SCT data was recorded simultaneously along with physiological parameters (ECG) with markers set for each flying segment. The NASA-TLX questionnaire form was completed by pilots during each break session. For example, just before flying at NWL task and after completion of NWL and after each sortie of MWL, HWL and VHWL tasks respectively. The consent form was signed by each participant before flying.

2.2 Subject Selection Criteria

All subjects were well trained, with age group of 26-34 year (mean age of 28.1±1.4) and were not prone to any drugs that are known to affect or assist the heart or brain functionality. Their medical reports within 12 month were examined and all are fit to the level of combat flying in flight simulators. Out of 20 subject, only 16 subject's data were considered for analysis, as 4 subject's data was rejected due to noisy signal, this could be due to electrode movement or other movement artefacts or other causes; that are yet to be investigated.

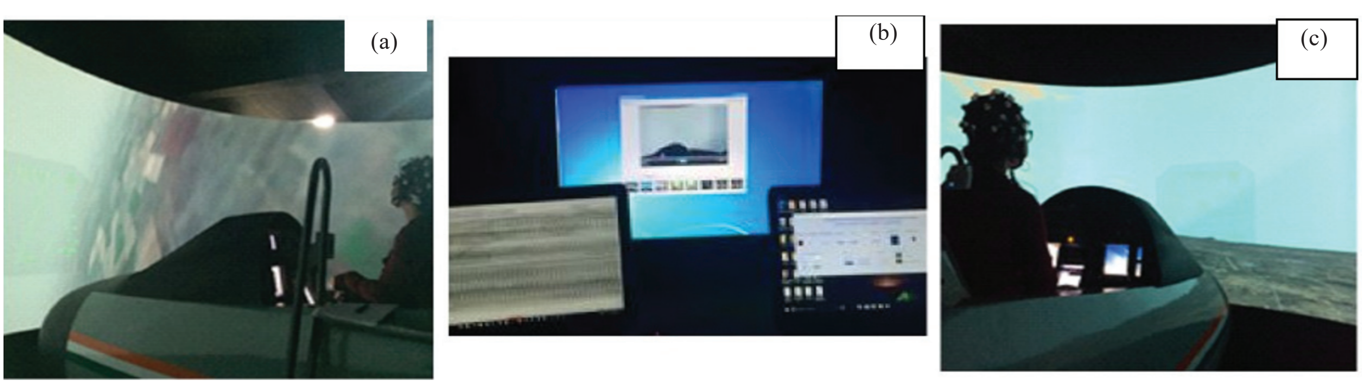

Figure 1. (a) Flight simulator in normal visible mode, (b) recording setup, and (c) low visible mode.

Table 1. The sub-task at different flying segments and corresponding pilot's action and expected demand in various task conditions

Task	Required pilots action	Demand in various workload conditions
START Break and throttle to idle Full brake Increase throttle to max Check rpm and release brake	Checking engine parameters Feel drag forces at throttling and releasing brake & ailerons, elevators, rudder control during banking	Mild physical demand but moderate to high preparedness for take-off during normal, low visible and while doing SCT (arithmetic & logic operations) in other sorties (workload conditions)
TAKE-OFF Use pedal to maintain runway Watch for speed to 120 knot Pull stick back Bring marker to the horizon Maintain 10º climb Climb to 4000 ft. and heading 09 Maintain 300 knot speed	More holding and use rudder Feel dragging force Use ailerons control to roll Straighten the flight Close gear and elevator control to pitch (lift) Change settings dry max Feel aircraft drag and pressure forces (use elevator) keep controlling aileron and rudder	More physical demand for handling joystick, complex psychomotor (eye, hand, leg coordination) and handed steadiness to maintain the proper rate of climb in low visible and more cognitive demand (multi-tasking, divided attention concentration) for SCT (arithmetic & logic operations) during moderate to very high workload sorties
CRUISE Maintain speed and altitude At 5N, right turn with 45º bank, 18 heading At 7N, right turn with 45º bank, 27 heading Make 0N, then 5N, turn 45º, 36 heading Take 45º turn, 09 heading Reduce speed to 200 knots and altitude 1000	Use all three controls Feel 1.5–2 G approximate in actual fly only throughout cruise, use of joystick with proper eye, hand and leg coordination, checking MFD for each turn	More physical demand and more cognitive demand for eye, hand and leg coordination under low visibility condition. High perceptual demand (attention memory, spatial relation, peripheral vision) to perform SCT and manuvering simultaneously in high and very high workload (with low visibility)
LANDING 12º alpha towards 0N Carriage down and reduce speed 170–180, landing gear release, align with runway Touch Down with 3º glide slope Para suit on and brake	Use control to lower aircraft Reduce speed and release gear Feel drag forces and pressure More mental and physical demand to align runway	More physical demand for motor control to align runway in all workload conditions & high perceptual load in low visibility due to rely on multiple displays (MFD). High attention switch and multitasking skills in high and very high conditions.

