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Evaluation of Workload in High Complexity Work Place: an Experiment During a Real Situation

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Some workplace have been widely changed with regard to their automation process, which has promoted a more complex environment concerning the task performance, demanding to the operator the introducing of new abilities. In the aeronautic activity the workload also has been diversified, as the mental demand has been enhanced. The needs of determining the impact of the workload on the operator due to such work place, evidencing a more complex nature, shows to be more important, mainly when looking at the certification requirements for new aircraft development. Such certification process is responsible for determining the minimum aircrew necessary, based on the distribution of the cabin workload, as well as keeping the situation awareness during the different phases of the flight. This study uses psychological and physiological methods of measurements to evaluate the workload in real situation during the end of the certification process of an aircraft, aiming at to identify potential methods to be implemented during the whole certification process. A protocol of workload evaluation was implemented based on the use of interview, NASA-TLX scale, heart rate (HR) and heart rate variability (HRV). Two pilots participated in the study. The measurements and interviews were conducted during flights performed in the final certification process of an aircraft produced in Brazil. A total of six take-off and six landings performed during three consecutive days were evaluated. Each route was previously determined, which involved some abnormal situations according to an established program for the evaluation of the aircraft in terms of human factor requirements. The data analysis was performed in a descriptive and qualitative basis due to the peculiarity of each task. Preliminary results indicate the landing to be more stressful than take-off, and for such situations, the pilot flying (PF) had the more workload during the tasks than the pilot monitoring (PM). When comparing all flights and their tasks, no important difference between the HR and HRV was observed, but, again, the landing showed a little higher stressful than take-off for the PF, as evidenced by the HR. However, the general results, including those from NASA-TLX, suggested a low workload for all tasks. With regards to the interviews, the more pronounced mental demands reported by the pilots in managing any fault of the aircraft were in those tasks that required anticipation, attention and monitoring procedures. Future studies should be conducted with the whole certification process and other scenarios in order to test the applicability of the methodology employed in the present study.

Introduction

Automation in aviation has promoted an increase in the complexity of the task performance of pilots due to the technological development. This automation has been introduced to increase the aircrew wellness, and, mainly, to minimize accidents, given that it has reduced the human error responsible for about 70% of accidents and incidents in aviation (BILLINGS, 1997). It is remarkable that the pilot's cockpit has had one of the most significant improvements aiming at the workload reduction, due to the automated devices, mainly in terms of releasing the physical workload of aircrew. However, the modifications performed so far have changed the workload of the aircraft operator, and its mental component has been enhanced while the physical has decreased.

The certification of new aircraft in term of human factor aspects has been applied, aiming at determining the workload of such aircraft, and minimum aircrew. The requirement of the establishment of minimum aircrew looks at a better distribution of workload during the different phases of flight (WISE & WISE, 2000; TATTERSALL, 2000). It is necessary to maintain a balance between demand of tasks and the capacity of the operator with different objectives, including those required to evaluate items related to certification of new aircraft for human factors. The literature shows a consistent search for assessment of mental workload by the use of subjective and physiological methods (BACKS, 1995). The main problem arises when one intends to measure the workload of pilots in cockpits, and to establish its minimum and/or maximum level permitted.

Objecting the further use in aircraft certification, RIBEIRO & de OLIVEIRA (2003) proposed a method for evaluation overall workload in pilots, which was firstly experimented in simulated flights and showed to be useful.

The present study evaluates the workload during real flights conducted during the last phase of the certification process of an aircraft aiming at identify potential methods of evaluation workload in such process.

Methods

The study was conducted during the certification process of an aircraft made in Brazil. Due to the complexity of the experimental protocol and availability of flights, only two high experienced pilots were monitored. They alternated the position of pilot flying (PF) and pilot monitoring (PM), but not in the same flight. Six flights were monitored during three consecutive days. Two phases were evaluated, take-off (began when the engine one was switched on and finished when the aircraft reached 15,000 ft), and landing (began at 10,000 ft and ended when all engines were off). The team formed by the certification authority, and the manufacturer technical staff determined each route and abnormal situations that occurred during the flight, considering the aircraft evaluation in terms of human factors. The research group did not take part in this process. The abnormal situations included the absence of electric, hydraulic and other automated systems during the flight.

Instruments of Evaluation

When compared to physical, the mental or cognitive workload is considered a little more difficult to be assessed (KANTOWITZ & CASPER, 1988). Combining the use of physiological and subjective techniques is more recommended, and has been considered as a better prediction of the workload in tasks of systems in development or implementation, with less interference in the task (WIERWILLE & EGGEMEIER, 1993). Thus, physiological and subjective techniques were employed in this study.

