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Effects of stress on performance during highly demanding tasks in student pilots

Toni Vallès-Català[a*], Anna Pedret[bc], Diana Ribes[d], David Medina[a] and Miquel Traveria[a]

a Centre d'Estudis Superiors de l'Aviació, Catalonia, Spain;

b Eurecat Centre Tecnològic de Catalunya, Catalonia, Spain;

c Functional Nutrition, Oxidation and Cardiovascular Disease Group, Universitat Rovira i Virgili, Catalonia, Spain;

d Departament de Psicologia, Universitat Rovira i Virgili, Catalonia, Spain

*Corresponding author, email address: tvalles.pdi@cesda.com

ABSTRACT

Objective: To study how stress affects the performance of student pilots under highly demanding conditions, during flight simulator sessions.

Background: Pilots usually suffer stress under highly demanding conditions. This can affect performance to such an extent that the human factor is the main cause of aviation accidents. Stress has not been studied recently in student pilots.

Method: We used a wristband to record in real-time the Electrodermal Activity (EDA, a reliable indicator of stress) of student pilots during several flight simulator sessions. Experienced flight instructors graded their performance during these flights. The sessions were split into different tasks to focus only on performance and EDA in Highly Demanding Tasks (HDTs).

Results: We found that students have higher EDA when correctly performing an HDT. Furthermore, we observed low EDA in students who perform well on the session as a whole but perform poorly on one particular HDT.

Conclusion:

The study indicates that high levels of stress are related to high performance at high levels of demand. We also observe that students (although they may perform well on the session as a whole) poorly performed a highly demanding task, during which they showed low levels of stress. We suggest that this could be due to fatigue, a lack of motivation, level of skills, or even overconfidence, all of which are variables that should be assessed in future work.

KEYWORDS

Pilot decision making; human error analysis; training using simulation

1. Introduction

The impact of the aviation sector on society is increasing. The number of commercial airline passengers has increased worldwide from 3.8 to 4.6 billion in 4 years (IATA, 2016, 2019a), and the International Air Transport Association (IATA) is aiming to reach 8.2 billion by 2037 (IATA, 2019b).

This increase should be linked to improvements in aviation safety. Nowadays, the human factor is the cause of 60-80\% of aviation accidents, 50\% of which are caused directly by pilots (Salas, Maurino, & Curtis, 2010; Shappell et al., 2007).

Flying airplanes involves a considerable cognitive demand in terms of information processing and decision making under the pressure of time. These conditions activate the nervous system in what is known in physiology as "arousal" (Pfaff, Martin, & Ribeiro, 2007). There is some evidence to suggest that stress and arousal influence the performance of certain perceptual-motor skilled professionals mainly in sports (Blascovich, Seery, Mugridge, Norris, & Weisbuch, 2004; Vine, Moore, & Wilson, 2016), but also in aviation (Allsop & Gray, 2014; Causse, Dehais, Péran, Sabatini, & Pastor, 2013; Hidalgo-Muñoz et al., 2018). One plausible explanation for this is that stress influences cognitive functions: on the one hand, many studies show that chronic stress negatively affects these cognitive functions. For a review, see Diamond (2012). On the other hand, acute stress has been shown to favour some of these functions (implicit memory performance, response inhibition, etc) (Plieger et al., 2017; Porcelli et al., 2008).

However, professional pilots are not the only ones to be exposed to a high level of stress. Student pilots are also exposed to stressful situations during training that recreate a similar environment to their future professional practice. So, student pilots experience stress during flight simulation sessions and this stress also influences their performance (Harnyoot, 2018).

The performance and attention of professionals and students can be influenced, positively or negatively by their subjective interpretation of stress (Moore, Vine, Wilson, & Freeman, 2014). When individuals are in a stressful situation, they consciously and unconsciously assess the demands placed on them and their abilities to face these demands. Individuals who judge that they have sufficient resources to deal with the situation, regard it as a challenge. Conversely, individuals who believe they do not have sufficient resources to deal with the situation, regard it as a threat (Blascovich et al., 2004). Moreover, stressful situations that are perceived as challenges are associated with better performance (Moore et al., 2014; Vine et al., 2016). Particularly in aviation, it has been shown that training pilots to cope with stress enhances their performance during flight (McClernon, McCauley, O'Connor, & Warm, 2011).

Monitoring the physiological status of pilots enables stress to be evaluated and performance and safety guaranteed. Moreover, monitoring the physiological status of student pilots during training sessions enables flight instructors to identify the highly demanding tasks that produce negative stress and train individual in greater depth so that they have the confidence and skills to deal with stressful situations and in the future.

