FLIGHT SIMULATOR TRAINING: PSYCHOPHYSIOLOGICAL RESPONSE

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Abstract: *Flight simulators have become indispensable in the aviation industry, providing accurate and detailed simulations of cockpit and environmental conditions. They serve a variety of purposes, including pilot training, aircraft design, and accident investigation. While simulators are able to replicate many aspects of real-world flying, there are still differences in stress levels and response intensities. As such, a comprehensive training program that includes both simulated and real-world experiences is necessary to ensure pilots are well-prepared for handling the diverse challenges of aviation operations.*

Keywords: *training programs, simulator, military aviation, mental workload*

1. INTRODUCTION

Flight simulators are essential in various aspects of aviation, including pilot training and maintaining pilot proficiency. Their importance extends beyond these areas including roles in air accident investigations, aircraft design studies, and simulations of air traffic. The increasing complexity of modern aircraft systems drives the integration of simulators into the aviation industry. As aircraft become further developed, simulators have become fundamental for training pilots and developing their skills in a controlled and safe environment. [3,20]

Simulators are of immense value in researching how aircraft could be designed to align better with human capabilities and limitations. This is particularly pertinent in endeavors to enhance safety and efficiency in aviation. The high fidelity with which simulators replicate the pilot's natural working environment makes them indispensable tools not just for training but also for comprehending the dynamics of aircraft and pilot interactions during flights and in critical situations. [3,8]

Using simulators helps bridge the gap between theoretical knowledge and real-world application, providing pilots with experiential learning and decision-making practice without the risks associated with actual flying. Additionally, the ability of simulators to recreate specific flight conditions and emergencies makes them critical for preparing pilots for various scenarios, thereby improving overall aviation safety. [1,19]

2. GENERAL CHARACTARESTIC

The evolution of flight simulators from their inception to modern equivalents represents a transformative journey in aviation training technology. Initially, flight simulators like the "Aeronautical Link Trainer" offered a rudimentary platform with limited cockpit instruments and no external environmental simulation.

However, today's simulators have revolutionized pilot training, providing high-fidelity recreations of both internal and external aspects of flight missions, complete with advanced motion simulation platforms. These modern simulators are not just tools, but the backbone of pilot training and professional development, their role being significantly influenced by factors such as safety, cost-efficiency, technical attributes, and training methodologies. [4,14,15]

Modern flight simulators serve as more than just educational tools. They are practical aids, demonstrating specific procedures and the use of aircraft systems, which effectively reduce the discrepancy between theoretical knowledge and practical application. They also cultivate practical skills and desirable personality traits in pilots, preparing them for high-pressure situations and unfamiliar challenges. Moreover, simulators play a central role in assessing pilot behavior, validating theoretical concepts, selecting suitable candidates, and conducting exams for aviation certifications. These functionalities underscore the simulators' versatility and necessity in pilot training programs, providing a reassuring sense of preparedness for real-world scenarios. [14,15]

Furthermore, the design of flight simulators is a complex process that integrates cutting-edge technology and a deep understanding of human factors, such as cognitive capabilities and information processing. This process is crucial in developing a pilot's ability to automate routine cockpit actions, which enhances focus on critical scenarios requiring quick decision-making. The realism of simulators, especially in replicating the aircraft's controls and the mission environment, is vital for practical training. Therefore, the need for pilots to exhibit initiative and perform specific actions automatically becomes even more critical. [14,15,18]

The historical context reveals that until the mid-1970s, flight simulators were often seen more as novelties than essential training tools within civil aviation. However, perceptions changed as the benefits of simulator training became evident, particularly during the oil crisis of the 1970s when simulators emerged as a cost-effective training alternative. Today, they are an integral part of aviation training, essential for advanced training and the basic training of new pilots, reflecting their enduring importance in the ongoing development of the aviation industry. [11,17]

3. MENTAL WORKLOAD

Mental workload is the amount of capacity required to perform a task. It is essential in evaluating system design, mission, and training in aviation. Mental workload is a precursor to performance and is influenced by uncontrollable circumstances, leading to variations. The interplay between mental workload, situation awareness, and performance has been studied in various settings, and it is clear that an increase in mental workload leads to a decrease in situation awareness and performance. [16]

A research project was conducted at the F17 Air Force Wing in Kallinge, Sweden, to examine five male fighter pilots' psychophysiological responses and evaluations during simulated and actual flights. Each pilot completed the same air-to-ground mission in a simulator and three times in a real aircraft. The mission was divided into four stages: flying to the target area, a high-speed, low-altitude pre-attack phase, an attack phase involving a pop-up maneuver and weapon deployment, and a disengagement phase returning home. The simulator and actual flights utilized the same scenario, tactics, and type of aircraft—a JA37 "Jaktviggen". Although this model was operational at F17 in 2002, it has since been replaced by the JAS39 Gripen. The simulator, crafted from an obsolete aircraft, featured a realistic cockpit and an immersive visual environment.