Physiologic evaluation: Heart Rate (HR) has been applied as a measurement of workload. Additionally, power spectral analysis of Heart Rate Variability (HRV) is a sensitive index of autonomic activities. Within the HRV, two main components have been identified, the Low Frequency (LF) at 0.03-0.15 Hz, reflecting both sympathetic and parasympathetic activity, and High Frequency (HF) at 0.15-0.4 Hz, which reflect the parasympathetic tone of the sinusoidal respiratory arrhythmia. LF/HF ratio has been proposed as an index that reflects the balance of the autonomic nervous activity (TASK FORCE of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). Moreover, previous studies have revealed a relationship between sympathetic activity and mental effort (SATO et al., 1998; KAMADA et al. 1992). Thus, in the present research the physiological evaluation was performed through the measurement of the HR and the analysis of the HRV.

The electrocardiogram (ECG) signal was captured and simultaneously digitally recorded in a ME3000P8 (Mega Electronics), after sampled at 1000 Hz. A specific program to detect the R-waves of the ECG signal and construct the RR intervals was developed in Matlab 5.02c (Mathworks). The time series formed by the RR intervals were thus interpolated so as the sample rate of the respective HRV signal was 2 Hz. The Heart Rate (HR) was calculated as the inverse of the mean of HRV. The power spectral was estimated through Auto Regressive model with an order of 12. From the HRV signal, the power of the LF band (between 0.03 and 0.15 Hz), the power of the HF band (between 0.15 and 0.4 Hz) was determined, and LF/HF computed. Prior to each flight the ECG of the pilots were registered during a rest period of 4 minutes. HR and LF/HF, determined in each phase of the flights, were further normalized with respect to those respective variables computed during the rest test.

Subjective evaluation: To evaluate mental workload the subjective techniques are more often applied. In such case, the perception of the worker to his performance in a specific task is used. This can be considered as indices of global sensitivity to the workload (WIERWILLE & EGGEMEIER, 1993). The subjective technique performed in this study is the Task Load Index Scale - NASA – TLX (HART & STAVELAND, 1988), considering their sensitivity which has showed to be consistent in many studies with different levels of demand (HARRIS *et al*., 1995; HANCOCK *et al*., 1995). The TLX has six components to measure workload: mental demand, physical demand, temporal demand, performance, effort and frustration level. The test was applied after the end of each phase of the flight. It was also included a sheet with the registers of activity/time during flights and interviews. After each flight a general interview was conducted with each pilot regarding workload, automation and performance.

Results

With regards to the NASA-TLX, only the results of physical demand (PD) and mental demand (MD) components of workload will be presented. Flights are numbered from 1 to 6, and some data from the flight number 6 were missed. When a pilot was in the PF position in the forward direction (A) of the route, during take-off (T) and landing (L), the other one was PF in the backward direction (B) of the same route.

When in the PF position, P1 presented higher PD and MD during most landing than take-off (Figure 1), but when assuming the PM position, the MD and PD did not show this behavior, alternating in intensity during T and L, independently of type of flight (Figure 2).

