Heart Rate Variability of a Student Pilot During Flight Training

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BACKGROUND: Heart rate (HR) indicates the number of beats per minute (bpm) of the heart, while heart rate variability (HRV) indicates the temporal fluctuation of the intervals between adjacent beats (NN). HRV expresses neuro-cardiac activity and is generated by heart-brain interactions and dynamics related to the function of the autonomic nervous system (ANS) and other components (e.g., body and ambient temperature, respiration, hormones, blood pressure). We are carrying out a series of experimental investigations with the aim of studying HRV in student pilots during training.

CASE REPORT: For this purpose, we used a Holter electrocardiograph equipped with three channels and five electrodes positioned on the chest of the subject who participated in our investigation. The case report refers to a student pilot who, during a flight mission with the instructor, had to face a forced landing and a flap failure. We report data based on analysis of the time domain and frequency domain related to operations on the ground before the flight, during the flight, and on the ground after the flight.

DISCUSSION: Our initial conclusion is that the extent of HRV constitutes an "energy store" for better cardiac performance in eustress activities. During advanced tasks, the "Total Power" of the heart decreases because the RR intervals are forced toward low values, where the heart is less able to be modulated by its many controllers. Furthermore, this experimental protocol can be useful to flight instructors for the training process of student pilots.

KEYWORDS: cardiac function, heart rate variability, flight training, eustress.

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Contraction of the heart occurs in an autonomous and rhythmic way since it contains pacemaker cells that can initiate depolarization of the atrial and ventricular cells via conducting tissue. The main groups of these pacemaker cells are located at the level of the sinoatrial and atrioventricular nodes (secondary starter).[10] The time course of the electrical events preceding the mechanical ones can be recorded as an electrocardiogram.

The frequency of contractions of the heart (systoles) per minute (heart rate) is an important parameter for understanding the function of this organ, but it does not explain its physiology or modulation. For example, a frequency of 70 bpm expresses a general trend of the heart rate (HR) but does not indicate the distribution during a given minute; there is no information about the time between one beat and the next (RR-Int). In other words, the detailed heart rate variability (HRV) cannot be described by the HR alone. Thus, within certain limits, this fluctuation does not express a malfunction, but rather a physiological behavior, given the conditions of dynamic equilibrium that distinguish the functioning of complex biological systems.

It is well known that the sinus rhythm is irregular under steady-state conditions.[7] The fluctuations that are evident between adjacent beats are negligible if one considers average values over time. However, their genesis appears to be linked to complex and nonlinear interactions between the various

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physiological systems involved in modulation.[7] The HRV is therefore a property of interdependent regulatory systems that operate at different time scales. It reflects a balanced action regulated by the sympathetic nervous system (SNS) and parasympathetic nervous system (PNS), as well as blood pressure (BP), vascular tone, gas exchange, the intestine, and perhaps even the facial muscles.[3]

When an organism prepares to face new tasks or improve acquired, predictable, or emergency situations, a series of new operating conditions is established involving organs and systems; these affect parameters such as BP, amplitude and frequency of the respiratory rhythm, the hormonal sphere, and the function of the myocardium. In essence, a kind of stress response occurs in which both the SNS and PNS play roles of primary importance.[1,4,11]

A recent study conducted at the Department of Cellular and Molecular Medicine, University of Arizona College of Medicine, showed that the HR can be used to assess the cognitive commitment of students. The results of this survey suggest that the analysis of the HR trend is a valid method for quantifying and interpreting a learning process in its various facets.[2]

Many parameters affect the performance of the heart. A learning process that occurs in conditions of extreme individual variability will have a success that depends on several concomitant factors. In this context, we proceeded to carry out a series of experiments with the aim of quantifying the HRV in student pilots who are preparing to obtain a flight license for private use (PPL), as well as in students who already have a PPL and theoretical part (ATPL), but who continue their studies in order to acquire a commercial pilot license (CPL). The final goal of our investigations was to determine whether the HRV could give indications about evolution of the learning process, framed in a broad autonomic and motivational context.

For this purpose, we are performing experimental procedures on both PPL and CPL student pilots during the instrumental flight training phase (CPL-IR) on a voluntary basis, with a guarantee of confidentiality for the purposes of processing personal data.

In this case report, we describe the results obtained from the HRV analysis of a PPL student pilot trainee who, for reasons of confidentiality, we will call "the subject".

CASE REPORT

The experimental protocol has been approved by the National Civil Aviation Authority (Aeromedical Section) of the Italian Republic.

