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Heart rate variability in student pilots during the flight training: a preliminary report[*]

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Summary

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 Autonomous Nervous System (ANS) and other components (body and ambient temperature, respiration, hormones, blood pressure). The flight activity, especially during training, provides for a prolonged state of alert of the student pilot, as well as careful management of the flight and simultaneous planning of the next steps, with attention to the unusual conditions and emergencies that may occur during all various stages. HRV can provide a good reference index for estimating the degree of evolution of the training process of student pilots and a valid tool for some indications of a physiological as well as clinical nature. To investigate this issue, we started a series of experiments, still ongoing, by coupling the flight task times of student pilots with changes in their HRV. Before each experimental session, the participating pilot student was equipped with five electrodes, three-channel Holter (ECG BIOMEDICAL, BI9100). For this purpose, we have defined three-time phases: ground flight operations (bfo), in-flight operations (dfo) and post-flight ground operations (afo). The HRV analysis was carried out using the time domain and frequency domain parameters. As regards the mean of the RR intervals in the dfo, an increase was observed in 29% of the sample, while a decrease was observed in the remaining 71%, compared to that in the bfo. The analysis of the data relating to very low frequencies (VLF), low frequencies (LF) and high frequencies (HF) in the sample highlighted the values indicated below. In dfo, an increase in VLF values in 18% of the sample and a decrease in 82% in the remaining 71% compared to what was observed in bfo. LF values in dfo increased in 29% of the sample and decreased in the remaining 71%, compared to bfo. Finally, the HF, in dfo increased in 29% and decreased in 71% of cases, compared to the values of the bfo. Additional significant differences were found between the cases in which the RR intervals decreased in the dfo compared to the bfo, and those in which the RR intervals increased in the dfo compared to the bfo. In conclusion, the observed data lead to reconsider some physiological correlates of the different components involved in the determinism of HRV of a subject who carries out intense psychophysical activity for a certain period. In fact, it is necessary to evaluate the role of the ANS, in its various divisions (parasympathetic, sympathetic, and enteric), as well as the activity of the baroreceptors, the respiratory cycle (respiratory sinus arrhythmia), the thermoregulatory and hormonal factors within the short and medium tasks term.

Keywords: *Electrocardiogram (ECG), Heart Rate Variability (HRV), Flight, Pilot.*

Riassunto

Variazione della frequenza cardiaca in allievi piloti durante l'addestramento al volo: risultati preliminari

La frequenza cardiaca (HR) indica il numero di battiti al minuto (bpm) del cuore, mentre la variabilità della frequenza cardiaca (HRV) indica la fluttuazione temporale degli intervalli tra battiti adiacenti (NN). L'HRV esprime l'attività neuro-cardiaca ed è generata dalle interazioni cuore-cervello e dalle dinamiche legate alla funzione del Sistema Nervoso Autonomo (SNA) e di altre componenti (temperatura corporea e ambiente, respirazione, ormoni, pressione sanguigna). L'attività di volo, soprattutto durante l'addestramento, prevede un prolungato stato di allerta dell'allievo pilota, nonché un'attenta gestione del volo e contemporanea programmazione dei passi successivi, con attenzione a condizioni inusuali e alle emergenze che possono verificarsi durante tutte le varie fasi. L'HRV può fornire un buon indice di riferimento per stimare il grado di evoluzione del processo formativo degli studenti piloti e un valido strumento per alcune indicazioni di natura fisiologica oltre che clinica. Per investigare su questa tematica, abbiamo avviato una serie di esperimenti, ancora in corso, accoppiando i tempi dei compiti di volo degli studenti piloti con le modifiche della loro HRV. Prima di ogni sessione sperimentale, lo studente pilota partecipante era dotato di cinque elettrodi, Holter a tre canali (ECG BIOMEDICAL, BI9100). Per questo scopo abbiamo definito tre fasi temporali: operazioni di volo a terra (bfo), operazioni durante il volo (dfo) e operazioni a terra dopo il volo (afo). L'analisi della HRV è stata effettuata mediante i parametri relativi al dominio del tempo ed al dominio della frequenza. Per quanto riguarda la media degli intervalli RR nelle dfo, è stato osservato un aumento nel 29% del campione rispetto alle bfo, mentre è stata osservata una diminuzione nel restante 71%, rispetto alle bfo. L'analisi dei dati relativi alle frequenze molto basse (VLF), alle basse frequenze (LF) ed alle alte frequenze (HF) nel campione ha evidenziato i valori di seguito indicati. Nelle dfo, un aumento dei valori di VLF nel 18% del campione ed una diminuzione nel 82% nel restante 71% rispetto a quanto osservato nelle bfo. I valori LF nelle dfo sono aumentati nel 29% del campione e diminuiti nel restante 71%, rispetto alle bfo. Infine, gli HF, nelle dfo sono aumentati nel 29% e diminuiti nel 71% dei casi, rispetto ai valori delle bfo. Ulteriori differenze sono state riscontrate fra i casi in cui gli intervalli RR diminuivano nelle dfo rispetto alle bfo, e quelli in cui gli intervalli RR aumentavano nelle dfo rispetto alle bfo. In conclusione, i dati osservati portano a riconsiderare alcuni correlati fisiologici delle diverse componenti coinvolte nel determinismo dell'HRV di un soggetto che svolge un'intensa attività psicofisica per un certo periodo. Occorre infatti valutare il ruolo del SNA, nelle sue varie divisioni (parasimpatico, simpatico ed enterico), nonché l'attività dei barocettori, il ciclo respiratorio (aritmia sinusale respiratoria), i fattori termoregolatori e ormonali all'interno dei compiti a breve e medio termine.

