

An Approach to Prediction of Mental Resilience in Fighter Pilot Selection

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Abstract: It is well known that human factors are associated with a substantial number of military aviation accidents. To avoid such catastrophic events, continuous enhancement of pilot selection processes using state-of-the-art scientific research results is needed since traditionally used self-report paper-and-pencil personality measures are highly prone to self-report bias. Based on our multidisciplinary research on stress, cognitive and fatigue resilience, we propose an approach for prediction of mental resilience which is based on: stress resilience features, like startle reactivity, respiratory sinus arrhythmia, cardiac allostasis; cognitive resilience features related to cognitive workload/overload, situational awareness, cognitive appraisal etc.; and fatigue resilience features, like dynamics of saccades, eye blink rates etc. These clusters of features mainly reflect interactions among all human brain regions, and their multimodal fusion may enhance assessment of pilots' mental resilience and combat readiness.

1 INTRODUCTION

It is well known that human factors are associated with a substantial number of military aviation accidents (de Hoyos, 2019). To avoid such catastrophic events, continuous enhancement of pilot selection processes using state-of-the-art scientific research results is needed since traditionally used self-report paper-and-pencil personality measures are highly prone to self-report bias (Birkeland et al., 2006). More objective and reliable selection processes can also minimize drop-out rates among pilot candidates in later and more expensive stages of training process. Therefore, selection procedures for military pilots deserve more attention as new scientific results become available (Broach et al., 2019). Unfortunately, scientific literature is remarkably scarce in addressing these crucial aspects of selection process, despite declaratively acknowledging the importance of stress resilience, stress tolerance and stress coping skills for future

fighter pilots. Empirical support regarding the role of personality in pilot performance is lacking, and further improvements in the pilot selection procedures are expected (Carretta, 2000). Despite the relatively low predictive validity of personality assessment instruments (Broach et al., 2019), specific personality characteristics closely related to stress resilience were shown to play a significant role in mission success in military or other dangerous occupations (Wood et al., 2015).

The features concerning stress and cognitive resilience, which may have long-term impact on future pilot's task performance are neglected in the pilot's selection process (Grassmann et al., 2017). Furthermore, some research recognizes individual differences in stress and cognitive resilience features as an important factor that has short-term and potentially long-term effects on individual task performance (Staal et al., 2008; Šarlija et al., 2021; Vine et al., 2015). Therefore, the value of objectivized assessment of stress and cognitive

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resilience in the early phases of pilot selection is not yet sufficiently recognized. In our recent project and articles, we have addressed the challenging problem of stress resilience prediction (Ćosić et al., 2019a; Ćosić et al., 2019b; Ćosić et al., 2019c; Šarlija et al., 2021), as well as cognitive resilience (Kesedžić et al., 2020). Mental resilience in this paper considers stress and cognitive resilience, as well as influence of fatigue on successful operations in military and civilian stressful and unpredictable environments. Therefore, prediction of mental resilience in the context of military pilot selection deserves particular attention. Based on our multidisciplinary research on stress, cognitive and fatigue resilience, we propose an approach for prediction of mental resilience which is based on: stress resilience features, like startle reactivity, respiratory sinus arrhythmia, cardiac allostasis; cognitive resilience features related to cognitive workload/overload, situational awareness, cognitive appraisal etc.; and fatigue resilience features, like dynamics of saccades, eye blink rates etc. These clusters of features mainly reflect interactions among all human brain regions, and their multimodal fusion may enhance assessment of pilots' mental resilience and combat readiness.

2 PREDICTION OF STRESS RESILIENCE BY PHYSIOLOGICAL FEATURES

Stress resilience represents a complex biological, cognitive, emotional, and behavioural phenomenon, which can be broadly defined, in the context of a human psychological trait, as the ability of positive adjustment to adverse events (Russo et al. 2012, Ćosić et al., 2019a; Ćosić et al., 2019b). Besides being a protective factor against the development of stress-related psychopathology (Walker et al., 2017), resilience is also defined in a task-related context as the ability of maintaining normal psychological and physical functioning, when exposed to extraordinary levels of stress (Russo et al., 2012; Šarlija et al., 2021). The latter is crucial in the context of highly demanding, safety-critical and stressful professions, such as military fighter jet pilots. In addition to the well-known psychometric self-report tools, stress resilience assessment can be objectivized by means of: (1) various metrics that might allow a deep and accurate insight into the biological factors contributing to the candidates' stress resilience (e.g. brain imaging, fear conditioning, gene analysis, etc.); and (2) various features based on the analysis of

objectively measurable responses of the peripheral physiological signals. Due to the cost- and time-ineffective nature of the first group of metrics, the latter has been the focus of our most recent research (Ćosić et al., 2019a; Ćosić et al., 2019b; Šarlija et al., 2021).

Prediction of stress resilience based on physiological features includes the analysis of peripheral physiological signals, such as electrocardiography, electrodermal activity, respiration, and *orbicularis oculi* electromyography of eyeblink intensity. Experimental protocols for elicitation, acquisition and analysis of these signals are related to: (a) resting autonomic functioning; (b) the startle reflex; and (c) psychobiological allostasis (Šarlija et al., 2021). Some of the most prominent specific physiological features for objectivization of stress resilience assessment, which have confirmed discriminative power between an a-priori more resilient and an a-priori less resilient group of participants, include: respiratory sinus arrhythmia, which measures heart rate variability in phase with inhalation and exhalation; startle reactivity, which measures the strength of reflexive defensive responding to an aversive unconditioned stimulus, i.e., abrupt, loud noise; cardiac allostasis, which measures adaptive reaction to a stressful event, involving a vigorous cardiac response to stress coupled with a significant cardiac recovery in the aftermath (Ćosić et al., 2019a; Ćosić et al., 2019b).

