

Original Article

In-flight Electrocardiography Monitoring in a Pilot During Cross Country Flight

William D. Kim, M.D.¹, Sang-Wook Kim, M.D., Ph.D.², Seong-Kyu Cho, M.D.¹, Ju Hyeon Byeon, B.S.¹, GunYoung Lee, Ph.D.³, WooSeok Hyun, Ph.D.⁴, JoungSoon Jang, M.D., Ph.D.^{2,5}

¹Chung Ang University College of Medicine, ²Department of Internal Medicine, Chung Ang University College of Medicine, Seoul, ³Department of Aeronautical Science and Flight Operation, Korea National University of Transportation, Chungju, ⁴Department of Computer Software, Korean Bible University, Seoul, ⁵Aerospace Medical Association of Korea, Seoul, Korea

Received: October 31, 2024
Accepted: November 18, 2024

Corresponding Author

JoungSoon Jang
Department of Internal Medicine, Chung Ang University School of Medicine, 102 Heukseok-ro, Dongjak-gu, Seoul 06973, Korea
Tel: +82-2-6091-6101
Fax: +82-2-6091-6102
E-mail: alsaba@daum.net

ORCID

<https://orcid.org/0000-0001-8137-9873>

Purpose: The diagnosis and management of cardiovascular diseases are important for pilots, as well as the assessment of workload. Heart rate variability (HRV) can be evaluated from electrocardiography (ECG) signals during flight phases to assess the activation of the autonomic nervous system.

Methods: In this study, continuous ECG activity was recorded of one pilot who flew as a pilot flying during a 4-hour long round trip using wearable ECG machine and was analyzed with MATLAB (R2020b ver. 9.9, The Mathworks Inc.). Total flight was divided into five phases: preflight, take off, cruise, landing, and postflight.

Results: Mean heart rate (HR) was lowest in the postflight phase (76 bpm), and highest in the landing phase (86 bpm). Landing phase showed the highest values in standard deviation of NN interval (59.3 ms), triangular index (11.7), and triangular interpolation of NN interval (195 ms), while the postflight phase had highest root mean square of successive difference (20.5 ms) and proportion of successive RR interval (3.4 ms). As for frequency-domain metrics, the landing phase had the highest low-frequency/high-frequency ratio of 5.33. Among the non-linear HRV measures, the landing phase presented the lowest SD1/SD2 ratio (0.15).

Conclusion: We observed the relative increase of mean HR and change of HRV in the landing phase, indicating elevated sympathetic nervous tone. Further studies should be considered to evaluate specific changes of ECG signals in flight phases and confirm the clinical use of the MATLAB signal analysis tools.

Keywords: In-flight, Electrocardiography, Pilots

I. INTRODUCTION

During flight, pilots experience physical, physiologic and psychologic stress which increase the workload of controlling the aircraft [1]. Overcoming this stress and

maintaining homeostasis is crucial to secure a safe flight for passengers and crew members. The pilot's condition is paramount in the cockpit environment in flight, and airplane hardware is now almost completely advanced, causing little flight problems. On the other hand, human fac-

tors involving pilots were the main cause of accidents, and about 70% are known to be resulted from human errors [2]. Pilot incapacitation may cause serious problems during flight; the deadliest of this condition is cardiac abnormality, including arrhythmias [3]. In fact, cardiovascular diseases are one of the major factors of disqualification in a pilot's medical examination [4]. However, most examinations do not reflect the state of the heart in actual flight, as they are measured in a steady state rather than in flight.

The heart regulates its contractility and rate according to the environmental changes, and the autonomic nervous system (ANS) contributes to this autoregulation [1]. The ANS is balanced by the sympathetic nervous system (SNS) and parasympathetic nervous system (PNS) tones; Activation of the SNS leads to elevated contraction and heart rate (HR), while the PNS contributes to the opposite. Heart rate variability (HRV) represents the changes in inter-beat intervals and can be used as indicators of ANS activation [9].

Electrocardiography (ECG) records the electrical signals of the heart during its cycle through systole and diastole. Non-invasive wearable ECG devices can immediately analyze HR and rhythms or save the recorded data for future interpretation [5]. As the data is in raw form, there are software programs that can process and convert it into images. MATLAB (The Mathworks Inc.) can be used for ECG signal analysis, and there are many toolbox kits that enable the simplification of this process. Previous studies have demonstrated changes in ECG signals during flight [6-8]. Yet there are no studies that divided the flight sequence into phases and compared HRV values with MATLAB to evaluate the workload in each phase.