Measurements of physiological status are based on the fact that the autonomic nervous system unconsciously regulates bodily fluctuations when there are changes in stressors (McKlveen, Myers, & Herman, 2015). The ability to maintain homeostasis can be monitored by the activity of the autonomic nervous system and by regulating the endocrine, cardiovascular and respiratory systems, which provides a wide range of measures for studying stress: (i) Cortisol levels increase in response to stressful situations in several professional contexts (Arruda, Aoki, Paludo, & Moreira, 2017; Bedini et al., 2017; Müller et al., 2009), aviation pilots included (Bostock & Steptoe, 2013). Cortisol can now be easily evaluated through saliva. (ii) Other studies use the Attentional Control Theory (Eysenck & Derakshan, 2011) which suggests that stress influences gaze behavior, so a Mobile Eye Tracker is used in flight simulators (Allsop & Gray, 2014; Tichon, Wallis, Riek, & Mavin, 2014; Vine et al., 2015). (iii) The analysis of cardiovascular control through heart rate (HR) and heart variation clearly concentrates most interest in aviation, because it is an effective tool for identifying changes in the autonomic nervous system in response to stressors (Bonner & Wilson, 2002; Cao et al., 2019; Hidalgo-Muñoz et al., 2018; Oliveira-Silva et al., 2016). (iv) Finally, subjective measurements of stress experienced by tests such as NASA-TLX have been widely used in the aviation community (Collet, Averty, & Dittmar, 2009; Grassmann et al., 2017; Karavidas et al., 2010).

However, some of these measurements have the limitation that they are not usually recorded in real-time: subjective tests are answered after the flight session and saliva is sampled discretely. Real-time data enables the session to be split into stages so that perceived stress can be analysed more accurately (Mansikka, Virtanen, Harris, & Simola, 2016; Moon & Qu, 2017).

The Empatica E4 wristband (Garbarino, Lai, Bender, Picard, & Tognetti, 2014) is an innocuous device designed to acquire information in real-time and continuously throughout daily life. It is used mainly to record electrodermal activity (EDA), a measure of electrical changes on the surface of the skin that are caused by innervating signals from the brain. These changes are associated with the arousal of the sympathetic nervous system and the characteristics of stress (Mangina & Beuzeron-Mangina, 1996). Various studies in the scientific literature have used EDA to study stress (Hackman et al., 2019; Sano et al., 2015), and the E4 wristband has been used several times for this purpose (Corino et al., 2017; Poh et al., 2012; van Dooren, de Vries, & Janssen, 2012). EDA has been applied in aviation by (Wilson, 2002), and has shown a high correlation between EDA and HR. Empatica E4 has also been used in aviation by Moon & Qu (2017), who have suggested that further research needs to be carried out on EDA response to flight tasks.

The E4 wristband also measures heart rate (HR), heart rate variability (IBI) and temperature (T), and records the 3-axis accelerometers (ACC). However, we prefer to use the EDA variable because E4 accurately measures HR only when stressors are strong (van Lier et al., 2019). EDA has rarely been used to study stress in student pilots.

This study is a first approximation to the study of how stress affects the performance of student pilots under highly demanding conditions during flight simulator sessions. To this end, we propose to split a flight simulator session into different tasks, and focus only on the EDA measured in highly demanding tasks. Understanding the stress students are under will enable us to train them accordingly and possibly reduce aviation accidents in the near future.

2. Methods

2.1. *Participants*

For two academic years (2017-18 & 2018-19), a total of 41 student pilots (35 men and 6 women) from the 2nd and 3rd years in CESDA (Centre d'Estudis Superiors de l'Aviació) voluntarily participated in a total of 75 experiments, with an average of two experiments per student. This research complied with the tenets of the Declaration of Helsinki and was approved by the local ethics committee (Ref. CEIm 164/2017). Informed consent was obtained from each participant after they had received written and verbal information about the study.

2.2. *Measures*

The Empatica E4 captures EDA by passing an innocuous amount of current between two electrodes in contact with the skin.

It records EDA four times per second (4Hz) and its units are microSiemens (μS). Although traditional recommendations suggest putting the E4 on the non-dominant wrist because of the reduced movement, recent studies show stronger recordings of EDA on the dominant wrist (Picard, Fedor, & Ayzenberg, 2016). Therefore, we put the wristband on the dominant wrist.