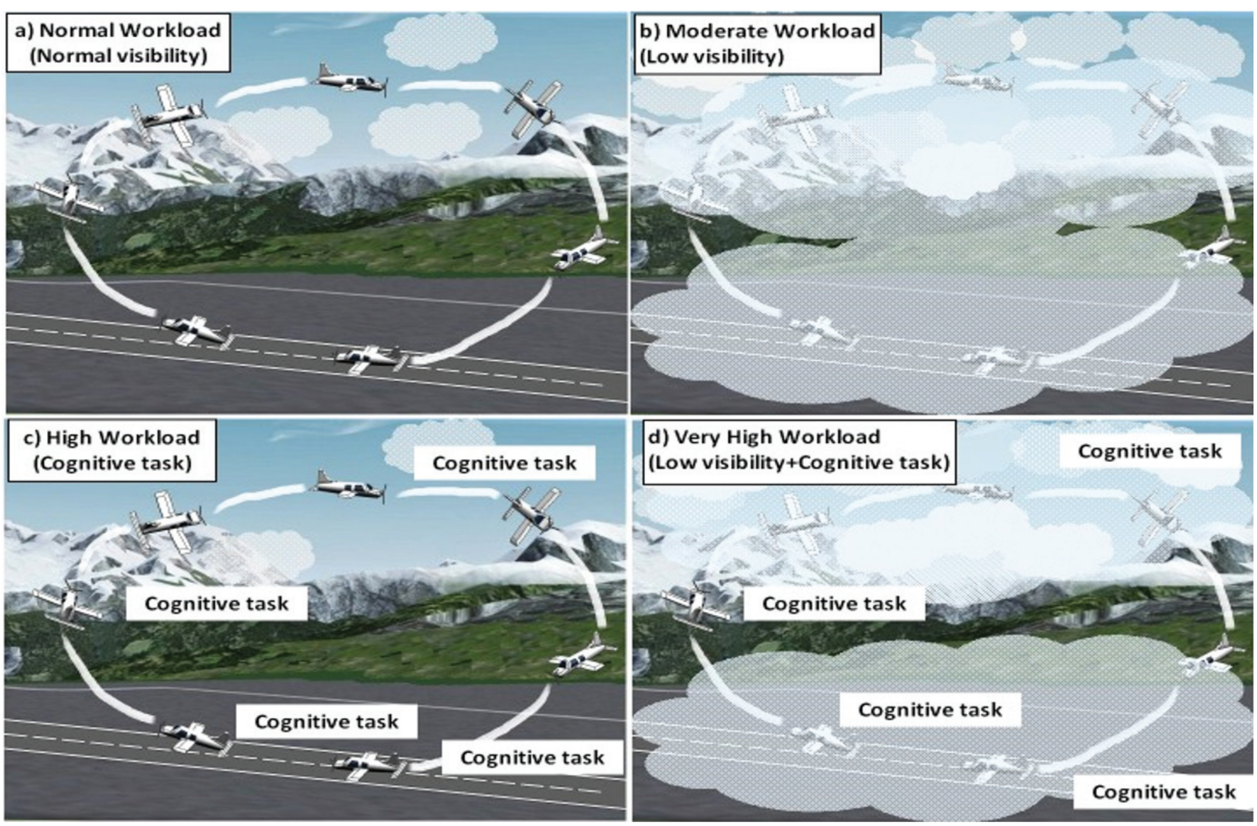

Figure 2. Flying protocol performed by test pilots at four different workload task (each task has 5 segments such as start, take off, cruise, landing and resting) (a) normal workload, (b) moderate workload, (c) high workload, and (d) very high workload.