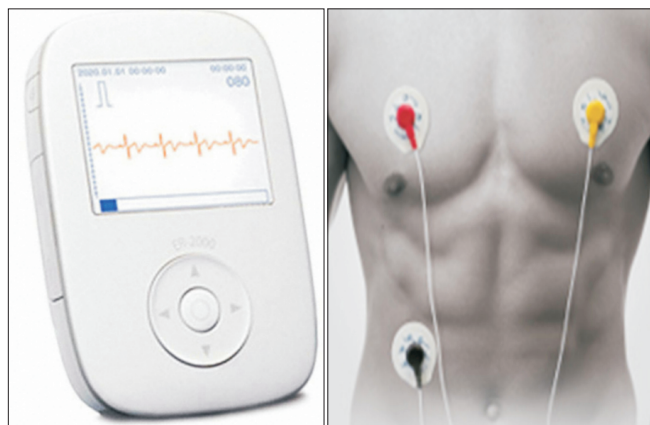


Fig. 1. Wearable electrocardiography (ECG) machine (ER-2000, Boryung Soo & Soo) and ECG electrodes in body.

In this study, we continuously monitor ECGs in real-time on pilots flying real-world and analyze their results analyzed by each flight sequence, using MATLAB toolkits. The results of this study are a pioneering experimental study to see if such real-time monitoring is possible.

II. MATERIALS AND METHODS

This study was approved by the Institutional Review Board (IRB) of Chung-Ang University Hospital. (IRB approval number: 1701-009-16033).

1. Participants

One healthy 62-year-old male pilot participated in this study on April 29, 2020. The participant was currently qualified to fly the aircraft, having private pilot license and instrument rating. Total logged flight time is 202 hours. The safety pilot has commercial pilot license and instructor rating. Body mass index of the pilot flying is 23.3 kg/m² and he has no known cardiovascular disease.

2. Data acquisition

Continuous ECG activity was monitored using conventionally available product ER-2000, an wearable ECG monitoring machine (Boryung Soo & Soo) set to Holter mode (Fig. 1). Lead I was recorded by attaching capacitive electrodes to the pilot's lower margin of bilateral clavicles at the midclavicular line and an additional ground electrode to the left midclavicular line at the umbilical level.

The pilot conducted a 4-hour roundtrip cross country flight with a cirrus SR-20 (HL-1284), a single engine 4-seat aircraft belonging to Korea National University of Transportation (Fig. 2). The flight was done under instrument flight rules and assigned altitudes were 7,000 and 8,000 feet above mean sea level respectively with 2 full stops. Each flight leg was divided into 5 phases: preflight, take off, cruise, approach and landing, and postflight. The



Fig. 2. The aircraft used in the test SR-20.

pilot continuously self-reported his stress condition and flight status for each flight phase.

3. Electrocardiography data processing and analysis

The obtained 4-hour length of ECG data was visualized using matplotlib by Python 3.7 (Python Software Foundation). Miscellaneous signals were defined as abnormal peaks showing more than 5,000 signal intensity compared with adjacent QRS complexes. These outliers were deleted from the raw data, starting from the end point of the previous T wave to the end of the T wave of the abnormal signal (Fig. 3).

This processed data was divided according to the five flight phases and loaded to the HRVTool ver. 1.07 (<https://marcusvollmer.github.io/HRV/>) using MATLAB (R2020b

ver. 9.9). HRV parameters were obtained in time, frequency, and non-linear domain [9]. Time-domain metrics represent the quantitative variability of HRV in a given length of ECG data, and standard deviation of NN interval (SDNN), triangular index (TRI), triangular interpolation of NN interval (TINN), root mean square of successive difference (RMSSD) and proportion of successive RRI >50 ms in relation to the total RRI (pNN50) were included. Frequency-domain parameters measure the power distribution of HR oscillation frequency bands; low-frequency (LF, 0.04–0.15 Hz), high-frequency (HF, 0.15–0.40 Hz), and LF/HF (ratio of LF-to-HF power) were measured. Non-linear metrics quantify the unpredictability of a time series; SD1 (Poincaré plot standard deviation perpendicular the line of