Parole chiave: *Elettrocardiogramma (ECG), Variabilità della Frequenza Cardiaca (HRV), Aviazione, Pilota.*

1 Introduction

The human heart is an organ consisting of two atria located above and two ventricles located below, weighing between 250 and 350g which, under standard conditions, pulsates at a rate of about 70 beats per minute (bpm). It is responsible for the distribution of blood through the arterial system, and its recovery through the venous system. More specifically, the aorta artery originates from the left ventricle which, through successive vascular branches, both in series and in parallel, supplies the capillary network for the exchange of gases and some solutes with the tissues. The blood flowing from this circulation reaches the right atrium, then the right ventricle and is then sent, via the pulmonary artery, to the alveolar parenchyma for gas exchange. Since this is a closed circulation, the blood flowing from the lungs reaches the left atrium via the pulmonary veins.

Thus, a double vascular network (with variable resistances) is created capable of transferring 5 litres of blood per minute in both the systemic and pulmonary circuits through contractile events of the heart muscle, called systoles and events of stasis or relaxation, called diastoles. Ventricular systoles push the blood with high pressure in the systemic circulation ($\simeq$ 120 mmHg) and low pressure in the pulmonary circulation ($\simeq$ 20 mmHg). Despite the cyclical nature of the contractile activity of the heart, the capillary flow is continuous since the arterial vessels are equipped with elasticity.

The contraction of the heart occurs in an autonomous and rhythmic way since it contains cells, called pacemakers, able to initiate, through a conducting tissue, the depolarization of the atrial and ventricular working cells. These main groups of pacemaker cells are located at the level of the sinoatrial and atrioventricular node (secondary starter) (Shields, 1969). For this reason, it can continue to contract even if deafferented.

The electrical events preceding the mechanical ones can be recorded through a method, the electrocardiogram, in which waves and lengths can be distinguished (Fig. 1).

Therefore, the contractions of the heart calculated per minute determine its frequency (HR), an important parameter for understanding the functionality of this organ, but not exhaustive for the purpose of understanding its physiology and the modulation exerted on it. In this regard, it will be easy to understand how a frequency of 70 bpm expresses a general trend without any indication on the distribution of these beats in the minute considered, that is, without information on the time between one beat and another (RR-Int).

In other words, there may be a variability in the distribution of these beats per minute while remaining seventy. This usually happens within a broadcaster that transmits information, music and more while oscillating on the frequency assigned to it by the competent authority. In the case of the myocardium, we will talk about variability of the heart rate distribution (HRV), that is, a fluctuation in time of adjacent interbeat intervals (McCraty and Shaffer, 2015). This fluctuation, if within certain limits, does not express a malfunction but a physiological behaviour, given the conditions of dynamic equilibrium that distinguish

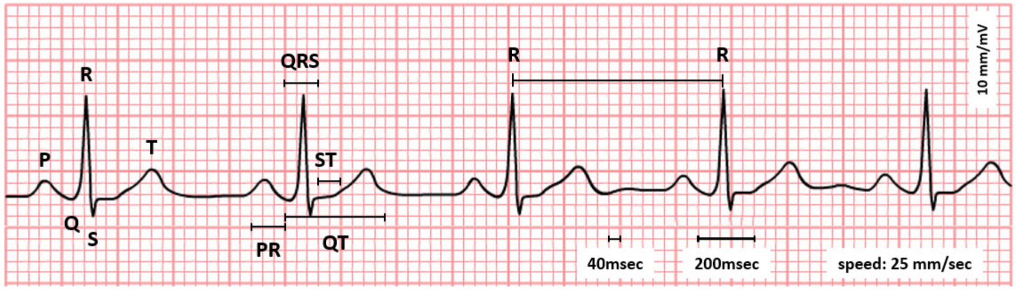

Figure 1: Human electrocardiographic trace. Waves (P, Q, R, S, T), sections (ST) and intervals (PR, QT, RR).

the functioning of biological systems, from simple unicellular to hypercomplex multicellular. Cells, tissues, and organs maintain a stationary state (homeostasis, as understood by Walter Cannon, 1929) which is an expression of a high entropy stability.