3. ANALYSIS

Analysis section has been divided into (a) physiological monitoring, (b) subjective assessment, and (c) statistical analysis as shown in Fig. 3.

3.1 Physiological Assessment (Cardiac Signal Analysis)

Single lead (Lead-1) Electrocardiogram (ECG) of wearable remote physiological monitoring system (WRPMS) has been used to collect the ECG of the pilot. This WRPMS system is an advanced version of smart vest[17] that was developed by Defence Bioenginnering & Electromedical Laboratory, (DEBEL) as shown in Fig. 3. It uses conductive fabric electrode and was housed in a chest belt along with data acquisition and wireless transmission system. ECG data is acquired and transmitted wirelessly to the recording unit, that was down sampled at 128 Hz and signal was analysed with 60 second moving window. Algorithm was developed for pre-processing, zero-phase digital filter and the dynamic threshold was set for finding R-peak and subsequently RR-peak interval (RRI). Further, the HRV parameters[8,18-19] such as time domain features (mean RR, SDNN, RMSSD), frequency domain features (HRV_T, VLF, LF, HF, Total power (TP), LFHF ratio, LFnu and HFnu) and nonlinear feature[20-21] (Ratio of SD, SD1 and SD2) were extracted from RRI and processed using Matlab™. HRV features, its physiological indications and their response while dynamic workload is as shown in Table 2.

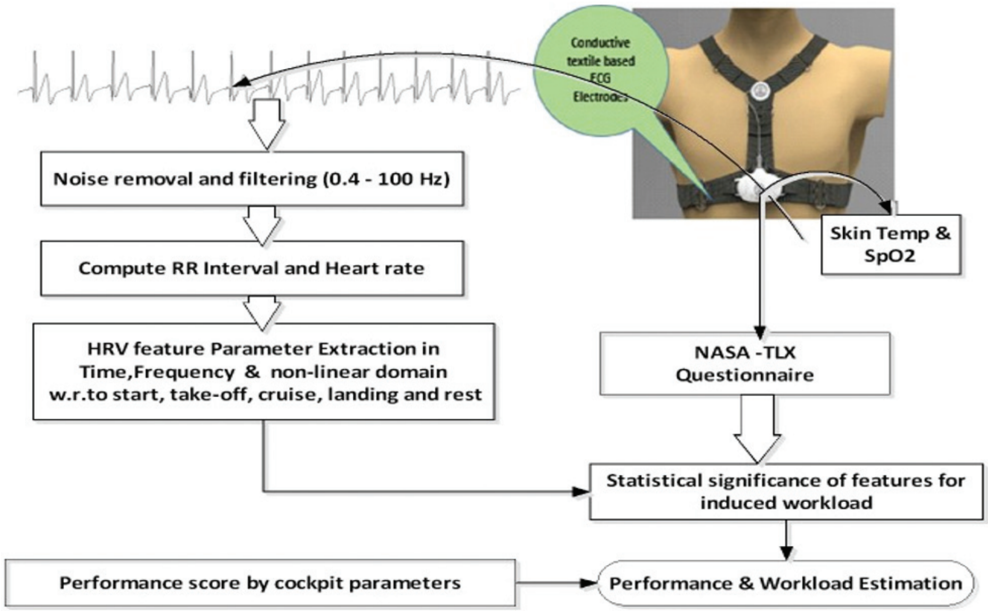

Figure 3. Functional representation of cognitive workload analysis for the pilot using wearable remote physiological monitoring system.