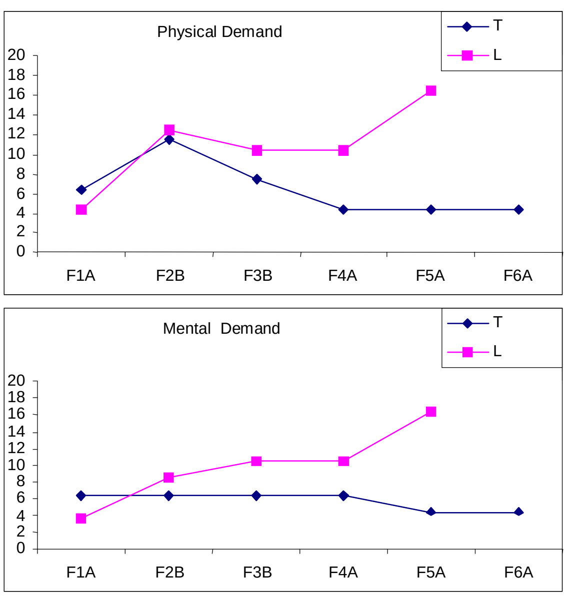

Figure 1. *Results of NASA-TLX of P1 as PF.*

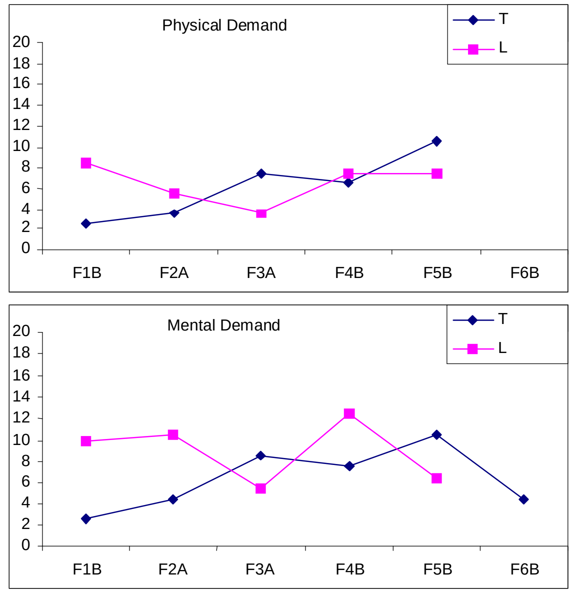

Figure 2. *Results of NASA-TLX of P1 as PM.*

The pilot P2 did not follow the same behavior. In the PF position, P2 showed PD to have almost the same value during take-off and landing (Figure 3). This was also true for this pilot while in the PM position (Figure 4). These results indicate that independently of the flight, which was related to different abnormal situation, no difference in the workload was perceived by this pilot among all performed tasks.

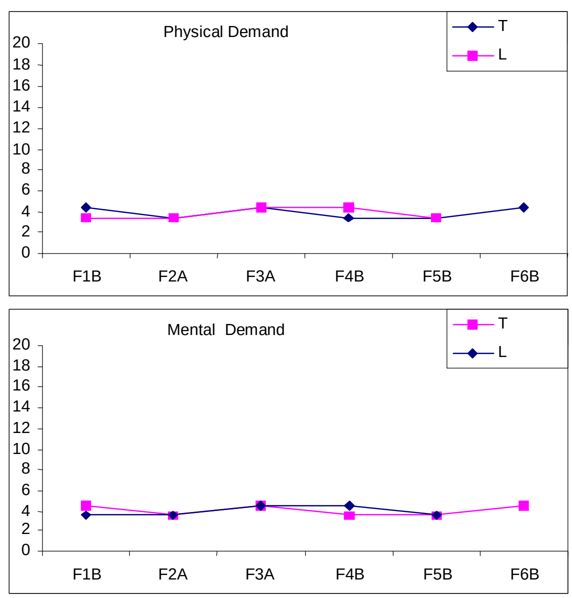

Figure 3. *Results of NASA-TLX of P2 as PF.*

The physiological measurements corroborated the results of many findings of the NASA-TLX in some aspects. The HR is expressed as percentage above that found during the rest test, and the HRV as the ratio between the values of the flight and the rest.

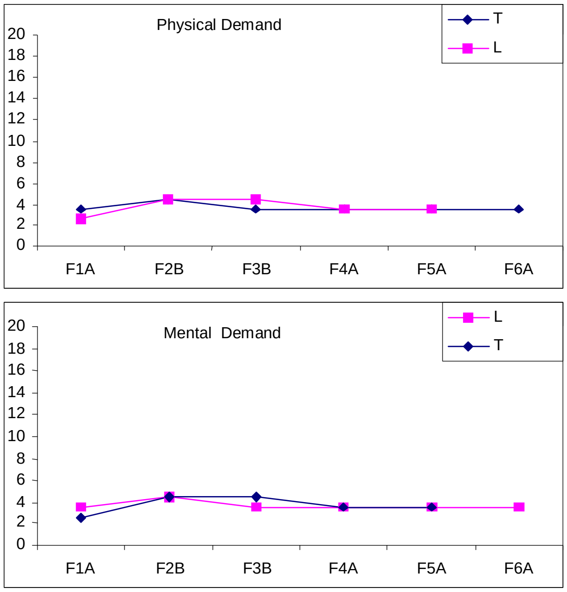

Figure 4. *Results of NASA-TLX of P2 as PM.*

The HR of pilot P1 as in the PF position was higher during landing than during take-off in all flights (Figure 5). The result of HRV also showed the LF/HF higher during landing than take-off (Figure 5), suggesting higher mental workload during landing. On the other hand, as PM, no clear pattern was observed for HR or HRV in this pilot (Figure 6).