Thus, the physiology of living beings is the result of continuous and dynamic interactions of a nervous, hormonal, and mechanical nature. At the cardiac level, it is well known that sinus rhythm is irregular under steady-state conditions rather than monotonously regular, such as a metronome (Shaffer *et al.*, 2014). These fluctuations that are evident between adjacent beats become negligible when one passes to the measurement of average values over time. However, their genesis must be carefully considered, which appears to be linked to complex and non-linear interactions between the different physiological systems involved in the modulation (Reyes del Paso *et al.*, 2013). HRV is, therefore, a property of interdependent regulatory systems that operate on different time scales. It reflects the balanced action between the Sympathetic Nervous System (SNS) and the Parasympathetic Nervous System (PNS), blood pressure (BP), vascular tone, gas exchange, the intestine and possibly also the facial muscles (Gevirtz *et al.*, 2017).

When an organism prepares to leave the state of stillness to face anticipated new things, new but predictable situations or sudden premonitory scenarios of an emergency, a whole series of new operating conditions are established within it. They affect some parameters such as BP, the amplitude and frequency of the respiratory rhythm, the hormonal sphere, and the functionality of the myocardium. In essence, a sort of stress response occurs in which the two components of the Autonomous Nervous System (ANS), Sympathetic (SNS) and Parasympathetic (PNS) play a role of primary importance (Benarroch, 2020; Ulrich-Lai and Herman, 2009; Lamotte *et al.*, 2021).

A recent study conducted at the Department of Cellular and Molecular Medicine, College of Medicine, University of Arizona, Tucson, Arizona, USA, showed that heart rate can be used for assessing the cognitive commitment of students. The results of this survey suggest that the analysis of the heart rate trend is a valid method for quantifying and interpreting a learning process in its various facets (Darnell and Krieg, 2019). Experimental investigations aimed at studying the effects of learning on heart rate were conducted on a bird, the starling, (Sturnus Vulgaris), at the Department of Biology, Tufts University, Medford, MA, USA. For this purpose, European starlings were exposed to a learning task to test whether the behavioural responses to learning were able to activate the sympathetic nervous system, through a quantification of HR variation (Glassman *et al.*, 2019). Flight also involves a series of stressors that affect a pilot's performance during all phases of flight (Cao *et al.*, 2019).

The parameters that affect the performance of the 'heart machine' are many, of different nature, entity, and functional specific weight. A learning process, which occurs in conditions of extreme individual variability, will have a success that will depend on a positive convergence of 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 the flight license for private use (PPL-SP), and in students, already in possession of PPL and theoretical part (ATPL) but who continue the studies for the achievement of the commercial pilot license (CPL-SP).

The purpose of these investigations was to verify whether the HRV could give indications about the evolution of the learning process, framed in a broader autonomic and motivational context.

2 Materials, Methods, and Data Analysis

The experiments were performed on PPL-SP, and CPL during the instrument flight training phase (CPL-IR-SP) which joined, on a voluntary basis, with a guarantee of confidentiality for the purposes of processing personal data.

Before each experimental session, the participating pilot student, immediately after his arrival, was equipped with five non-invasive 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 tracking of the aircraft (time, altitude ground, speed) for the entire duration of the flight allowed to couple the times in which the flight activities scheduled by the instructors according to the training plan took place, with the time Holter for the following data analysis.

To this end, we have defined three-time phases: ground flight operations (bfo), in-flight operations (dfo) and post-flight ground operations (afo). HRV was quantified according to the guidelines of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (Malik *et al.*, 1996).

Within the time domain, we quantified the mean of the RR intervals (RR-Int, msec), of the standard deviation of all the mean normal-to-normal (NN) intervals (SDNN, msec), of the square root of the mean of the sum of squares of the differences between adjacent intervals (RMSSD, msec) and the percentage of adjacent NN intervals that differed from each other by more than 50 msec (pNN50%).

