An Approach to Prediction of Mental Resilience in Fighter Pilot Selection

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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 source of variability that have 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 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 abstract 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 so far on stress and cognitive resilience we propose an approach for prediction of mental resilience which is based on multimodal measurements and related stress resilience features like startle reactivity, respiratory sinus arrhythmia, cardiac allostasis, as well as cognitive resilience features related to cognitive appraisal, cognitive overload, performance, attention, and fatigue. These features mainly reflect interactions between limbic and prefrontal structures of the human brain and their fusion may provide assessment of pilots' mental resilience and combat readiness.

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.

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).

PREDICTION OF FATIGUE BY OCULOMETRIC FEATURES

Most accidents in aviation are caused by human error, which is a result of impaired mental performance and attention failure. 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 for impaired performance, errors, and 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 fixation, 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 mental resilience. Furthermore, pupil size features are influenced by emotions, muscular fatigue, cognitive processes, and mental workload are common in cognitive load assessment (Gambiraža et al., 2021). The most often blink-related feature is blink rate, which is associated with physiological factors such as fatigue, task demands, attention, and tension.

Eye tracking could also predict pilot's mental resilience based on features of gaze pattern dynamics calculated in response to generic, challenging, and stressful visual tasks of short duration. Examples of these visual tasks are antisaccade, free-viewing and smooth pursuit task. Evaluating pilot's oculometric performance on such generic tasks would separate those candidates who develop fatigue sooner from those who develop it later, i.e., from those who are more resilient. We have also developed and optimized general stimulation paradigms for elicitation of facial and eye gaze features for mental resilience prediction (Ćosić et al., 2019b).

CONCLUSION

Prediction of future fighter pilots' stress and cognitive resilience proposed in this abstract 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 here in Croatia (Ćosić et al., 2019b) and we do believe that such approach can be successfully applied in future fighter pilot selection processes. Croatian military aviation accidents, which were likely caused by human error (Croatia Week, 2014 Aug 6; Defense Brief, 2020 Jan 27, 2020 May 7; FlightGlobal, 2010 Sep 24; Reuters 2007 Jul 9), require more attention from the perspective of human factors. Therefore, the main objective of this abstract is to stimulate discussion within broader research and military community to enhance future selection process of Croatian pilots on Rafale F3-R jet fighters.

REFERENCES

Aghajani, H., Garbey, M., & Omurtag, A. (2017). Measuring mental workload with EEG+ fNIRS. *Frontiers in human neuroscience*, 11, 359.

Arnsten, A. F. (2009). Stress signalling pathways that impair prefrontal cortex structure and function. *Nature reviews neuroscience*, 10(6), 410-422.

Birkeland, S. A., Manson, T. M., Kisamore, J. L., Brannick, M. T. & Smith, M. A. (2006). A meta‐analytic investigation of job applicant faking on personality measures. *International Journal of Selection and Assessment, 14*(4), 317-335.

Broach, D., Schroeder, D., & Gildea, K. (2019). *Best practices in pilot selection* (No. DOT/FAA/AM-19/06). United States. Department of Transportation. Federal Aviation Administration. Office of Aviation. Civil Aerospace Medical Institute.

Carretta, T. R. (2000). US Air Force pilot selection and training methods. *Technical rept.*, *AFRL WRIGHT-PATTERSON AFB OH HUMAN EFFECTIVENESS DIRECTORATE*

Ćosić, K., Šarlija, M., Ivkovic, V., Zhang, Q., Strangman, G., & Popović, S. (2019a). Stress resilience assessment based on physiological features in selection of air traffic controllers. *IEEE Access*, 7, 41989-42005.

Ćosić, K., Popović, S., Šarlija, M., Mijić, I., Kokot, M., Kesedžić, I., ... & Zhang, Q. (2019b). New tools and methods in selection of air traffic controllers based on multimodal psychophysiological measurements. *IEEE Access*, 7, 174873-174888.

Ćosić, K., Popović, S., Šarlija, M., Mijić, I., Kokot, M., Kesedžić, I. (2019c) Multimodal physiological, voice acoustic, eye gaze and brain imaging features of stress resilience. NATO Report of the Project NATO.MD.SFPP 984829 "Multidisciplinary Metrics for Soldier Resilience Prediction and Training".

Croatia Week. (2014 Aug 6). Croatian MIG-21 Fighter Pilot Hailed a Hero after Ejecting From Crashing Jet. https://www.croatiaweek.com/croatian-mig-21-fighter-pilot-hailed-a-hero-after-ejecting-from-crashing-jet/

de Hoyos, J. U. (2019). Human Factor in Military Aviation Accidents: A Resume of 31 USAF accidents extracted from Accident Investigation Board (AIB) public reports. Independently published.

Defense Brief. (2020 Jan 27). Croatian Air Force Kiowa helicopter crashes into Adriatic Sea. https://defbrief.com/2020/01/27/croatian-air-force-kiowa-helicopter-crashes-into-adriatic-sea/

Defense Brief. (2020 May 7). Two die in crash of Croatian Air Force Zlin training aircraft. https://defbrief.com/2020/05/07/two-die-in-crash-of-croatian-air-force-zlin-training-aircraft/

Dehais, F., Dupres, A., Di Flumeri, G., Verdiere, K., Borghini, G., Babiloni, F., & Roy, R. (2018, October). Monitoring pilot's cognitive fatigue with engagement features in simulated and actual flight conditions using an hybrid fNIRS-EEG passive BCI. In *2018 IEEE International Conference on Systems, Man, and Cybernetics (SMC)* (pp. 544-549). IEEE.