Before the experimental session and immediately after his arrival, the subject was equipped with five noninvasive electrodes, positioned in areas of the thoracic skin, and connected to a three-channel Holter (ECG Biomedical, BI9100), which remained active until completion of the experimental session. The flight track (altitude, direction, and time) of the aircraft for the entire duration of the flight allowed us to correlate the times at which the flight activities scheduled by the instructors took place with the Holter recordings; this was followed by analysis. The aircraft used was a Tecnam.[12]

The training mission consisted of three phases: (1) a ground phase that included a briefing with the flight instructor; (2) an in-flight phase during which, in addition to normal operations, the student had to manage sudden emergencies such as a forced landing and a flap failure. A ground phase (3) including a debriefing was scheduled at the end of the mission.

Apart from the initial arrival and waiting time (a & w), we defined three time phases: before ground flight operation*s* (bfo), in-flight operations (dfo) and postflight ground operations (afo). During the flight, the instructor suddenly created two emergency conditions. The first related to a forced landing (FL) and the second related to a landing under flap failure conditions (FF). The HRV was quantified according to the guidelines of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996).[5] We assessed the HRV based on the time domain and frequency domain analysis.[9]

In the time domain, we quantified the mean of all RR-wave intervals and their averages before, during, and after various tasks. In the frequency domain, we quantified total power (TP) that mainly reflected the level of the autonomic nervous activities (both parasympathetic and sympathetic nervous system) and high frequency normalized units (HF, nu) versus low frequency normalized units (LF, nu) to emphasize the balance between the sympathetic and parasympathetic arms of the autonomic nervous system.

The duration of the Holter recording was 152 min, with a number of total beats of 13,793. The average HR was 90 bpm [minimum value = 66; maximum = 135, minimum HR (minute), tachycardia beats = (2.7%) 366, bradycardia beats = 0, RR-Int = 669.9 ms]. The standard deviation of the interbeat intervals of normal sinus beats was 87 ms, very low frequency = 469.5 ms^2, low frequency = 1086.6 ms^2, and high frequency = 266.5 ms^2.

Fig. 1 depicts the mean of RR-intervals for all flight missions; RR-interval averages in bfo, dfo and afo; and LF versus HF normalized units.

The mean RR-intervals were quite variable, although a common trend was observed in the RR-Int parameter: a decrease of values in the dfo compared to the bfo and afo values. The comparison between LF and HF normalized units shows an increasing tendency of the former and a downward trend of the latter.

Fig. 2 depicts the time and frequency domain analysis when the subject was faced—in flight—with two sudden events: a forced landing and a flap failure. The histograms compare the values found in the two emergencies. During the forced landing, the RR-Int was slightly higher than before, while during the flap failure the RR-Int was lower than before.

Concerning the frequency domain values for the specific FL and FF tasks, it can be seen that during the FL task, the total power increases and then decreases, while during the FF it decreases, and then increases. Comparative analysis of the LF