Note that participants barely move, and from the wristband recordings we found a low correlation between each axis accelerometer and EDA (the Pearson coefficient is 0.6 at max, see S1 in supplementary material).

We also subtracted noise when capturing EDA using the approach proposed by (Xia, Jaques, Taylor, Fedor, & Picard, 2015): a multiclass machine learning classifier that considers temperature and movement.

To measure the performance of the pilot, studies use either deviation in the speed, height and pitch of the airplane (Mansikka et al., 2016; McClernon et al., 2011; Vine et al., 2015) or the subjective mark given by the instructor (Cao et al., 2019; Karavidas et al., 2010; Koglbauer, Kallus, Braunstingl, & Boucsein, 2011). The objective data is provided by the simulator but ours do not allow this information to be retrieved, so we used the subjective evaluation of a wide range of instructors, which is more desirable than the opinion of a single instructor. Moreover, all instructors apply the same criteria based on deviation in the speed, height and pitch of the airplane.

Instructors are trained to evaluate performance by following standard procedures defined by our university aviation school. Each session is split into different tasks, and instructors are trained to label the performance on each task with three options: '-' for low, '=' for regular and '+' for high. The mean of all the tasks provides an overall mark which is used for the student's degree. In our study, we use task performance and also the overall marks (see S8 in supplementary materials for two rubrics that instructors use to evaluate different tasks and also to obtain the overall mark).

Finally, we define the demand of a task as the workload on the student pilot demanded by the instructor. Tasks performed throughout a session vary in demand, since we are interested in stressful situations, we will focus on tasks where instructors require high demand. Instructors coincide when labelling similar tasks as being highly or lowly demanding.

2.3. ***Experiment***

All the flying experience is on one or two engine propeller airplanes to finally obtain the Airline Transport Pilot License and the Bachelor's Degree in Commercial Aviation Pilot and Air Operations. Experiments were held with one instructor in one of two simulators of a generic multiengine (Alsim A2G10 similar to turboprop B200 for 2nd year students, and DA42-NG similar to piston DA42 for 3rd year students). A total of 13 instructors participated in the study.

Pilot students from 2nd and 3rd year perform different flight sessions sequentially called missions, in order to pass the flight subject of our degree. Tasks given to the students vary considerably from mission to mission. However, they can be classified into five groups: 2nd-Maneuvers (non-precision approaches, wind corrections); 2nd-Interceptions; 3rd-Maneuvers (in 3rd year students are introduced to a twin-engine aircraft); 3rd-Cross country (approaches, go-around); 3rd-Emergencies (engine failure, systems failure). A wide variety of experimental missions enable our conclusions to be generalized.

The temperature inside the simulator was set to 20º throughout the year to protect the simulator computers and ensure reliable experimentation.
Experiments lasted 1h 31min ± 3min.

Each experimental session ewas performed as follows:

- We put the E4 wristband on the student's dominant wrist before the session started and switched it on. During the routine preflight checks, data was recorded but not considered for the study.
- From take-off to landing, the training flight session was split into different tasks: depending on the session students were given different tasks which they were informed of in advance, and the experimenter used an online chronometer (http://cronometro-online.chronme.com) to record the time at which the task changed so that the EDA data could be split afterwards. Finally, between landing and switching off the wristband, data was again recorded but not considered for the study.
- After the wristband had been switched off, the overall mark of the session was recorded. The instructor evaluated the demand of each taskand the performance

following standard procedures: "-" for low performance, "=" for standard performance and "+" for high performance.

In some sessions, the instructor froze the simulation to clarify concepts. This data was not considered (see grey tasks in Figure 2 from a real experiment). The experimenter sat silently behind the student so that the student would not notice any difference with non-experimental simulator flights.

Of all the tasks in a session, we are interested only in those that were highly demanding. We refer to the EDAs contained in such periods as Highly Demanding Tasks (HDTs). We also classify these tasks in terms of how they are performed: (i) we refer to *OK* tasks when a HDT was correctly performed; and (ii) we refer to *NOK* tasks when a HDT was poorly performed, see Figure 1 for an accurate definition. Note that in the same session a student pilot can perform an *OK* task and a *NOK* task separately, or even two different *OK* tasks (for an example see Figure 2).