Our recent work proposes a more comprehensive set of stress resilience features and application of machine learning models for prediction of task performance under stress (Šarlija et al., 2021). The proposed approach could be used in prediction of performance envelope limits in realistic stressful occupational settings, such as the military flight simulator.

3 PREDICTION OF COGNITIVE RESILIENCE BY FNIRS FEATURES

Cognitive resilience is the ability to overcome negative effects of stress on cognitive functioning (LaRosa, 2017) and depends on individuals' cognitive appraisal, cognitive skills, as well as neural interconnectivity, particularly between limbic and prefrontal brain structures (Arnsten, 2009). Various mental states are known to impair cognitive performance and can jeopardize flight safety, such as cognitive fatigue (Dehais et al., 2018), cognitive

decline and overload. An important factor in pilot selection process is the evaluation of applicants' cognitive abilities, mostly estimated using a computerized test battery, which have high validity, and low cost (Broach et al., 2019). However, new methods in cognitive load estimation using objective neurophysiological measures can be added to these procedures.

Functional near-infrared spectroscopy (fNIRS) signals have shown correlations between prefrontal cortex activation and performance on cognitive tasks, and can be used in prediction of pilots' mental states in mitigation of human error (Verdière et al., 2018), as well as in cognitive load classification (Kesedžić et al., 2020). The continuous cognitive load estimation is of special interest in safety-critical professions, since the excessive or insufficient cognitive load is associated with decreased task efficiency (Derosière et al., 2013). Therefore, the prediction of cognitive resilience is of particular importance in fighter pilot selection processes since impairments in cognitive resilience affect pilot's performance in stressful conditions. Consequently, there is a growing interest in development and implementation of various tools and means for monitoring and prediction of pilot cognitive performance (Dehais et al., 2018).

Specific cognitive tasks and corresponding neurophysiological measures which are already used in aviation research (Verdière et al. 2018; Dehais et al., 2018), allow the prediction of cognitive resilience. Experimental measurements concerning the prediction of cognitive resilience may include generic cognitive tests, like working memory tests, arithmetic tests, n-back tests, and a variety of performance tests on flight simulators in the later phases of pilot training. Using comprehensive correlation analysis and machine learning on multimodal stimuli and corresponding fNIRS features datasets, assessment and prediction of pilots' limits concerning cognitive load/overload, task performance, attention and fatigue, as well as lack of situational awareness can be achieved. fNIRS features include classical oxygenation features, like signal average, peak, variance, skewness, kurtosis, area under the curve, slope, etc., extracted from different prefrontal cortex regions. These features were already used in research of cognitive skills such as working memory (Fishburn et al., 2014), fatigue (Skau et al., 2019), cognitive flexibility (Kalia et al., 2018), mental workload (Aghajani et al., 2017), as well as cognitive load (Kesedžić et al., 2020).

4 PREDICTION OF FATIGUE RESILIENCE BY OCULOMETRIC FEATURES

Most accidents in aviation are caused by human error, which is a result of impaired mental performance. In terms of the air force and selection of fighter pilots, oculometric features have shown to be useful for detecting fatigue or high-workload conditions, as well as, for investigating motion sickness, hypoxia, and expertise. Fatigue increases the risk of impaired performance causing accidents in fighter pilots, and it is of high importance to select resilient individuals to prevent possible catastrophic outcomes. Human performance can be predicted using different oculometric features related to fixations, saccadic movements, pupillary response, and eye blinking (Martinez-Marquez et al., 2021).

Fixation-related features are associated with visual processing and fatigue. Feature such as fixation duration is a predictor of fatigue development, and longer fixation duration indicates increased fatigue (Zargari Marandi et al., 2018). Saccades-related features such as saccade velocity, saccadic length, saccade rate, and the number of saccades are associated with mental workload, lethargy, and fatigue, and can be used for prediction of fatigue resilience. Furthermore, pupil size features are influenced by emotions, muscular fatigue, as well as cognitive workload (Gambiraza et al., 2021). The most common blink-related feature is blink rate, which is associated with stress, fatigue, task demands, attention, tension etc.

Eye tracking could also predict pilot's overall mental resilience based on features of gaze pattern dynamics, which can be computed in response to a variety of visual tasks, like antisaccade, free-viewing, smooth pursuit tasks, etc. Evaluating pilot's oculometric performance on such tasks would separate those candidates who develop fatigue sooner from those who develop it later, i.e., from those who are more fatigue resilient. We have also developed and optimized general stimulation paradigms for elicitation of facial and eye gaze features for overall mental resilience prediction (Ćosić et al., 2019b).

5 CONCLUSION

Prediction of future fighter pilots' stress, cognitive and fatigue resilience proposed in this paper is particularly important due to self-report bias of standardized psychological instruments in selection

process for attractive high-value jobs (Galić et al., 2012). These multimodal neurophysiological measurements and analyses have been successfully applied in selection processes for air traffic controllers in Croatia (Ćosić et al., 2019b) and we do believe that similar approach can be successfully applied in future fighter pilot selection processes. The 2020 report of the National Commission for Military Aviation Safety to the U.S. President and Congress (NCMAS, 2020 Dec 1), as well as Croatian military aviation accidents (Croatia Week, 2014 Aug 6; Defense Brief, 2020 Jan 27, 2020 May 7; FlightGlobal, 2010 Sep 24; Reuters 2007 Jul 9), stress importance of human factors in military aviation. Therefore, the main objective of this paper is to stimulate discussions within broader international military research community to enhance future pilot monitoring processes across their professional lifecycle based on innovative neuro-psycho-physiological assessments, particularly here in Croatia regarding upcoming Rafale F3-R jet fighters.

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