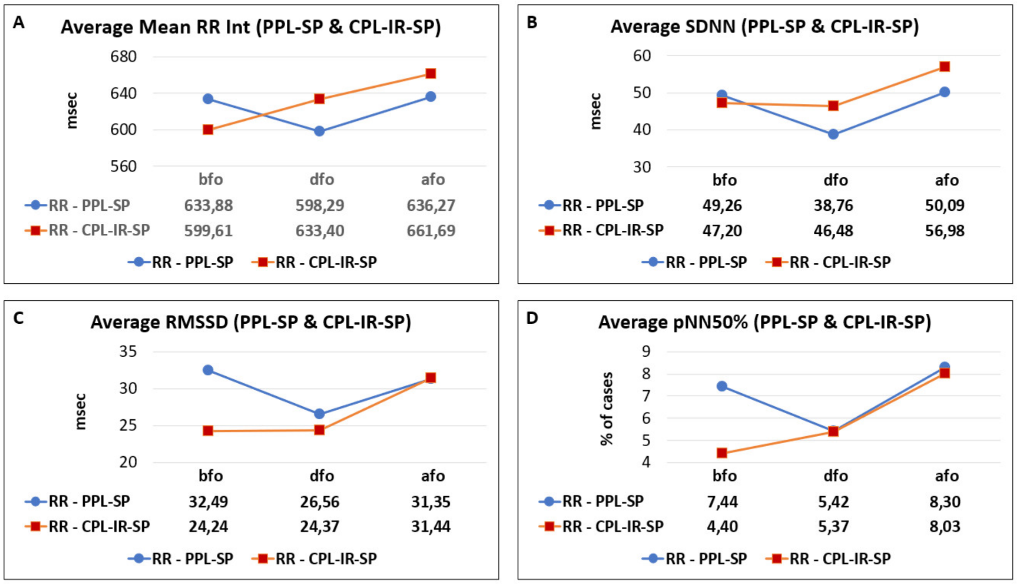

Figure 2: Time domain analysis. Trend and comparison of RR-Int (A), SDNN (B), RMSSD (C) and pNN50% (D) values between PPL-SP and CPL-IR-SP.

Within the frequency domain, we quantified the total power (TP, $msec^2$), the very low frequencies (VLF, $msec^2$, the low frequencies (LF, $msec^2$, the high frequencies (HF, $msec^2$), the LF/HF ratio, the normalized LF [LF (n.u.)] and the normalized HF [HF (n.u.)].

3 Results

The experimental results obtained refer to 17 pilot students of both sexes, aged between 18 and 42 years, of which 12 PPL-SP and 5 CPL-IR-SP. An initial analysis concerned any differences between the two types of pupils. Figure 2 summarizes the trends relating to the time domain analyses.

The mean values of all four parameters decrease in PPL-SP in dfo [RR-Int (from 633.40 to 598.29), SDNN (from 47.20 to 38.76), RMSSD (from 32.49 to 26.56), pNN50% (from 7.44 to 5.42)]. The behaviour in the CPL-IR-SP in the dfo is different, where the values of RR-Int and pNN50% increase in the dfo, while the values of SDNN decrease and those of RMSSD remain unchanged [RR-Int (from 599.61 to 633.40), pNN50% (from 4.40 to 5.37), SDNN (from 47.20 to 46.40), RMSSD (from 24.24 to 24.37)].

We therefore examined the response patterns, distinguishing the students into two categories, namely PPL-SP and CPL-IR-SP whose RR-Int decreased in dfo, compared to bfo and PPL-SP and CPL-IR-SP whose RR-Int increased in dfo, compared to bfo. The values of SDNN, RMSSD and pNN50% decreased in cases where RR-Int decreased in dfo compared to bfo. In cases where RR-Int increased in dfo compared to bfo, the SDNN values remained almost unchanged, while those of RMSSD underwent a slight increase that became more marked in the pNN50% values (Fig. 3).

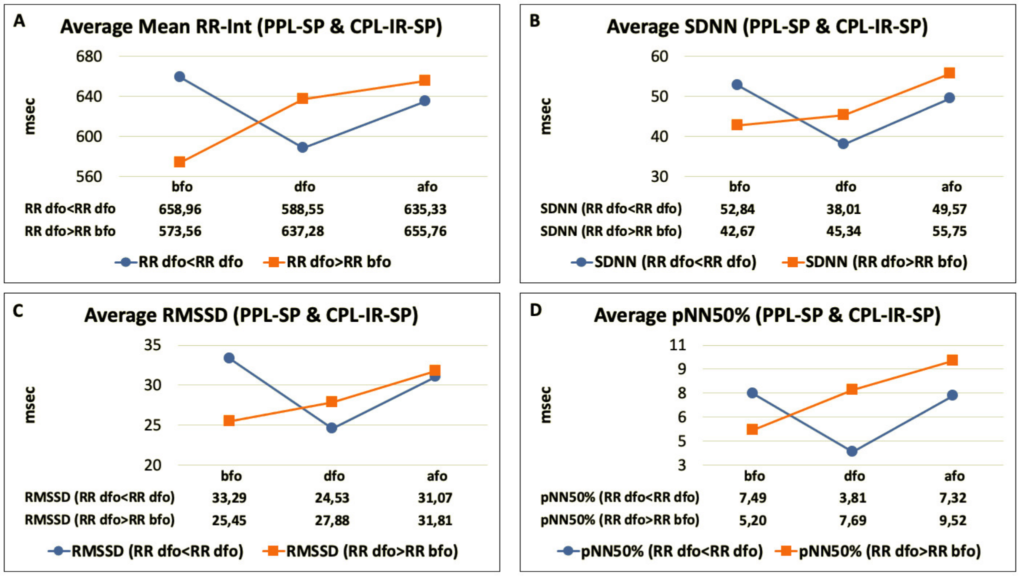

Figure 3: Time domain analysis. Trend and comparison of RR-Int (A), SDNN (B), RMSSD (C) and pNN50% (D) values between PPL-SP and CPL-IR-SP whose RR-Int values decreased in dfo compared to those of bfo and PPL-SP and CPL-IR-SP whose RR-Int values increased in dfo compared to those of bfo.

