Advances in Biology & Earth Sciences
Vol.10, No.2, 2025, pp.185-189
https://doi.org/10.62476/abes.102185

Editorial Perspective

BIOLOGICAL INSIGHTS FROM SALIVA DIAGNOSTICS TO ASSESS HUMAN FACTORS AND FLIGHT SAFETY PERFORMANCE IN AVIATION SIMULATORS

Arif Pashayev[1], Garay Garaybayli[2], Arif Mammadov[3,1], Rovshan Khalilov[4], Aziz Eftekhari[5*]

[1]Department of Human Factor in Aviation, Azerbaijan National Aviation Academy, Baku, Azerbaijan
[2]Department of Psychiatry, Azerbaijan Medical University, Baku, Azerbaijan
[3]Department of Normal Physiology, Azerbaijan Medical University, Baku, Azerbaijan
[4]Department of Biophysics and Biochemistry, Baku State University, Baku, Azerbaijan
[5]Department of Biochemistry, Faculty of Natural Sciences, Ege University, Izmir, Turkiye

Abstract. In aviation human factors research, the development of non-invasive biological monitoring technologies has created exciting new avenues. It is becoming more widely acknowledged that saliva, a complex biofluid full of hormones, enzymes and biomarkers, is a potent diagnostic tool for evaluating fatigue, cognitive awareness and physiological and psychological stress - all of which are critical components of flight safety. The potential integration of saliva diagnostics in flight simulation environments to assess and improve pilot performance and decision-making is examined in this perspective article. We contend that saliva-based evaluations can offer personalized, real-time biological feedback to supplement behavioral and cognitive measures that are typically employed in human factors research. The combination of aviation simulation, salivary analytics and wearable biosensing presents a worthy opportunity to improve our comprehension of pilot preparedness and resilience. Finally, we propose a multidisciplinary framework that influences salivary biomarkers as part of an adaptive, biologically-informed training and safety ecosystem in modern aviation.

Keywords: *Salivomics, flight safety, aviation simulators, biomarkers, stress.*

[*]***Corresponding Author:*** *Aziz Eftekari, Department of Biochemistry, Faculty of Natural Sciences, Ege University, Izmir, Turkiye, e-mail: Eftekhari.aziz@gmail.com*

Received: *16 June 2025;* ***Accepted:*** *5 July 2025;* ***Published:*** *6 August 2025.*

1. Introduction

In the aviation sector, safety results are closely linked to human performance (Olaganathan, 2024). Understanding and reducing human error is still a major concern as flight operations grow more intricate and dependent on human-machine interactions. Behavioral observation, self-report measures and simulator performance metrics have been the traditional methods used to study human factors in aviation (Xu *et al*., 2025). Although these techniques are instructive, they do not offer real time biological data regarding the pilot's internal physiological and mental states.

Recent advancements in non-invasive diagnostics have made it possible to test biomarkers for stress, fatigue, circadian rhythms and cognitive function (Vivarelli *et al*., 2023; Pan, 2025).

One of the most promising media for these types of analysis is saliva. Saliva contains a variety of biological signals that show the functioning of the immune system, hypothalamic-pituitary-adrenal (HPA) axis and autonomic nervous system, such as cortisol, alpha-amylase, immunoglobulins and neuropeptides (Hoyt & Zimmermann, 2020). These systems have a significant role in controlling how people react to demanding tasks, time constraints and making decisions in the face of uncertainty - all of which pilots frequently encounter. This perspective article investigates the innovative use of saliva diagnostics in aviation simulators as a means of evaluating and enhancing pilot performance and security. We review the current status of research on salivary biomarkers, suggest ways to incorporate these measurements into flight simulation procedures and talk about the wider ramifications for safety evaluation, training and the future of human-machine cooperation in aviation.

2. Saliva diagnostics

Aviation psychology has long conducted studies on understanding human performance under stress (O'Hare, 2017). In particular high-stakes situations like flight decks or aviation simulators are the most important goals of studies (Hawkins, 2017; Yeshmanov, 2025). Many methods have ever been developed to evaluate human factors and the majority of them depend on performance metrics, self-report questionnaires and behavioral observation (Salas *et al*., 2017). While these tools offer insightful information, they are lacking in one crucial area (Parasuraman & Rizzo 2006; Davies *et al*., 2013). They are not able to clarify the physiological state of the operator. It is frequently impossible to observe inside a pilot's body and brain during stressful situations. This is where biological markers, especially those in saliva, can provide a new level of insight (Hellhammer *et al*., 2009; Granger & Taylor, 2020).