However, its motion simulation capabilities were deactivated during the study, so there was no motion feedback. Measurements of heart rate, heart rate variability, and eye movements were recorded with a portable device. Additionally, pilots assessed their mental workload, situational awareness, and performance in both settings. The psychophysiological data were standardized to highlight pilot commonalities, discounting individual variations. [5,9,7]

The outcomes from the psychophysiological measurements indicate no significant differences in the participant's responses in the simulator versus actual flight. Both settings showed a marked increase in heart rate, a decrease in heart rate variability, and a reduction in eye movements at the moment of weapon deployment, as depicted in Fig. 1. The similarity in psychophysiological reactions between simulated and actual flights was strikingly high, particularly for heart rate and heart rate variability. The correlation in eye movements was also strong, albeit slightly less so. [9]

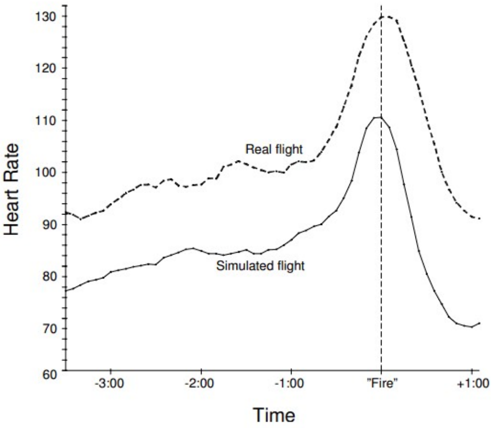

FIG. 1. Comparison between psychophysiological reaction during simulated and real flight

While the overall patterns of psychophysiological responses were similar, there was a noticeable difference in intensity; participants exhibited a higher heart rate when piloting the real aircraft than the simulator. [5,9]

The findings also reveal a variation across the three iterations of the mission. The first sortie produced a higher heart rate in both simulated and real flights than the subsequent two, as illustrated in Fig. 2. [5,9]

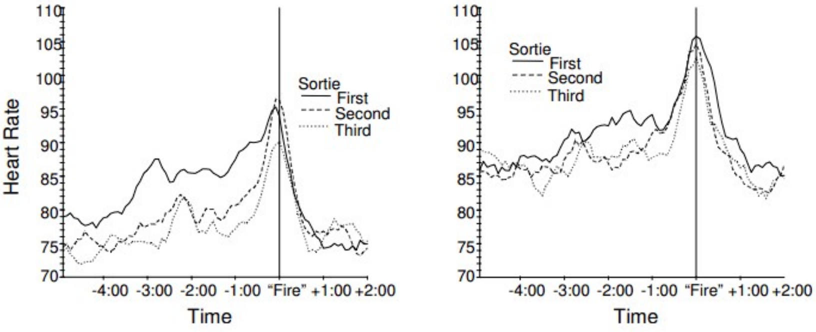

FIG. 2. Heart rate across three consecutive flights: simulated flights on the left, real flights on the right.

Although there is a primary effect based on the type of flight (simulated or actual), there is no interaction between the type of flight and the time (or sortie).

This indicates that the reactions did not differ between simulated and real flights or between sorties despite a variance in intensity. Statistically, the response curves are parallel. Like heart rate, heart rate variability also follows a consistent pattern, as shown in Fig. 3. In both simulated and real flights, the first sortie displayed lower heart rate variability than the latter. [5,9]

Although a main effect exists for the type of flight (simulated or actual), there is no interaction between the type of flight and time (or sortie). This indicates that despite differences in levels between simulated and real flights (and among sorties), the response curves remain parallel, demonstrating very similar pilot reactions. [7]

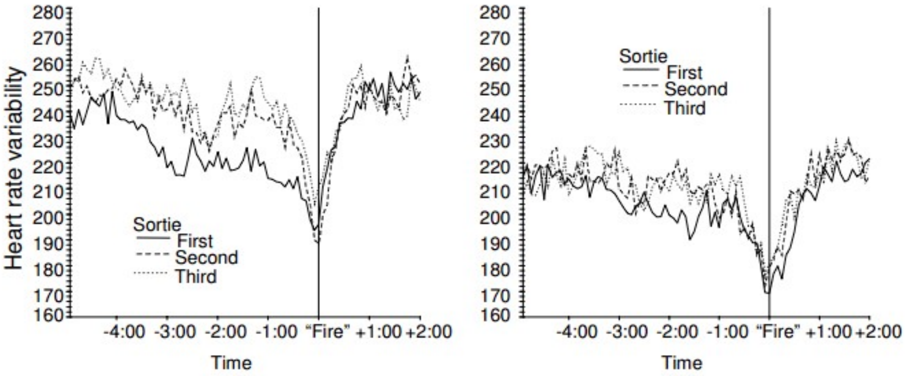

FIG. 3. Heart rate variability across three consecutive flights: on the left are the simulated flights, and on the right, the real flights. The vertical scale is arbitrary