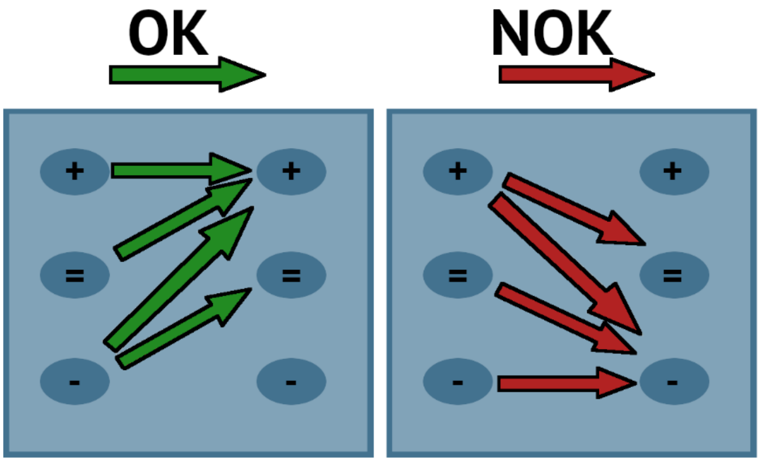

Figure 1. ***OK*** **and** ***NOK*** **definition in highly demanding tasks**. We classify highly demanding tasks in terms of how they are performed with respect to the previous task. performance can be "-" for low, "=" for regular and "+" for high. ***OK*** **task:** performance is better than the previous task, or performance is high in both. ***NOK*** **task:** performance is worse than the previous task, or continues to be low. Note that there are nine different options, and we separate them into four *OK* and four *NOK*, leaving out the ninth option "maintaining regular performance" as indeterminate.

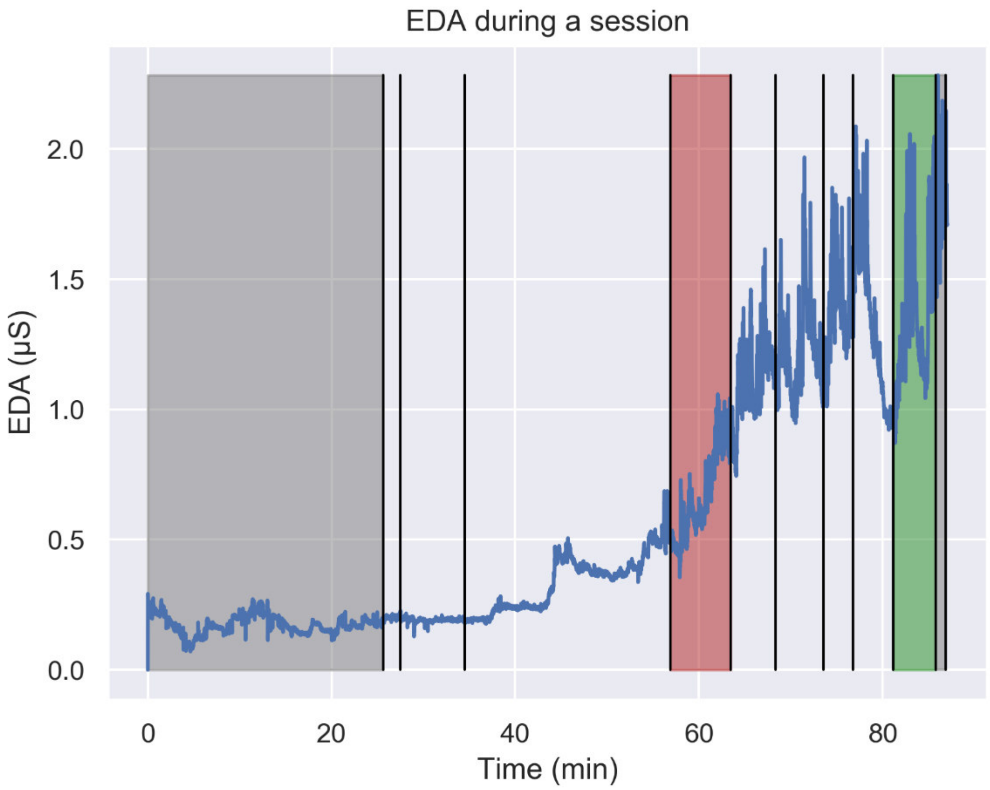

Figure 2. Example of the information we retrieve from one session. Empatica E4 records Electrodermal Activity (EDA) (blue line) during a session of 1h 27min. We manually split the session into different tasks using a chronometer (black vertical lines), and finally the instructor evaluated the demand and performance for each task. In this session, there were two high demanding tasks: one shown in red (*NOK* task) and the other shown in green (*OK* task). Observe that we remove the tasks in which the student is not "on flight" (before taking-off, after landing, etc.) (shown in grey).