Table 2. HRV features and its effect expected due to increase in pilot's workload

Features	Description	Physiological indication	Expected effect
MeanRR	Mean of NN intervals	Rate of pumping of blood to heart	Decrease
SDNN	Std. deviation of NN intervals	Long-term elements and circadian rhythms	Decrease
RMSSD	Square root of mean squared diff between successive NN interval	Short cyclical variability in the autonomic tone	Increase
HRV_T	Integral of the density of the RR interval histogram divided by its height	Estimatation of overall HRV	Increase
VLF	0.0033–0.04 Hz	Slow changes in heart rate	Increase
LF	0.04–0.15 Hz	Index of both sympathetic and parasympathetic	Increase
HF	0.15–0.4 Hz	Parasympathetic activity	Decrease
LF/HF	Ratio between LF & HF	Overall autonomic activity	Increase
Total Power	VLF + LF + HF	Overall autonomic activity	Increase
LFnu	Normalised low frequency (0.04–0.15 Hz)	Sympathetic branch of ans	Increase
HFnu	Normalised high frequency (0.15–0.4 Hz)	Parasympathetic branch of ans	Decrease
SD1	Standard deviation of short term RRI	Short-term variability influenced by parasympathetic	Increase
SD2	Standard deviation of long term RRI	Long-term variability reflects sympathetic activation	Decrease
Ratio_SD	SD1/SD2	Overall autonomic activity	Increase

3.2 Subjective Assessment

The subjective assessment by NASA-TLX was to measure the workload[22] after completing each task. It consists of six subscales such as mental demand (MD), physical demand (PD), temporal demands (TD), Performance (PE), Effort (EF) and Frustration (FR). The first three subscales indicate demands on the subject and rest three scales indicates the interaction of participant with task. The objective assessment of pilot's flying performance score was arrived from recorded cockpit parameters and the SCT score arrived by analysing the number of commissions, omission, and errors at each task.

3.3 Statistical Analysis

HRV feature parameters were tested for normality and found that parameters were not normally distributed; so Friedman test was performed to identify significant difference between the measured parameters (HRV features) at five flying segments (start, take off, cruise, landing and rest) in all four conditions (NWL, MWL, HWL and VHWL) and also comparing NWL with other higher workload conditions. In addendum, the NASA-TLX score in MD, PD, TD, PE, EF and FR were compared at five flying segments in all four conditions. To identify the exact workload at which these differences existed, post-hoc wilcoxon signed ranks analysis was performed for the cases where Friedman test result showed significant difference. Statistical analysis was reported with a significant level at $p < 0.05$ and analyses were performed using SPSS™.

4. RESULTS

In the fighter aircraft simulator, time taken to complete one full sortie would be approximately 550 s - 600 s. While the pilots perform the assigned task, single lead ECG signal was collected continuously till the end of each sortie (i.e. 600 s). Feature set matrix size of 16x60x14 for each flying segment. In this study, HRV analysis was carried out for two findings

(a) within workload condition, that is, start, take-off, cruise, landing and resting in each sortie condition
(b) between workload conditions, that is, NWL (baseline condition) is compared with other three work load conditions (MWL, HWL, VHWL).

Table 3. Performance score and secondary task assessment of pilot in flying segments during various workload conditions (subject n=16)

Workload (WL)	Segments	Flying performance score (%) Mean± SD	Cognitive task performance score Mean± SD (inclusive of no of commission, omission, error)
Normal WL	Start	98.5±2.1	–
	Take-off	93.1±4.2	–
	Cruise	95.8±6.1	–
	Land	97.3±3.4	–
Moderate WL	Start	98.6±2.2	–
	Take-off	88.1±3.2	–
	Cruise	92.3±3.3	–
	Land	89.1±4.2	–
High WL	Start	97.8±2.5	91±4.5
	Take-off	87.2±5.4	70±8.5
	Cruise	91.2±3.2	85±9.1
	Land	91.1±5.5	65±9.8
	Rest	98.1±2.1	85±3.2
Very high WL	Start	98.8±3.1	85±3.9
	Take-off	88.2±6.7	65±7.6
	Cruise	87.2±8.2	70±5.4
	Land	86.1±5.2	61±8.1
	Rest	96.2±2.8	70±3.4

4.1 Within Workload Conditions

HRV features such as mean RR, SD2, SDNN, VLF, Ratio-SD and total power (TP), LFnu and HFnu were found to be significant at all five flying segments, for all four workload conditions as well. To be very specific, HRV features such as Ratio_SD, SD2, SDNN, VLF and TP has a lower mean ±standard error (14±3.2 < 28±6.1) at start and, take-off segments when compared to cruise and, landing in most of workload conditions.