Derosière, G., Mandrick, K., Dray, G., Ward, T. E., & Perrey, S. (2013). NIRS-measured prefrontal cortex activity in neuroergonomics: strengths and weaknesses. *Frontiers in human neuroscience*, 7, 583.

Fishburn, F. A., Norr, M. E., Medvedev, A. V., & Vaidya, C. J. (2014). Sensitivity of fNIRS to cognitive state and load. *Frontiers in human neuroscience*, 8, 76.

FlightGlobal. (2010 Sep 24). Croatian MiG-21 pilots escape mid-air collision. https://www.flightglobal.com/croatian-mig-21-pilots-escape-mid-air-collision/96039.article

Galić, Z., Jerneić, Ž., & Kovačić, M. P. (2012). Do applicants fake their personality questionnaire responses and how successful are their attempts? A case of military pilot cadet selection. *International Journal of Selection and Assessment*, 20(2), 229-241.

Gambiraža, M., Kesedžić, I., Šarlija, M., Popović, S., & Ćosić, K. Classification of Cognitive Load based on Oculometric Features. In *2021 44th International Convention on Information, Communication and Electronic Technology (MIPRO)* (pp. 377-382). IEEE.

Grassmann, M., Vlemincx, E., von Leupoldt, A., & Van den Bergh, O. (2017). Individual differences in cardiorespiratory measures of mental workload: An investigation of negative affectivity and cognitive avoidant coping in pilot candidates. *Applied Ergonomics*, 59, 274-282.

Kalia, V., Vishwanath, K., Knauft, K., Vellen, B. V. D., Luebbe, A., & Williams, A. (2018). Acute stress attenuates cognitive flexibility in males only: an fNIRS examination. *Frontiers in psychology*, 2084.

Kesedžić, I., Šarlija, M., Božek, J., Popović, S., & Ćosić, K. (2020). Classification of cognitive load based on neurophysiological features from functional near-infrared spectroscopy and electrocardiography signals on n-back task. *IEEE Sensors Journal*, 21(13), 14131-14140.

LaRosa K. (2017) Cognitive Resilience. In: Kreutzer J., DeLuca J., Caplan B. (eds) Encyclopedia of Clinical Neuropsychology. Springer, Cham.

Martinez-Marquez, D., Pingali, S., Panuwatwanich, K., Stewart, R. A., & Mohamed, S. (2021). Application of eye tracking technology in aviation, maritime, and construction industries: a systematic review. *Sensors*, 21(13), 4289.

Reuters. (2007 Jul 9). Two killed in Croatian military chopper crash. https://www.reuters.com/article/idUSL09167014

Russo, S. J., Murrough, J. W., Han, M. H., Charney, D. S., & Nestler, E. J. (2012). Neurobiology of resilience. *Nature neuroscience*, *15*(11), 1475-1484.

Skau, S., Bunketorp-Käll, L., Kuhn, H. G., & Johansson, B. (2019). Mental fatigue and functional near-infrared spectroscopy (fNIRS)–Based assessment of cognitive performance after mild traumatic brain injury. *Frontiers in human neuroscience*, 145.

Staal, M. A., Bolton, A. E., Yaroush, R. A., & Bourne Jr, L. E. (2008). Cognitive performance and resilience to stress. In B. J. Lukey & V. Tepe (Eds.). *Biobehavioral resilience to stress* (pp. 259-99). Boca Ratton, FL: CRC Press.

Šarlija, M., Popović, S., Jagodić, M., Jovanovic, T., Ivkovic, V., Zhang, Q., ... & Ćosić, K. (2021). Prediction of task performance from physiological features of stress resilience. *IEEE Journal of Biomedical and Health Informatics*, 25(6), 2150-2161.

Verdière, K. J., Roy, R. N., & Dehais, F. (2018). Detecting pilot's engagement using fNIRS connectivity features in an automated vs. manual landing scenario. *Frontiers in human neuroscience*, 12, 6.

Vine, S. J., Uiga, L., Lavric, A., Moore, L. J., Tsaneva-Atanasova, K., & Wilson, M. R. (2015). Individual reactions to stress predict performance during a critical aviation incident. *Anxiety, Stress, & Coping, 28*(4), 467-477.

Walker, F. R., Pfingst, K., Carnevali, L., Sgoifo, A., & Nalivaiko, E. (2017). In the search for integrative biomarker of resilience to psychological stress. *Neuroscience & Biobehavioral Reviews*, *74*, 310-320.

Wood, J., Shurlow, C., & Haynes, J. (2015). *Objective versus subjective military pilot selection methods in the United States of America*. SCHOOL OF AEROSPACE MEDICINE WRIGHT-PATTERSON AFB OH.

Zargari Marandi, R., Madeleine, P., Omland, Ø., Vuillerme, N., & Samani, A. (2018). Eye movement characteristics reflected fatigue development in both young and elderly individuals. *Scientific reports*, 8(1), 1-10.