2.4. *Statistical analysis*

We observe the dependent variable EDA in different independent variable scenarios: demand, performance and overall mark. Then all EDA values within a task are labelled HDT if demand is high or LDT otherwise (Lowly Demanding Tasks will be used as a baseline). We also split HDT tasks depending on their performance: *OK* or *NOK*.

In order to compare whether EDA values from one task are statistically greater than EDA values from another task, we use the Mann-Whitney one-tailed test $\alpha = 0.001$ to compare non-normal distributions.

Finally, we compute the Spearman rank correlation between all overall marks and EDA values. Since we have several EDA measurements within a session, and only one overall mark, we consider the mean of all EDA values within an HDT to obtain a single value for each session and enable correlation computation.

3. Results

We obtained complete data for 72 out of 75 flight sessions (40 out of 41 students). However, not all sessions contain HDTs: 39 sessions contain at least one *OK* task, 38 sessions contain at least one *NOK* task, and 30 sessions contain at least one of each. Note that these sessions may contain more than one *OK* or *NOK* task, which means that more than 30 comparisons are possible.

We find that in 36 out of 56 cases (64.3%) EDA values in *OK* tasks were statistically greater than in *NOK* tasks.

All sessions contain several LDTs (an average of five per session), which make more comparisons possible. We find that in 144 out of 255 cases (56.5%) EDA values in *OK* tasks were statistically greater than LDTs, and in 108 out of 213 cases (50.7%) EDA values in *NOK* tasks were statistically greater than LDTs.

Finally, we find a significant but moderate negative correlation between EDA values within *NOK* tasks and overall marks (the Spearman rank correlation is -0.52 with a p-value of 0.0008). Figure 3A shows the histogram of all EDA values in *NOK* tasks split by the threshold mark 7.26 (the mean of all overall marks in the study). Note that we observe no difference in EDA distributions of *OK* tasks when splitting by overall marks in Figure 3B (the Spearman rank correlation is -0.36 with a p-value of 0.025).

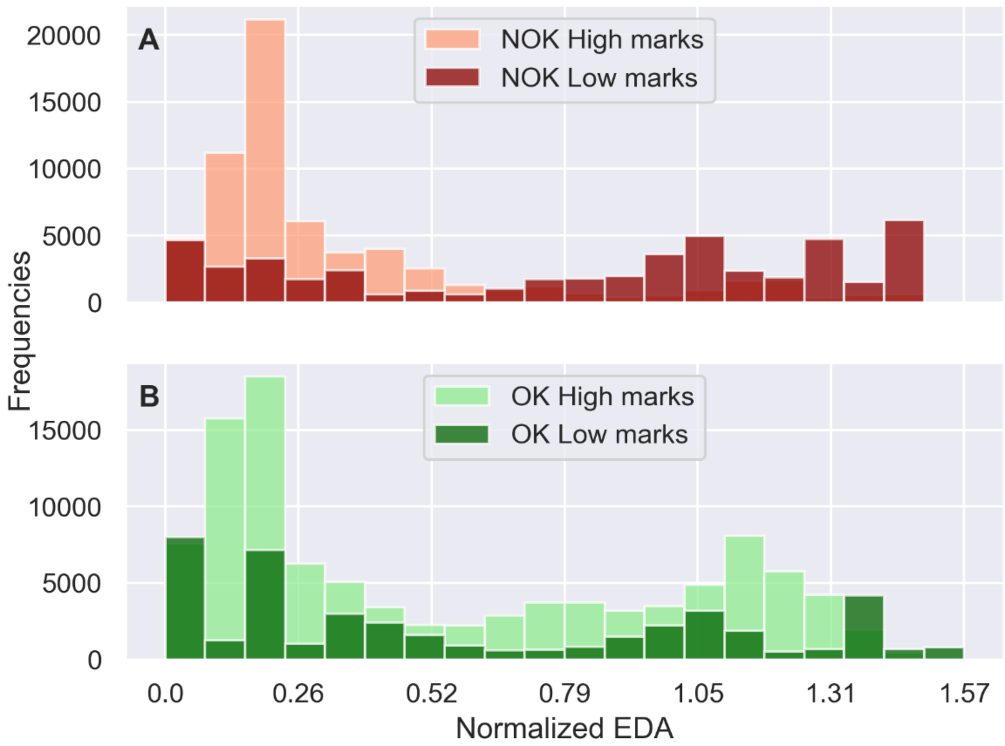

Figure 3. Distribution of normalized EDA over all the sessions by task performance and overall marks. We first split all EDA values from HDT into poorly performed *NOK* (**A**)) and correctly performed *OK* (**B**)). Then we further split EDA values in terms of the student pilot overall mark (we consider the mean of all the overall marks among the experiment sessions

[7.26] as the threshold). Observe that in *NOK* tasks, student pilots with a high overall mark have lower EDA values than those with a high overall mark, This is not the case in *OK* tasks.