The mean flying performance score of pilots at each segment across all four task conditions and SCT score are obtained by analysing cockpit parameters as tabulated in Table 3. Result shows that the performance was gradually reduced at take-off, cruise and landing phase in higher workload conditions when compared to NWL. Particularly, take-off and landing performance was challenging (mean score was 86–88% with SD ±3.5) in MWL and VHWL conditions, wherein low visibility and SCT was induced. However, the overall score indicates that pilot's mental capacity was able to match to increased task.

4.2 Between the Workload Tasks

Here, normal work load was compared with moderate, high and very high workload and its statistical significant p-values are as tabulated in Table 4 and their respective mean, and standard error plot are as shown in Fig. 4. When the NWL is compared with MWL condition: HRV_T mean value is low ($p<0.05$) during take-off comparing to the landing. Other features such as SD2, SDNN, VLF and TP are also significant ($p<0.05$) during cruise in NWL while comparing to MWL.

For assessing the NWL with HWL: Features such as VLF, TP, SD2, SDNN and HFnu are observed to be significantly low ($p<0.05$) during take-off (low mean value as shown in Fig. 4) and VLF, TP, HFnu and LFnu are significantly high (high mean value) during cruise and Ratio_SD, SD2, SDNN are significantly high during resting segment. Similarly between NWL with VHWL; the features LFnu and HFnu were significantly high (mean value are high) during take-off; SD1, RMSSD, VLF, TP are significantly high during cruise; SD1, SD2, Ratio-SD, SDNN, VLF, TP are significantly high during landing and, LF and HF are significantly low during resting segment.

Overall, results as shown in Table 5 infer that, HRV features such as SD2, SDNN, VLF, TP are significant in all flying segments across all work load conditions and LFnu and HFnu could probably differentiate the task of low visibility and SCT.

Table 4. HRV features showing significant difference between various workload conditions

Fly segment	Take-off (p-Value)			Cruise (p-Value)			Landing (p-Value)			Resting (p-Value)		
	NWL *vs* MWL	NWL *vs* HWL	NWL *vs* VHWL	NWL *vs* MWL	NWL *vs* HWL	NWL *vs* VHWL	NWL *vs* MWL	NWL *vs* HWL	NWL *vs* VHWL	NWL *vs* MWL	NWL *vs* HWL	NWL *vs* VHWL
Ratio SD	0.25	0.5	0.12	0.5	0.5	0.7	0.286	0.5	0.012*	0.5	0.022*	0.56
SD1	0.35	0.5	0.35	0.5	0.5	0.045*	0287	0.53	0.045*	0.5	0.5	0.779
SD2	0.45	0.035*	0.57	0.04*	0.5	0.5	0.31	0.553	0.045*	0.5	0.035	0.15
meanRR	0.45	0.78	0.57	0.5	0.5	0.5	0.666	0.115	0.5	0.5	0.5	0.5
SDNN	0.45	0.035*	0.32	0.045*	0.5	0.196	0.5	0.3	0.032*	0.5	0.031*	0.092
RMSSD	0.8	0.85	0.67	0.8	0.5	0.045*	0.5	0.02*	0.5	0.5	0.5	0.812
HRV_T	0.019*	0.56	0.56	0.7	0.5	0.5	0.045*	0.5	0.5	0.35	0.5	0.3
VLF	0.15	0.02 *	0.35	0.035*	0.5	0.035*	0.12	0.5	0.045*	0.17	0.041*	0.46
LF	0.53	0.43	0.67	0.5	0.5	0.5	0.5	0.5	0.45	0.17	0.5	0.036*
HF	0.24	0.58	0.87	0.5	0.5	0.5	0.5	0.5	0.45	0.89	0.5	0.036*
Total power	0.15	0.022 *	0.75	0.036*	0.5	0.032*	0.23	0.15	0.042*	0.15	0.042*	0.52
LFHF ratio	0.19	0.53	0.75	0.5	0.5	0.5	0.5	0.5	0.5	0.09	0.57	0.24
LFnu	0.34	0.25	0.045*	0.5	0.03*	0.5	0.5	0.5	0.5	0.08	0.04*	0.195
HFnu	0.9	0.15	0.045*	0.5	0.045*	0.5	0.5	0.5	0.5	0.07	0.04*	0.23