We also proceeded to study the trend of the duration and intensity of the RR-Int parameter in the two types of SP considered.

Figure 4 depicts the time distribution of the prementioned parameters, bfo, dfo and afo.

Figure 5 summarizes the trends relating to the analysis of the frequency domain of the students as distinguished above.

4 Discussion

Mammalian anatomy describes the heart as an unequal organ innervated by the ANS through its sympathetic and parasympathetic components. In resting conditions, the control of the PNS predominates over that exercised by the SNS. In fact, a human heart beats at a rate of about 70 bpm, but if it is deafferented by parasympathetic control, its rate goes beyond 100 bpm. On the other hand, a moderate parasympathetic stimulation can lead to a short stop (Olshansky *et al.*, 2008); moreover, from a temporal point of view, the parasympathetic effect is more immediate than the sympathetic one with a ratio of about 5: 1. In the event of high levels of stress, nocturnal increases in the activity of the gastrointestinal tract may occur, including asthmatic symptoms (Nada *et al.*, 2001; Ballard, 1999). The relationship between the PNS and SNS branches is complex (both linear and non-linear) and it would be wrong to describe it as an oscillating but 'zero sum' system. It has been observed that an increase in PNS activity may not correspond to a decrease in that SNS or, even, to a non-variation (Billman *et al.*, 2015).

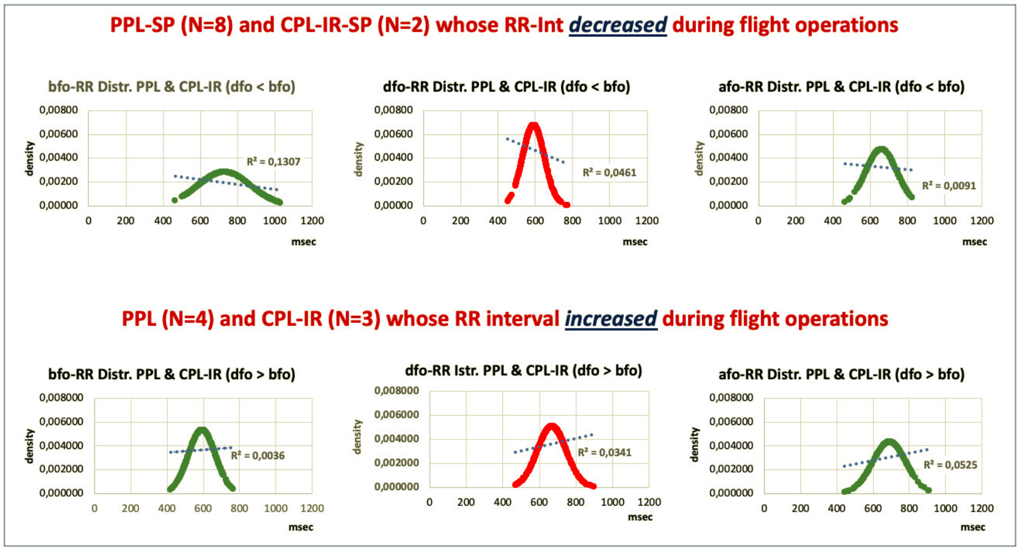

Figure 4: RR-Int distribution in PPL-SP and CPL-IR-SP, bfo, dfo and afo.

The autonomic, cardiovascular, central nervous, endocrine, and respiratory systems, as well as baroreceptors and chemoreceptors, exert effects on HRV, influencing the frequency spectrum (Shaffer *et al.*, 2014). The baroreceptors located in the arch of the aorta and in the carotid sinus, intended for pressure control via reflex, contribute to the short-term regulation of HRV (Eckberg and Sleight, 1992). For example, during inspiration the HR increases, and the BP increases after 4-5 sec later, but the baroreceptors detect this increase and discharge more rapidly. During exhalation the HR decreases and the BP falls. This baroceptive activity affects HRV, giving rise to respiratory sinus arrhythmia (RSA) (Karemaker, 2009). In our analysis of the time domain and the frequency domain, we used some parameters to understand the effects exerted by the various cardiac inputs in the short and medium term, of whatever nature they were.