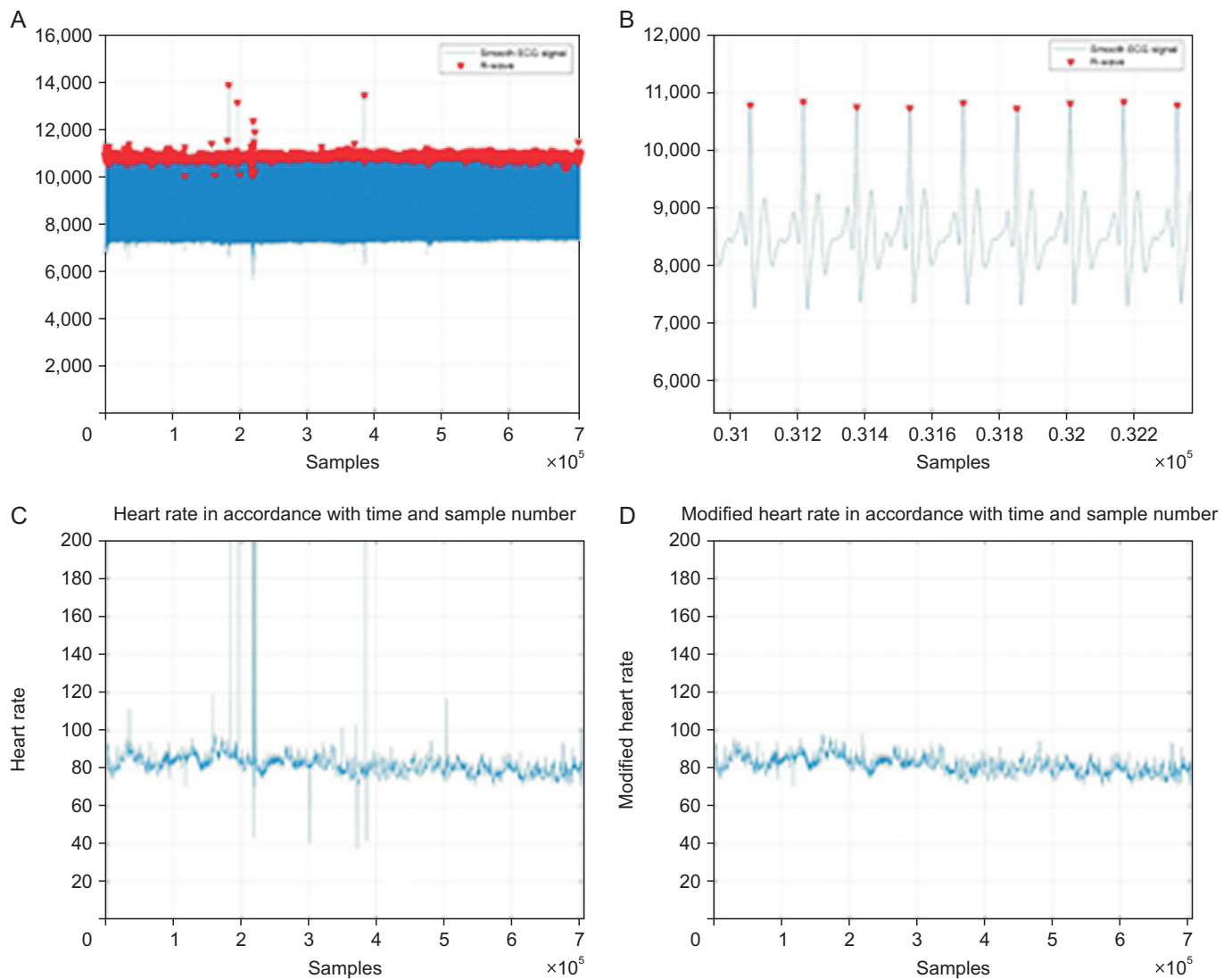


Fig. 3. Heart rate observed during the test.

identity), SD2 (Poincaré plot standard deviation along the line of identity), and SD1/SD2 ratio were included. R wave detection was additionally required for frequency domain HRV calculation. RR intervals were calculated after R wave detection and visualized to a RR tachogram, finally being inversed to acquire instant HR values (Fig. 4). To exclude outliers, NN interval value was set up as minimum 110 ms to maximum 180 ms. The outlying values were replaced with preceding NN interval values. Power spectral density was calculated by normalization of the RR interval and using the Fast Fourier transform.

III. RESULTS

1. Heart rate analysis

Instant HR was calculated, and the mean values are represented in Supplementary Table 1. Landing phase showed the shortest mean RR interval of 140.4 ± 11.6 ms, while postflight phase had maximum value of 157.2 ± 9.4 ms. Thus, the landing phase had the highest mean HR of 86 bpm, and postflight had the lowest value of 76 bpm (Fig. 3).