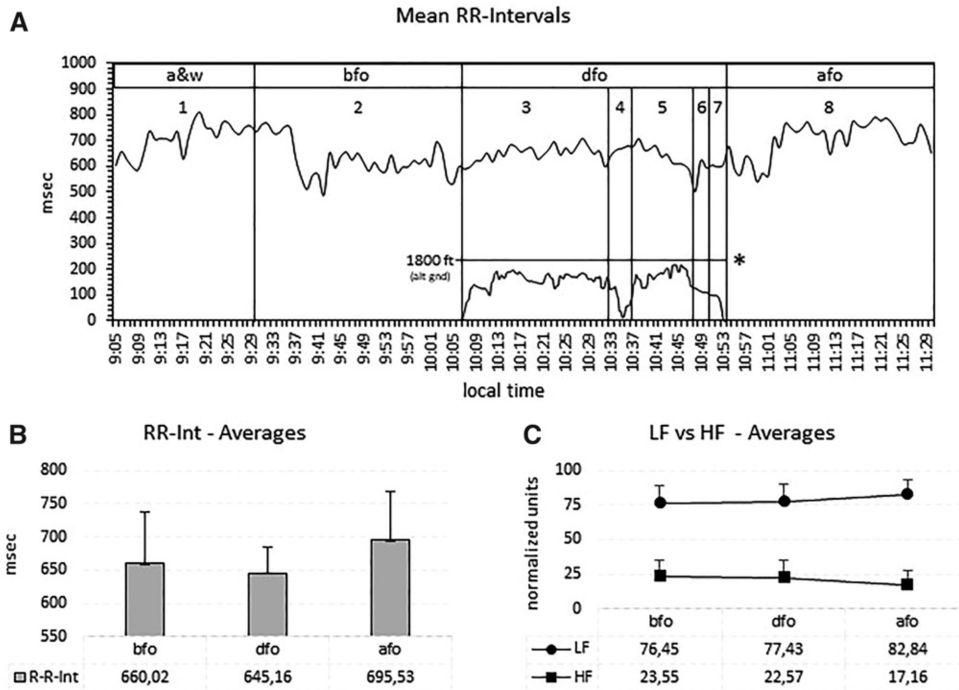

Fig. 1. A.) Plot of Mean RR Intervals and time of the start and end of each task. [1, arrival and waiting (a & w); 2, before flight operations (bfo); 3, during flight operations (dfo), navigation, and maneuvers before forced landing; 4, dfo (forced landing); 5, dfo (before flap failure); 6, dfo (flap failure); 7, dfo (landing); 8, after flight operations (afo)]. The insert inside marked with an asterisk indicates the flight time and the ground altitude (alt gnd) of the aircraft. B.) RR-Interval averages before (bfo), during (dfo), and after flight operations (afo). C.) Low frequency (LF) versus High Frequency (HF), normalized units (n.u.).

and HF normalized data for forced landing and flap failure indicates that, in both tasks, the LF increased during the FF task, but it was more pronounced in the FF task. However, the HF decreased in both cases, although the decrease was more pronounced in the FF task.

DISCUSSION

The progress of the subject's training depends on many variables. They include information analysis; level of attention and vigilance; memorization processes; learning technique; situation awareness; avoidance and management of errors; cooperation and communication; personality; attitude and behavior; self-discipline; workload; state of alertness; stress; and fatigue.[13]

As the subject proceeds with his mission, he will begin to put into place mechanisms such as acquisition, planning, implementation, verification, correction, and improvement of his performance, as well as anticipation processes (feedforward mechanisms) that are fundamental for the construction of a probable scenario. In other words, he begins an adventure that will see him engaged, together with his flight instructor, in a game where progress and outcome will depend on his will and desire to succeed. In doing so, he will try not to disappoint himself or his instructor.

The mammalian heart is innervated by the autonomic nervous system through its sympathetic components (SNS) and parasympathetic components (PNS). In resting conditions, the control of the PNS predominates over that exercised by the SNS. A human heart beats at a rate of about 70 bpm, but if it is deafferented by parasympathetic control, its rate increases to above 100 bpm. However, moderate parasympathetic stimulation may stop the heartbeat for a short time.[6] Moreover, from a temporal point of view, the parasympathetic effect is more rapid than the sympathetic effect, with a ratio of about 5:1. The relationship between the PNS and SNS branches is complex and evolves both linearly and nonlinearly. For this reason, it should not be described as a system where the gain or loss of one component is perfectly balanced by the loss or gain of another component in an equal and opposite sum. Increased PNS activity may be associated with a decrease, increase, or no change in SNS activity.[8]

An aircraft flight and all related activities presuppose performances that result from concomitant actions of organs and systems, starting with all divisions of the nervous system and continuing to involvement of central and peripheral mechanoreceptors and chemoreceptors. The data obtained from our experiments lead us to two types of consideration, one concerning pilot training and the other concerning cardiac function. Continuous and nonlinear interaction between organs and systems affects the intensity and duration of the parameters described above.

Time domain analysis showed that the decrease of RR-Int in dfo compared to bfo is due to the fact that, during this phase, the subject is trained on new tasks or reviews those that were previously learned but not yet definitively acquired. In other words, the HRV reflects the variations in a subject's performance in relation to the level of achievement of a given task.