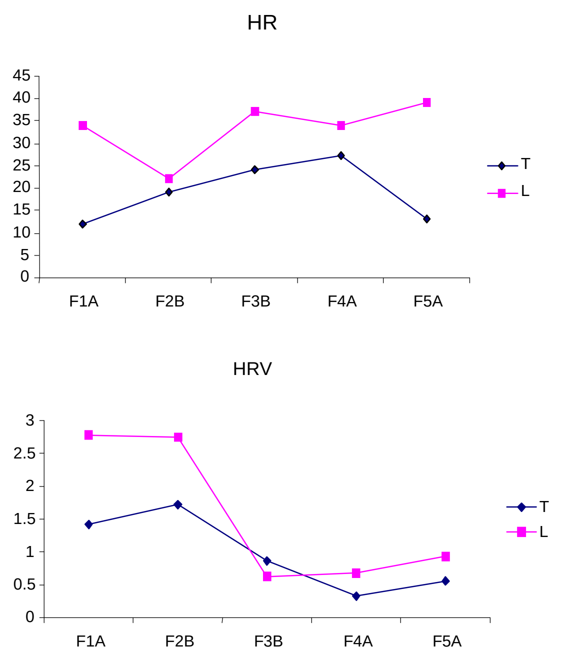

Figure 5. *Results of HR and HRV of P1 as PF.*

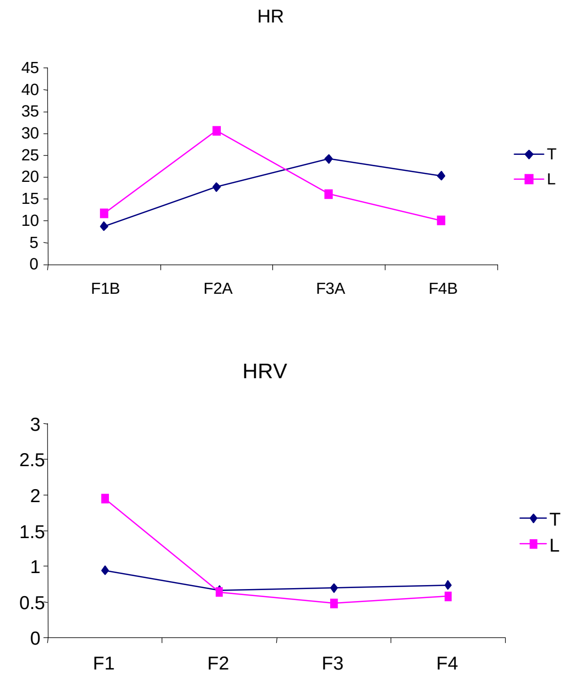

Figure 6. *Results of HR and HRV of P1 as PM.*

With regards to pilot P2 in the PF position, HR was higher during landing than take-off in all flights and little difference was observed in the HRV when comparing the phases of flight (Figure 7). When in the PM position, again no pattern was observed for HR and HRV, and in one flight the HR was lower than that presented during the rest test (Figure 8).