2. Heart rate variation analysis

Parameters of HRV were calculated using HRVTool ver.1.07 (Fig. 5) and the results are summarized in Supplementary Table 1.

Diagram of the HR for the entire duration of the flight,

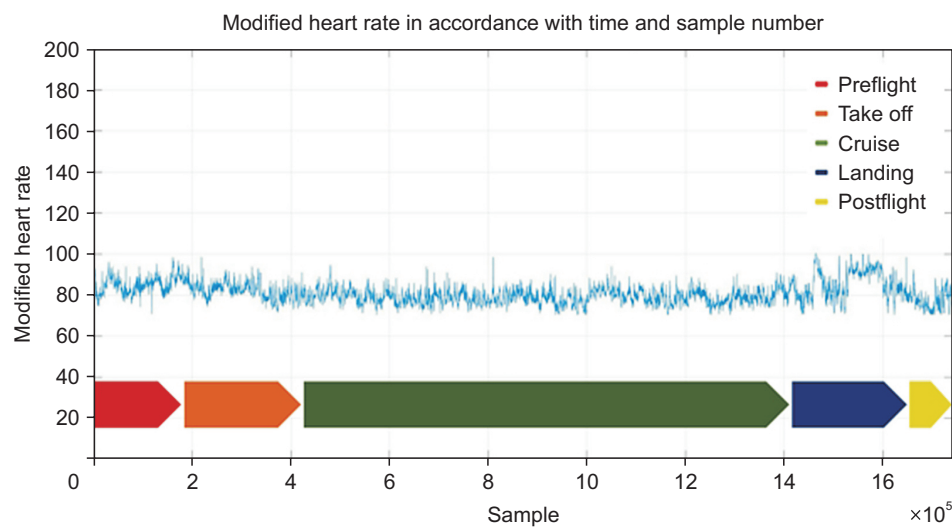


Fig. 4. Heart rate variation by five flight segments.



Fig. 5. Heart rate variations observed using analytical tool.

divided into flight phases shows that most HRs ranged between around 70 and 100, with the smallest fluctuations during the cruise (Fig. 4).

For the time-domain indices, landing phase showed increase in SDNN (74.9%), TRI (34.5%), and TINN (38.3%). Postflight phase showed decrease in the three parameters, while having the highest RMSSD (20.5 ms) and pNN50 (3.4 ms). Cruise phase had the smallest value of SDNN and pNN50 by 33.9 ms and 1.2 ms, respectively.

Regarding the frequency-domain indices, there was increase of LF in take off phase and decrease in HF in landing phase, leading to increase in LF/HF ratio in both phases. There was decrease in LF/HF ratio in postflight phase, resulting from dominant elevation of HF.

For the non-linear HRV parameters, there was minimal change in SD1 values, but significant increase of SD2 in landing phase, leading to decrease of SD1/SD2 ratio (0.15).

IV. DISCUSSION

1. ECG data preprocessing

When processing the raw ECG data, standards were set to find abnormal R waves. However, there were QRS complexes that could not entirely be classified as outliers due to the dispositioning in the signal baseline of some sections. The baseline was identified as starting from the end point of the T wave of the preceding QRS complex to the start of the P wave of the following signal, and oscillation of it caused error in evaluating signal intensity. The main causes of artifacts in ECG signals are thought to be interference from the surrounding or muscle twitching and respiration of the subject [10], which may have led to baseline wandering. Islam et al. [11] demonstrated the use of MATLAB functions and toolboxes to remove this oscillation in baseline, using a digital filter or wavelet transform method. When processing the data, our judgement criteria was based on whether the wave had a regular ECG signal shape, and followed the overall trend of adjacent signals.

2. Heart rate response to flight conditions

Among the five flight phases, landing phase showed the highest mean HR. During approach and landing, the pilot is in full arousal state with high levels of concentration and anxiety, leading to activation of the SNS (Fig. 4). In response the HR is elevated, and cerebral blood flow is increased [8].

Cruise and postflight phases showed relatively low mean HRs, implying activation of PNS and decreased stress.