* Parameter that are significantly different in the flying segment (P<0.05).

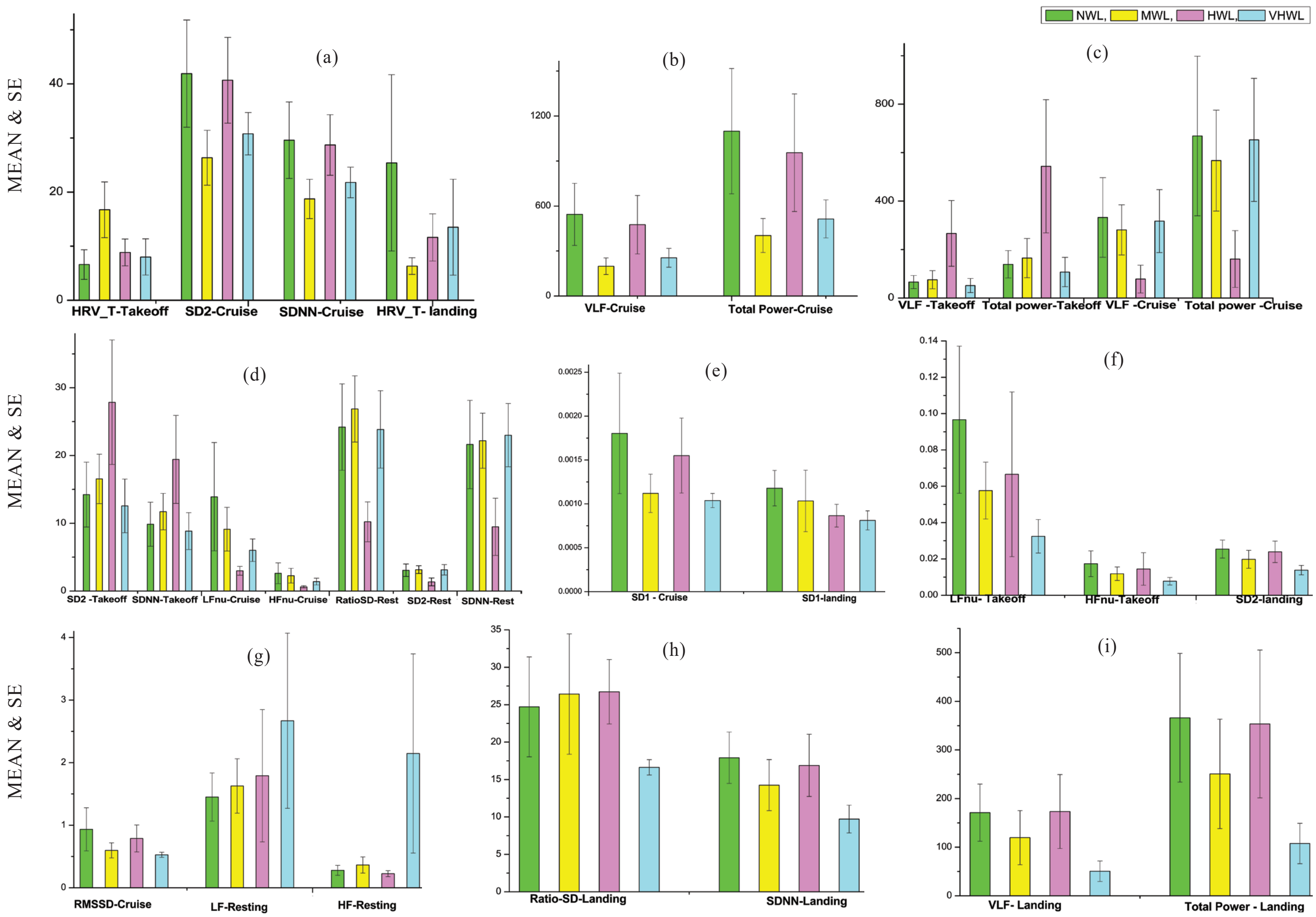

Figure 4. Mean and standard error values of significant HRV features in 'between the four workload conditions' ((a)-(b) : NWL *vs* MWL, (c)-(d) : NWL *vs* HWL, (e)-(i) : NWL *vs* VHWL.

Table 5. Significant HRV features at different flying segments in different workload comparison

Flying segments	NWL *vs* MWL	NWL *vs* HWL	NWL *vs* VHWL
Take-off	HRV_T	SD2,SDNN,VLF,TP #	LFnu*, HFnu*
Cruise	SD2,SDNN,VLF,TP #	LFnu*, HFnu*	SD1,RMSSD,VLF,TP
Landing	HRV_T, RMSSD	HRV_T, RMSSD	Ratio_SD,SD1, SD2,SDNN,VLF,TP#
Resting	No Significance	Ratio_SD,SD2,SDNN,VLF,TP#, LFnu*, HFnu*	LF, HF

Significant feature in all segments across all workload conditions; * Significant feature for differentiating low visibility and secondary cognitive task

On the other hand, all six components of NASA-TLX index such as MD, TD, PD, FR, EF and PE were analysed and statistical significance were found across all four task workloads as shown in Fig. 5. All NASA-TLX components show the significant ($p<0.05$) difference at before flying than other four task load conditions. Thus, result infers that low visibility and SCT increases perceptual activity required such as thinking and