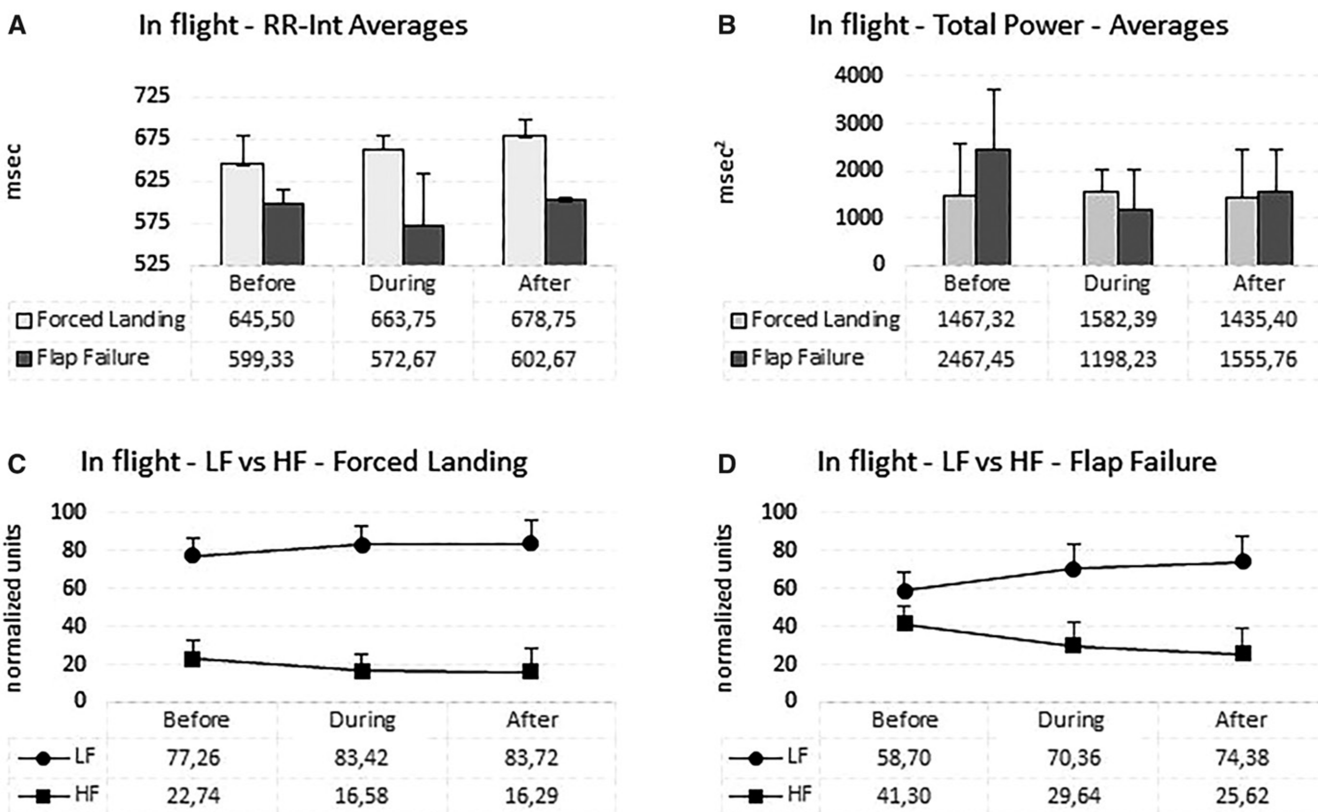

Fig. 2. Comparison of time domain and frequency domain of data related to forced landing and flap failure. A.) In-flight RR-Interval averages. Before forced landing and before flap failure (before); during forced landing and during flap failure (during); after forced landing and after flap failure (after). B.) In-flight Total Power averages. Before forced landing and before flap failure (before); during forced landing and during flap failure (during); after forced landing and after flap failure (after). C.) Low Frequencies (LF) versus High Frequencies (HF), normalized unit averages in forced landing. Before forced landing (before), during forced landing (during), and after forced landing (after). D.) Low Frequencies (LF) versus High Frequencies (HF), normalized unit averages in flap failure. Before flap failure (before), during flap failure (during), and after flap failure (after).

Thus, a decrease in HRV indicates a condition of eustress, while an increase indicates better control of the performance. In afo conditions, HRV parameters tend to be restored, but this is not always the case in the short term. HRV shows the variation of intensity and duration, so that the interaction between the SNS and PNS determines new dynamic balances. Therefore, the information from other organs and systems, connected with the heart by the circulatory stream, is also affected. Reducing RR-Int results in decreased HRV; this places the heart in an unfavorable condition for further performances. Conversely, an increase in RR-Int translates into a return of HRV towards modulability values which make the heart perform again.

For power spectrum analysis, our data show that HRV can exhibit good oscillations if the cardiac machine is near resting condition; otherwise, it will work with reduced power. The comparison of the normalized values of the low frequencies (expression of sympathetic activity) and the high frequencies (expression of parasympathetic activity) are consistent with the concept that an organism (phenotype), in variable states of alert, responds to what is foreseen by its biochemical architecture and physiology (genotype). The autonomic nervous system plays a primary role in this case.

The activity of SNS is prevalent when an organism operates in conditions of intense work, both foreseen and unexpected. HR increases with consequent decrease in HRV. To this must be added the fact that an unexpected task can fit into an already intense functional context. Both parameters described above are very useful for quantifying heart performance.

In conclusion, the amount of HRV constitutes an "energy store" for better cardiac performance in eustress activities. During advanced tasks or emergency situations, the "total power" of the heart decreases because the RR intervals are forced toward low values, where the heart is "less willing" to be modulated by its many controllers. Flight activity involves continuous demanding tasks that can be potentially "read" through analysis of the HRV; a high HRV ensures better management of tasks that require a greater commitment of the cardiovascular function. Furthermore, this experimental protocol can be useful to flight instructors for the training process of student pilots.

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