3. Heart rate variability and autonomic nervous system

Among the time-domain indices of HRV, landing phase showed the greatest value in SDNN, TRI, and TINN. SDNN is related to both SNS and PNS activity and is shows correlation with TRI, which represents signal irregularity [9]. In our results, the two parameters showed similar tendency during overall flight phases in general. Significant increase at landing phase is shown, indicating prominent variability and irregularity of HR. Lowered SDNN and TRI showed relaxed state at postflight phase. In addition, TRI can be used for arrhythmia detection and the cut-off value is 20.42 [9], and no arrhythmic pattern was present in our results.

RMSSD is an index used to reflect short-term variation in HR and predict interbeat variation in high frequency band [9]. pNN50 is also related to short-term variability, indicating the action of the PNS [9]. Both parameters showed little change until exhibiting notable increase in postflight phase. This suggests that vagal tone rises after the end of the landing phase, showing antagonistic effect to the increased SNS tone. Cao et al. [6] analyzed HRV changes and performance in commercial airplane pilots during flight simulation, showing decreased SDNN and RMSSD at the most difficult tasks, while higher values were associated with increase in task performance. However, the total flight was not divided into sequences by time course but was divided by task difficulty, and pilots underwent simulations rather than real flight situations.

HF band, also known as the respiratory band, reflects the PNS activity during respiratory cycle. Both SNS and PNS contribute to LF power, primarily by the PNS. Therefore, LF/HF ratio reflects sympathovagal balance, with high value implying sympathetic nerve dominance [6]. HF value was recorded highest at cruise phase, sharply decreasing at landing phase and recovering at postflight phase. Thus, PNS tone was depressed during landing phase where there was high workload, and vagal tone increased when the stressor was eased at postflight phase. LF/HF ratio was maximal at landing phase and decreased at postflight phase. Considering that the mean HR is the maximum in the landing phase, this suggests that the given task acts as a stressor and shifts the sympathovagal balance to SNS dominance.

The non-linear HRV measurements are calculated by analyzing a Poincaré plot with an ellipse fit in. SD1 represents the width of the ellipse, reflecting baroreflex sensitivity, and is related to RMSSD, SDNN, pNN50, LF, and HF power [9]. SD2 measures the ellipse length, correlating with baroreflex sensitivity and LF power, while SD1/SD2 ratio weighs the autonomic balance similar to LF/HF ratio [9]. The SD1/SD2 ratio showed significant decrease in the landing phase, recovering again in the postflight phase. This was mainly attributed from the change in SD2, while SD1 showed minimal difference throughout the flight. This result indicates that the ANS balance has been given more weights to SNS in the landing phase, and then returns to its original state in the postflight phase.

4. Limitations

There are some limitations in the current study to be mentioned. First, the raw ECG data had to be manually edited and this may have caused data loss. This may bring overlooking of normal variant or pathogenic signals, which may be important in patients with cardiovascular diseases. However, the amount deleted was significantly minimal compared with the entire data, thus having less effect on the results. Second, the pilot's ECG data in resting phase were not obtained, which may have resulted in lack of complete comparison of the results. However, the pilot's state in preflight phase was relatively stable, enabling comparison of following sequences to be done. Finally, the HR and HRV results of different phases could not be statistically compared due to limited participant number. We plan to conduct our study further on to include more cases and confirm our results.

V. CONCLUSION

In this study, we observed the changes in HR and HRV of one pilot in different phases when operating a 4-hour flight. The landing phase showed the highest increase in mean HR and change in HRV, implicating the elevation of SNS and stress level. Future prospective studies with a larger cohort are required to confirm our results.

CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

FUNDING

None.

ACKNOWLEDGEMENT

None.

ORCID

William D. Kim, <https://orcid.org/0000-0002-7285-9290>
Sang-Wook Kim, <https://orcid.org/0000-0002-7208-8596>
Seong-Kyu Cho, <https://orcid.org/0009-0005-6219-8037>
Ju Hyeon Byeon, <https://orcid.org/0009-0007-5346-6735>
GunYoung Lee, <https://orcid.org/0000-0003-2480-9595>
WooSeok Hyun, <https://orcid.org/0000-0002-4474-7646>
JoungSoon Jang, <https://orcid.org/0000-0001-8137-9873>

AUTHOR CONTRIBUTIONS

Conceptualization: JSJ, SWK. Data curation: JSJ, GYL. Analysis and interpretation: WDK, SWK, SKC, JHB, WSH. Writing the original draft: WDK. Critical revision of the article: SWK, JSJ. Final approval of the article: all authors. Overall responsibility: JSJ.

SUPPLEMENTARY MATERIALS

Supplementary data is available at <https://doi.org/10.46246/KJAsEM.240023>

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