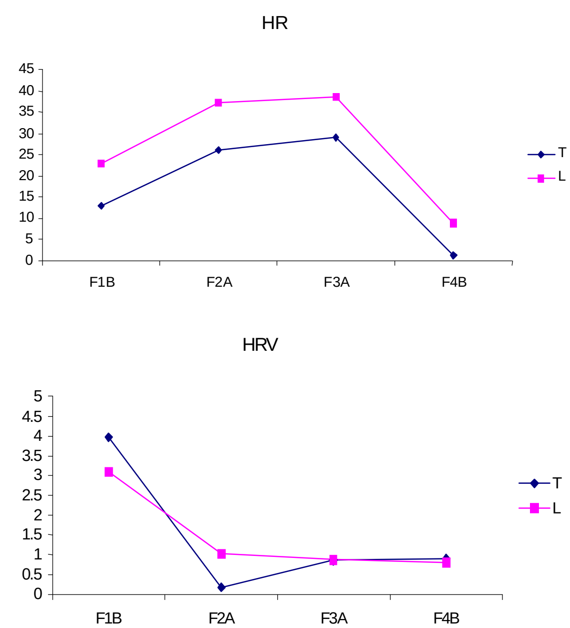

Figure 7. *Results of HR and HRV of P2 as PF.*

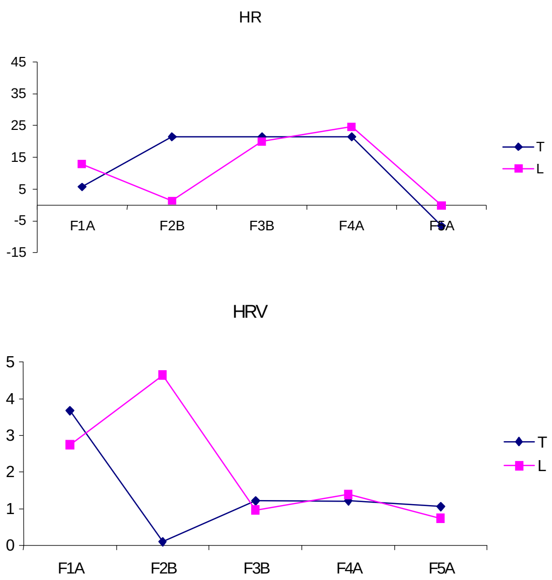

Figure 8. *Results of HR and HRV of P2 as PM.*

Concerning the interviews, during the most time evaluated the pilots did not report important physical demands due to the abnormal situations in the flight. The most relevant report that should be pointed out is the mental demand due to the anticipation. This was attributed to the intrinsic characteristic of the situation caused by the necessity of pilot's anticipation.

Discussion

The international institutions of regulation in aviation have proposed the certification process of aircraft for human factors. Thus, specific methods of measurements of workload have to be developed. This work investigated the use of some methods in the evaluation of pilot's workload only during a short window of the last part of the certification process of a new aircraft.

Although the study evaluated only two pilots, when comparing the workload of PF and PM, there is no clear suggestion that the first has higher demand than the second, either physical or mental. This is not in agreement with the study of RIBEIRO & de OLIVEIRA (2003), who suggested higher mental demand for PM than PF and the contrary for physical demand. The difference between the aircraft used in the present work and the simulator used by RIBEIRO & de OLIVEIRA (2003) in them study might explain these controversy results. Despite the presence of abnormal condition in the flights of this investigation, the aircraft is thoroughly atomized and, thus, even during abnormal condition, could not have highly introduced extra mental or physical workload. Another reason is the high experience of the pilots with the aircraft, which was obtained during all the process of its certification.

HR showed to be potentially able to identify differences between positions and between tasks. The higher value of HR found in PF than PM is not surprising because the literature has previously reported this difference. According to BACKS (1995) HR is higher in the pilot who is in control, than in other aircrew and decreases when the pilot leaves the control and increases in the pilot taking over the control. Furthermore, it should be taken into consideration that these results are related to take-off and landing while during cruise HR might be expected do decrease.

The most interesting discussion arises when interpreting the results of HRV. VELTMAN & GAILLARD (1998) show that mental effort suppresses the activity of the cardiovascular control system, suggesting that there is more respiratory activity during rest than during a task in the LF band (<0.15 Hz) in mental tasks, which thus make difficult to interpret the effect of mental workload in HRV. In the present study the HRV was evaluated by means of LF/HF ratio since studies have proposed that during mental effort this ratio tend to increase when compared to the rest (SATO et al., 1998; KAMADA et al. 1992). As presented in the results of NASA-TLX, the HRV suggested more mental workload during landing than take-off and no clear difference could be observed concerning the different position assumed by the pilots.

It has been hypothesized that autonomic responses such as of HR are multidimensional determined and not just reciprocally coupled, meaning that there might be an activation of one branch with the inhibition of the other or even the co-activation and co-inhibition. Thus, although the HRV has been showed as a potential tool to evaluate autonomic response, even in the present study, their results should be interpreted carefully.

An important finding concerning the physiological measurements is the consistency of the data when focusing a pilot in particular. The values found are within a short range, and short range was also observed in the results of NASA-TLX. In general, the workload appeared to be low and little difference were observed when comparing the different flights. One question that still remains is how to quantify the workload in an objective criterion.

With regards to the item stressed by the pilots during the interview - the anticipation -, this is expected to be present when the pilots have to analyze the possible consequences of any atypical situation that the aircraft has to be submitted to. They have to do this anticipation in order to be prepared for other unexpected abnormal occurrence, as bad meteorological and/or visibility condition. During landing, some of the abnormal conditions involving the suppressing of automation devices, as the electric fail in the flight F5A, were described as demanding from the PF abilities required in traditional flights, since the automation was not available.

Conclusion

As a conclusion, the methods employed appear to constitute in a good tool in the evaluation of workload during the certification process of aircraft for human factors. The main problem that still remains is to establish the minimum and maximum values for the variables measured in order to define what is the desired or undesired workload when certifying a new aircraft. It should be also taken into consideration that this study investigated the use of some methods in the evaluation of pilot's workload during the last part of the certification process of a new aircraft. In fact, the study should be extended to the whole process and should have the participation of more pilots.

Acknowledgments

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