Within the time domain, the SDNN parameter is influenced by both the PNS and the SNS and is highly correlated with the VLF, LF and TP (Umetani *et al.*, 1998). Although this parameter assumes a considerable weight in long-term recordings, we have observed significant variations in dfo compared to bfo, imagining that it may also be influenced by LF. The RMSSD parameter reflects the interbeat variance in HR and is used to estimate the changes induced by vagal activity (Shaffer *et al.*, 2014). Finally, the pNN50% parameter is closely correlated with the PNS activity (Umetani *et al.*, 1998).

Within the frequency domain, the VLF band is indicated as the contribution by the intracardiac nervous circuit and the SNS (Shaffer *et al.*, 2014). It is described as an expression of physical activity, thermoregulatory, of the renin-angiotensin system and of endothelial influences on the heart (Akselrod *et al.*, 1981; Claydon and Krassioukov, 2008). It has been observed that the PNS can contribute to the value of VLF, as its block clears the value (Taylor *et al.*, 1998). On the other hand, blocking the SNS does not affect its intensity. The LF band mainly reflects the baroceptive activity; its intensity may depend on both sym-

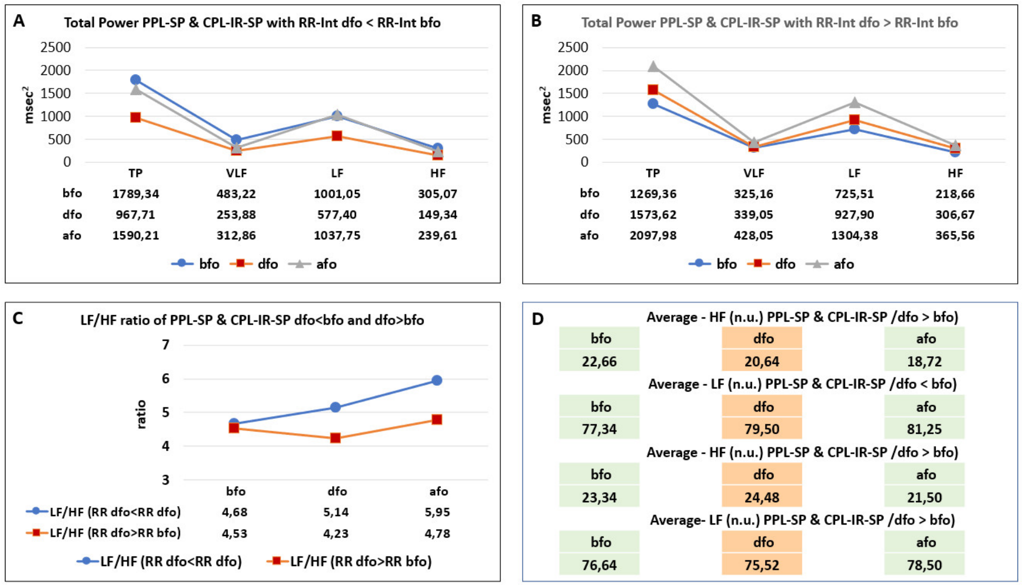

Figure 5: Frequency domain analysis. Trend and comparison of Total Power (TP), VLF, LF and HF values in the two groups of student pilots considered.

pathetic and parasympathetic activity (Berntson *et al.*, 2007; Lehrer, 2007) but primarily on the baroceptive one (Goldstein *et al.*, 2011). The HF band is usually called the respiratory band; it reflects parasympathetic activity and is linked to the breath, because it corresponds to the concomitant frequency variations with the respiratory cycle (Grossman and Taylor, 2007). There is a strong correlation between HF and RMSSD and pNN50 (Kleiger *et al.*, 2005).

The analysis of the LF/HF ratio is relevant for 'weighing' the contribution of the two divisions of the SNA, as a low ratio reflects the dominance of the PNS, while a high one that of the SNS. However, this is a not entirely tenable conclusion (Billman *et al.*, 2015), since the contribution of SNS and PNS may be different since these interactions are complex, non-linear, and frequently non-reciprocal (Shaffer and Ginsberg, 2017).

Finally, the values of LF (n.u.) and HF (n.u.) are used to emphasize sympathetic and parasympathetic regulation respectively (Medi-Core).

Flight and everything connected with it presupposes human performance that is the result of a continuous alerting of organs and systems, starting from all divisions of the nervous system up to the involvement of central and peripheral mechanoreceptors and chemoreceptors. The data obtained from our experiments lead us to two types of considerations, one concerning the training of student pilots, the other concerning the performance of heart functioning.

The continuous and non-linear interaction between organs and systems affects the intensity and duration of the parameters discussed above (see Fig. 2).