decision making in-flight control. However, it was observed that there is no significance between MWL and HWL for any of the demands except the component performance (PE). The reason could be that the pilots had felt that low vision was more significant than performing multi-tasking like SCT. But, in VHWL condition, all components were significantly different when compared to before flying, NWL and HWL as it shows that there is an increased demand and frustration in VHWL task.

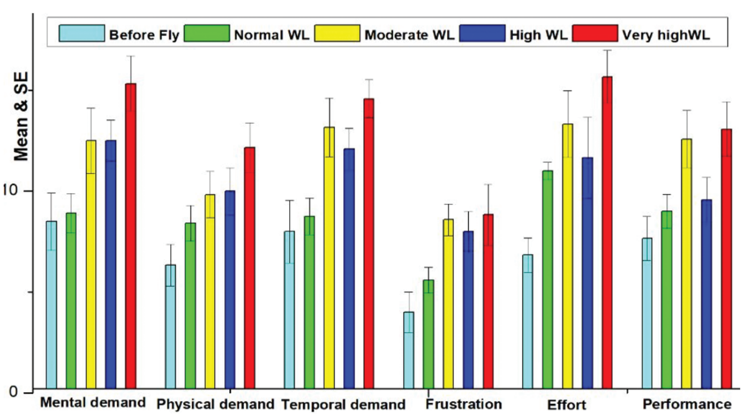

Figure 5. Mean and standard error of NASA-TLX score at before and after flying of each workload condition.

5. DISCUSSION

This study indented to empirically understand the response of ANS using HRV parameters (ECG changes) during dynamic workload environment for pilots. Furthermore, NASA-TLX was performed as a subjective assessment tool and correlated them with pilot's performance score for task performed at various workloads, to understand the relation between the performance and attention, working memory solicitation strategies adapted for achieving the goal assigned for each workload. As shown in the result, the goal was met; statistical analysis revealed a strong significant difference between workload with respect to HRV parameters.