Saliva has been mentioned as a powerful diagnostic fluid. Its contents reflect the biological information of the body and has easy sampling (Dongiovanni *et al*., 2023). Salivaomisc has been rapidly turned into a center of attention parallel with the advancements of wearable technologies and portable biosensors (Samson & Koh, 2020). Operational and training environments like flight simulators also benefit from salivaomics (Monnoyer *et al*., 2021; Łoś & Waszkiewicz, 2021; Jantaratnotai *et al*., 2022). Among the most instructive are the stress hormone cortisol, the sympathetic nervous system activity marker alpha-amylase, the immunological response indicator secretory immunoglobulin A and the circadian rhythm hormone melatonin (Łoś & Waszkiewicz, 2021; Salarić *et al*., 2021; Szabo & Slavish, 2021; Jantaratnotai *et al*., 2022).

Considering two pilots participating in the same emergency simulation during training. Both are successful in terms of procedures and outcomes. Their inner reactions, however, may reveal different tales if we dig deeper. Elevated cortisol and alpha-amylase levels may be signs of high acute stress, which may ultimately impair resilience (Łoś & Waszkiewicz, 2021; Monnoyer *et al*., 2021; Jantaratnotai *et al*., 2022). The other's moderate, well-regulated biomarker reactions could be an indication of effective stress management (Szabo & Slavish, 2021). Such biological data, when

tracked over time, can reveal information about a pilot's performance as well as their capacity to adapt, regulate and recuperate under pressure.

Saliva diagnostics connect biology, behavior and cognition (Łoś & Waszkiewicz, 2021; Szabo & Slavish, 2021). A panel of Salivary biomarkers in pilots can provide a comprehensive image of their health status when combined with other performance metrics like reaction time, decision accuracy or even variations in heart rate and eye movement (Jantaratnotai *et al*., 2022; Dongiovanni *et al*., 2023). In simulation centers usually the risk of cause and effect examinations is low. So, the implementation of salivaomics would offer a beneficial real-time assessment (Monnoyer *et al*., 2021).

The potential to construct a physiological timeline of stress and recovery by coordinating biomarker sampling with particular mission phases - prior to takeoff, during high workload maneuvers and following task completion - is among the most exciting opportunities (Monnoyer *et al*., 2021; Tammayan *et al*., 2021). This timeline could be used to pinpoint crucial turning points when recovery is insufficient or cognitive load becomes excessive (Łoś & Waszkiewicz, 2021; Szabo & Slavish, 2021). Trainers could then provide individualized feedback that addresses both technical and human aspects of performance by customizing debriefings based on the pilot's body reaction in addition to what they did (Honceriu *et al*., 2021).

However, there are some difficulties in combining saliva diagnostics into aviation training. Data ownership, permission and privacy are ethical concerns that require be carefully considered (Granger & Taylor, 2020; Alotaiby, 2024; Patel, 2025). Pilots and trainees must be reassured that their biological information will be used for instructional purposes rather than for monitoring, as the data gathered from biomarkers is sensitive and personal (Granger & Taylor, 2020; Patel, 2025). Additionally, because of logistical concerns like sample collection and storage duration, standardized processes are required to ensure reliability (Szabo & Slavish, 2021).

Furthermore, interpretation is crucial. High cortisol level might show both ongoing stress or a part of a momentary adaptive reaction. Accordingly, factors like individual baselines, task difficulty and environmental issues might influence the interpretations. This requires the presence of different scientist with different specialties (Łoś & Waszkiewicz, 2021; Szabo & Slavish, 2021).

The potential advantages outweigh these difficulties. Salivary diagnostics present a chance to go beyond a one-size-fits-all method of performance evaluation and training. They make it possible to comprehend how various people react to comparable tasks and stressors in a more complex way (Tammayan *et al*., 2021). As time goes on, trends may show which trainees handle stress the best, who might use more help or how stress biology is impacted by interventions like mindfulness, better sleep habits or workload modifications (Beckner *et al*., 2022). The ultimate goal is informing pilots about their wellbeing during flight not gathering useless information. Salivaomics as a tool that aware pilots form their physiolocal and psychological health can provide a platform to minimize human errors with economical solutions (Vicente-Rodríguez *et al*., 2020).

3. Conclusion

Ensuring optimal human performance is more important than ever as aviation continues to push the limits of complexity. Saliva diagnostics, which were previously limited to clinical or laboratory settings, have the potential to completely transform

aviation human factors research and practice. Salivary biomarkers can be incorporated into simulator-based evaluations to provide previously unheard-of insights into the mental and physical conditions that support pilot performance.

Saliva based methods with real time, non-invasive interdisciplinary collaboration doesn't replace common human factors analysis but improves it with better precision and detail as a fundamental part of next-generation aviation safety systems. Growing collaboration between human and machine in aviation showing that omics-based safety procedures and training are critical for ensuring trust, performance and resilience in the cockpit.

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