The decrease in RR-Int in PPL-SP in dfo compared to bfo derives from the fact that, during this phase, they are trained on new topics or review what was previously learned but not yet acquired permanently. In afo, they resume the HRV conditions of the bfo, the mean values of SDNN and pNN50% undergo a rebound, while those of RMSSD a slight decrease compared to what was found in bfo. On the other hand, the CPL-IR-SP have reduced RR-Int already in the BFOs (see Fig. 3). This could be explained taking into account the fact that the briefing with the flight instructor is, in itself, already complex. It also provides for a preliminary study of all information regarding the instrument flight mission, where spatial disorientation, together with inputs from peripheral sensors (vestibular, visual, and skin), can constitute a primary factor of interference, during first training missions.

Time analysis - HRV undergoes a variation in intensity and duration, when the interaction between SNS and PSN determines new dynamic balances on which information from other organs and systems connected with the heart through the circulatory stream are also affected. A reduction in the RR-Int means a decrease in HRV, almost as if to mean that the cardiac machine is already working at a condition that makes it little available towards further modulations in input. Conversely, an increase in the RR-Int expresses a return of the HRV towards the availability for a modulation (see Fig. 4).

Power Spectrum Analysis - Our data show that HRV is maximal if the cardiac machine is in steady-state conditions (see Fig. 5A); otherwise, it will work with a reduced power, if a new task is inserted on a previous one still in progress (see Fig. 5B). The LF/HF ratio undergoes an increase in a heart that starts towards a new or not yet consolidated task or towards a control task on what has already been learned (see a flight of proficiency check (see Fig. 5C). The normalized values of LF and HF are consistent with the concept that an alert organism (phenotype) responds to what is predicted by its biochemical and physiological architecture (genotype) (see Fig. 5D).

The amount of heart rate variability 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 towards low values, where the heart is 'less willing' to be modulated by its many controllers. The flight activity involves continuous demanding tasks that can be 'read' through the analysis of heart rate variability.

In conclusion, flying on an aircraft is very different from flying an aircraft, even if the verb is the same, and the HRV testifies to this. The training of a pilot student can be useful for the study of the HRV.

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References

Akselrod, S., Gordon, D., Ubel, F. A., Shannon, D. C., Berger, A. C., and Cohen, R. J. (1981). *Power spectrum analysis of heart rate fluctuation: a quantitative probe of beat-to-beat cardiovascular control*. Science **213**(4504), 220. doi:10.1126/science.6166045.

Ballard, R. D. (1999). *Sleep, respiratory physiology, and nocturnal asthma*. Chronobiol. Int. **16**(5), 565. doi:10.3109/07420529908998729.

Benarroch, E. E. (2020). *Physiology and pathophysiology of the autonomic nervous system*. Continuum (Minneap. Minn.) **26**(1), 12. doi:10.1212/CON.0000000000000817.

Berntson, G. G., Cacioppo, J. T., and Grossman, P. (2007). *Whither vagal tone*. Biol. Psychol. **74**(2), 295. doi:10.1016/j.biopsycho.2006.08.006.

Billman, G. E., Huikuri, H. V., Sacha, J., and Trimmel, K. (2015). *An introduction to heart rate variability: methodological considerations and clinical applications*. Front. Physiol. **6**, 55. doi:10.3389/fphys.2015.00055.

Cao, X., MacNaughton, P., Cadet, L. R., Cedeno-Laurent, J. G., Flanigan, S., Vallarino, J., Donnelly-McLay, D., Christiani, D. C., Spengler, J. D., and Allen, J. G. (2019). *Heart rate variability and performance of commercial airline pilots during flight simulations*. Int. J. Environ. Res. Public Health **16**(2). doi:10.3390/ijerph16020237.

Claydon, V. E. and Krassioukov, A. V. (2008). *Clinical correlates of frequency analyses of cardiovascular control after spinal cord injury*. Am. J. Physiol. Heart Circ. Physiol. **294**(2), H668. doi:10.1152/ajpheart.00869.2007.

Darnell, D. K. and Krieg, P. A. (2019). *Student engagement, assessed using heart rate, shows no reset following active learning sessions in lectures*. PLoS One **14**(12), e0225709. doi:10.1371/journal.pone.0225709.

Eckberg, D. L. and Sleight, P. (1992). *Human Baroreflexes in Health and Disease* (Clarendon Press, Oxford).

Gevirtz, R. N., Lehrer, P. M., and Schwartz, M. S. (2017). *Cardiorespiratory Biofeedback*. In Schwartz, M. S. and Andrasik, F., editors, *Biofeedback: A Practitioner's Guide*, pages 196–213 (The Guildford Press, New York), 4 edition.

Glassman, L. W., Hagmann, C. E., Qadri, M. A., Cook, R. G., and Romero, L. M. (2019). *The effect of learning on heart rate and behavior of European starlings (Sturnus vulgaris)*. J. Exp. Zool. A Ecol. Integr. Physiol. **331**(9), 506. doi:10.1002/jez.2319.