For instance, during take-off phase, pilot carried out complex psychomotor activities such as eye, hand, and leg coordination, to maintain steady rate of climb with increased cognitive demands particularly in low visibility and with SCT activity. This demands a person to maintain the balance status to accomplish the targeted task, so (HRV_T at MWL and SD2, SDNN, VLF, TP at HWL and LFnu, HFnu at VHWL) the modulation of sympathetic and parasympathetic has to maintain the balance ANS. During cruise, more physical loading expected due to manoeuvering at 300bN speeds at 4000 feet for approximately 300 s - 500 s and more perceptual demand (attention memory, spatial relation and peripheral vision) are required to simultaneously handle the additional task (low visibility, with SCT) and manoeuvering the aircraft. During this phase, HRV features findings indicates the increased task performed as an effect of increased sympathetic activity (LFnu) and reduced parasympathetic (HFnu), when SCT was performed.

In the fourth segment (landing), the complex psychomotor response required to maintain steady rate of descending with high perceptual process such as speed estimation, peripheral vision and depth perception due to rely on multiple displays (MFD) at increased task conditions. HRV significant features such as HRV_T at low vision, RMSSD at SCT and Ratio_SD, SD1, SD2, SDNN, VLF and TP at VHWL infer that the fluctuation of sympathetic and parasympathetic system occurs to maintain the balance in ANS in association with workload dynamics, similar to take-off phase. Finally, in resting segment, no significance features were found at low visibility mode (MWL) due to no activity, but significance was observed for SCT activity.

Overall results infer that, during increasing workloads the sympathetic activities were more dominant. Thus, the results of this study were in-line with the earlier studies of HRV features in PCWL[12-13]. However, it has been observed that high parasympathetic activities were demanded during landing in MWL and HWL condition; this is associated with pilot's cognitive and physical task. During VHWL, pilot's workload has even more increased and the significant feature set infers that biological system has extended to bring a sympathovagal balance.

As a validation of HRV study and evaluate the attention measure, NASA-TLX (Fig. 5) was performed and the result indicates that, increased cognitive demand for maintaining steady state of ascending, descending (during take-off, landing) and for attention memory, spatial relation and peripheral vision (during cruise). However, for between task NWL vs HWL (normal visibility with SCT) EF and PR are not significant, which indicates pilots handled SCT with increased MD, TD, FR. On the other hand while comparing NWL with MWL and

VHWL (low visibility present at both task) the interaction components EF, PE, FR are always found significant, this in tune indicates that higher task load was met by increased level of effort and performance. Further, when comparing NWL vs VHWL result (as PD also becomes significant) indicates the increased psychomotor skills. Thus, NASA-TLX score supports HRV findings (cognitive workload) at various workload tasks.

On the other hand, even though the HRV features indicate significance at various flying phases and various workload task conditions, pilot was able to fly aircraft with mean flying performance score (obtained from cockpit simulator) of 80–97% as shown in Table 3, across all workload task. This shows, measuring PCWL and performance by subjective and objective techniques during different flying segments across dynamic workload environment demands on adaptability of pilot's ANS to meet the required performance. In future, neuronal activities study like EEG and NIRS could be used for understanding the functional connectivity among dynamic workload and relation between cardiac and cognitive markers.

6. LIMITATION OF THE STUDY

The main limitation of our study is the population size. This study demands skilled test pilots to maintain the study homogeneity. In addition, to complete the full experimental protocol it takes approximately 3 h - 4 h; during this period, subject had to wear the chest belt continuously for ECG acquisition. Second, the countering of G-forces, especially acting very high in fighter aircraft pilots in Z direction (head–toe), else if not countered properly, the pilot shall enter into G-induced loss of consciousness (G-LOC) at 4.5–5 +Gz in shorter time, cannot be simulated by this simulator, hence we did not consider the impact of G-Forces towards cognitive workload and attention of pilot.

7. CONCLUSIONS

This study finding has shown the correlation among physiological workload measure and pilot's performance (objective-simulator score) in dynamic workload environment. Further it has been validated using the self-assessment (subjective-NASA-TLX). These results could form as baseline to assess pilot's cognitive capacity and improve the performance during training in flight simulator and in real flight conditions. To realise a real-time PWL indicator, we are further extending this study to investigate a greater number of pilots during many complex manoeuvering and exercises to classify different cognitive status in regular fighter aviation environments, as future work, which is also useful for cockpit ergonomics study.

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