Eye movement data also indicate a high degree of similarity between simulated and real flights, as shown in Fig. 4. [2,9]

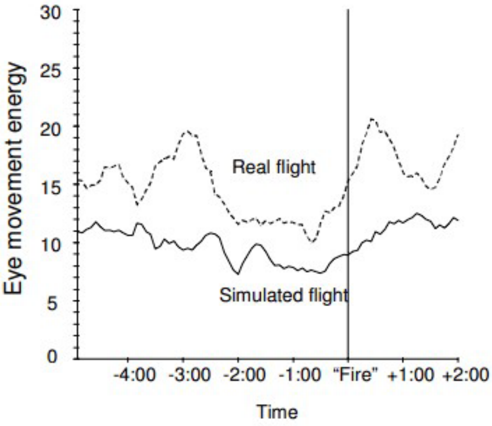

FIG. 4. Eye movement energy in simulated and real flight

During the attack phase, when weapons were deployed, participants reported the highest levels of mental workload, coinciding with their peak heart rates, as illustrated in Fig. 5. The correlation between these two measures was relatively strong. [9,10]

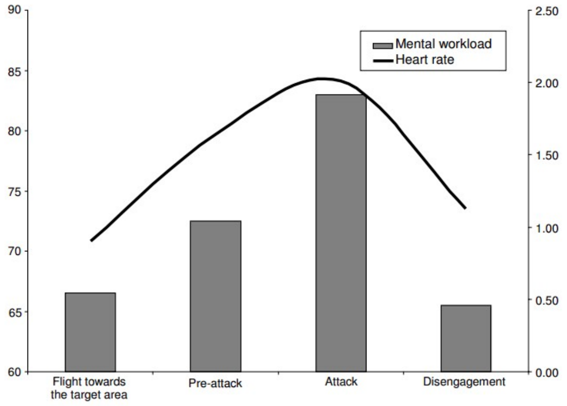

FIG. 5. The similarities between heart rate (scale on the left side) and ratings of mental workload (scale on the right side)

The relationship between mental workload, heart rate, situational awareness, and performance is depicted in a diagram, as shown in Fig. 6. The model illustrates that an increase in mental workload corresponds with an increase in heart rate and a decrease in situational awareness, which in turn leads to a decline in performance. [10]

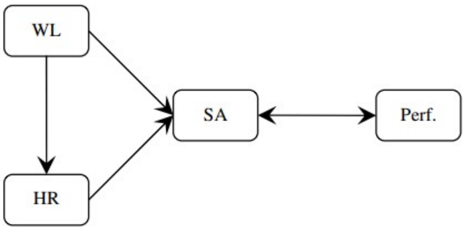

FIG. 6. Diagram describing the relationship between Mental Workload (WL), Heart rate (HR), situation awareness (SA) and performance (Perf)

After analyzing the similarities and differences in psychophysiological reactions between simulated and real flights, some noteworthy findings were discovered. It was observed that the increase in heart rate during similar flight phases is consistent across both simulated and real flights, which is valid for all psychophysiological measures observed. However, there were also significant differences; the heart rate was consistently lower in the simulator, heart rate variability was higher, and eye movements were reduced compared to actual flights. [9,10]

Furthermore, the relationship between psychophysiological data and self-reported mental workload was explored, revealing that variations in these measures could be integrated into a statistical causal model. Particularly, heart rate was found to closely correlate with the ratings of mental workload, highlighting its potential as a predictive indicator of psychological stress during flight operations. This thorough analysis helps in comprehending the effects of simulation versus actual flight conditions on pilot performance and physiological responses. [7,9,10]

CONCLUSIONS

The assessment of mental workload presents a comprehensive approach to evaluate flight simulators' training potential, focusing on user experience rather than just technical specifications. It is important to note that a high mental workload does not always equate to effective training, as excessively high workload situations can hinder learning and have a negative impact on the overall training process. To enhance training outcomes, it is decisive to analyze the differences between simulated and real flights.

Interestingly, pilots tend to exhibit similar responses to specific events, whether in a simulator or an actual aircraft, indicating that simulators can replicate real flight experiences to a significant degree. Comparable increases in heart rate under both conditions further support this conclusion, demonstrating that practical training can occur in simulated environments.

In conclusion, flight simulators are essential tools in the aviation industry, providing significant benefits in training, safety, and cost efficiency. However, they cannot fully replicate the nuances and intensities of real flying, highlighting the importance of a balanced training approach that combines simulated and real-world experiences. This approach ensures that pilots are thoroughly prepared for all aspects of flight operations.

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