Goldstein, D. S., Bentho, O., Park, M.-Y., and Sharabi, Y. (2011). *Low-frequency power of heart rate variability is not a measure of cardiac sympathetic tone but may be a measure of modulation of cardiac autonomic outflows by baroreflexes*. Exp. Physiol. **96**(12), 1255. doi:10.1113/expphysiol.2010.056259.

Grossman, P. and Taylor, E. W. (2007). *Toward understanding respiratory sinus arrhythmia: relations to cardiac vagal tone, evolution and biobehavioral functions*. Biol. Psychol. **74**(2), 263. doi:10.1016/j.biopsycho.2005.11.014.

Karemaker, J. M. (2009). *Counterpoint: respiratory sinus arrhythmia is due to the baroreflex mechanism*. J. Appl. Physiol. **106**(5), 1742. doi:10.1152/japplphysiol.91107.2008a.

Kleiger, R. E., Stein, P. K., and Bigger, J. T., Jr (2005). *Heart rate variability: measurement and clinical utility*. Ann. Noninvasive Electrocardiol. **10**(1), 88. doi:10.1111/j.1542-474X.2005.10101.x.

Lamotte, G., Shouman, K., and Benarroch, E. E. (2021). *Stress and central autonomic network*. Auton. Neurosci. **235**(102870), 102870. doi:10.1016/j.autneu.2021.102870.

Lehrer, P. M. (2007). *Biofeedback training to increase heart rate variability*. In Lehrer, P. M., Woolfolk, R. L., and Sime, W. E., editors, *Principles and Practice of Stress Management*, pages 227–248 (The Guilford Press, New York).

Malik, M., Bigger, J. Th., Camm, A. J., Kleiger, R. E., Malliani, A., Moss, A. J., and Schwartz, P. J. (1996). *Heart rate variability: Standards of measurement, physiological interpretation, and clinical use*. Eur. Heart J. **17**(3), 354. doi:10.1093/oxfordjournals.eurheartj.a014868.

McCraty, R. and Shaffer, F. (2015). *Heart rate variability: New perspectives on physiological mechanisms, assessment of self-regulatory capacity, and health risk*. Glob. Adv. Health Med. **4**(1), 46. doi:10.7453/gahmj.2014.073.

Medi-Core, *Heart Rate Variability Analysis System*. Ver. 3.0, http://medi-core.com/.

Nada, T., Nomura, M., Iga, A., Kawaguchi, R., Ochi, Y., Saito, K., Nakaya, Y., and Ito, S. (2001). *Autonomic nervous function in patients with peptic ulcer studied by spectral analysis of heart rate variability*. J. Med. **32**(5-6), 333—347. PMID: 11958279.

Olshansky, B., Sabbah, H. N., Hauptman, P. J., and Colucci, W. S. (2008). *Parasympathetic nervous system and heart failure: pathophysiology and potential implications for therapy*. Circulation **118**(8), 863. doi:10.1161/circulationAHA.107.760405.

Reyes del Paso, G. A., Langewitz, W., Mulder, L. J. M., van Roon, A., and Duschek, S. (2013). *The utility of low frequency heart rate variability as an index of sympathetic cardiac tone: a review with emphasis on a reanalysis of previous studies*. Psychophysiology **50**(5), 477. doi:10.1111/psyp.12027.

Shaffer, F. and Ginsberg, J. P. (2017). *An overview of heart rate variability metrics and norms*. Front. Public Health **5**. doi:10.3389/fpubh.2017.00258.

Shaffer, F., McCraty, R., and Zerr, C. L. (2014). *A healthy heart is not a metronome: an integrative review of the heart's anatomy and heart rate variability*. Front. Psychol. **5**, 1040. doi:10.3389/fpsyg.2014.01040.

Shields, H. E. (1969). *Cardiac anatomy and physiology*. Nurs. Clin. North Am. **4**(4), 563. doi:10.1016/S0029-6465(22)00627-2.

Taylor, J. A., Carr, D. L., Myers, C. W., and Eckberg, D. L. (1998). *Mechanisms underlying very-low-frequency RR-interval oscillations in humans*. Circulation **98**(6), 547. doi:10.1161/01.cir.98.6.547.

Ulrich-Lai, Y. M. and Herman, J. P. (2009). *Neural regulation of endocrine and autonomic stress responses*. Nat. Rev. Neurosci. **10**(6), 397. doi:10.1038/nrn2647.

Umetani, K., Singer, D. H., McCraty, R., and Atkinson, M. (1998). *Twenty-four hour time domain heart rate variability and heart rate: relations to age and gender over nine decades*. J. Am. Coll. Cardiol. **31**(3), 593. doi:10.1016/s0735-1097(97)00554-8.