When the instructors and session missions are different, our analysis of the data finds that these variables have no influence on the observed results (see S6 in supplementary materials).

4. Discussion

The aim of the present study was to analyse how stress affect the performance of 41 student pilots performing Highly Demanding Tasks (HDTs) during 75 flight simulator sessions. We split each session into separate tasks, and differentiated those that the instructor regarded to be highly demanding. To measure stress we used a wristband (Empatica E4) to measure electrodermal activity (EDA) throghout the session, and the instructor rated the performance on each task within the session separately.

First, we observe that EDA increases in those students who correctly perform an HDT, suggesting that they perceive it as a challenge. This finding is in line with findings by previous studies by (Vine et al., 2016) and (Blascovich et al., 2004). It is reasonable to think that highly demanding tasks require greater arousal if they are to be completed correctly, but this is not the case with students who perform a HDT poorly..

Second, we further analyse this latter group of student pilots to determine why they did not experience an increase in arousal when attempting a highly demanding task. The overall mark of the sessions of these students who performed an HDT poorly reveals two different arousal behaviours:

- Some students did indeed experience an increase in arousal in highly demanding tasks: those who were given a low overall mark. These students performed several tasks poorly and

–on the basis of the work by Vine et al. (2016) and Blascovich et al. (2004)– we suggest that these students experienced a threat situation.

- Surprisingly, those students experiencing a lack of arousal were those students who were given a high overall mark, although they performed that particular highly demanding task poorly (see S7 in supplementary for more information).

Several factors may explain the results observed in students who show low EDA levels and poor performance in highly demanding situations. On the one hand, the students' motivation in that simulator session may not have been enough, a factor that has been decisive in previous related studies (Frederick and Hall, 2003; Lee, 2005).

Another factor that could influence the observed results is fatigue, which directly influences performance (Roach, Petrilli, Dawson and Thomas, 2006). In this regard, for future studies it would be important to take into account variables such as the academic workload of the students in the different simulator sessions and hours of sleep.

Another variable that may also influence the observed results is the students' level of skill and knowledge. Performance may not be satisfactory in the situations that involve a high demand because they are novel and they can draw on no previous experience to solve them because they have not been adequately prepared. So they give up. In this regard, previous studies show that the decision to give up attempting to solve a problem is affected by the size of the problem and by the probability that it can be solved (Payne & Duggan, 2011). In the particular case of student pilots, exposure to highly demanding situations in a flight simulator does not compromise students' physical integrity so the feeling of threat may be relative. Bonner & Wilson (2002) found that heart rate increase less during emergencies in a flight simulator than in a real flight.

On the other hand, the belief that they master certain situations because the procedures have been consolidated and/or prepared may generate in students a state of false confidence that would explain the low levels of EDA. Previous studies show that overconfidence predicts the performance of pilots (Sulistyawati, Wickens & Chui, 2011).

All these factors could influence the results and, as the situations are complex, we cannot rule out interaction between some of them. The results of this study, which sought to approximate the effect of stress on performance in highly demanding situations, suggest that future studies should consider a whole series of variables that could condition the performance of student pilots in the simulator, such as motivation, fatigue, skill level and knowledge.

One main limitation to the present study should be addressed in future work. The performance was subjectively measured by the instructor, as it was in some previous studies (Cao et al., 2019; Karavidas et al., 2010), but it would be preferable to compare these scores with objective data such as information from the simulator (deviation of speed, altitude or direction), (Allsop & Gray, 2014; McClernon et al., 2011; Vine et al., 2015). However, our simulator does not allow this information to be retrieved. Nevertheless, instructors are trained to evaluate performance by following standard procedures defined by our university aviation school (see S8 in supplementary materials for two rubrics used to evaluate the various items in the sessions [for instance, note that altitude is evaluated several times]). The instructors who participated in the study have considerable experience of both real flight (mean of 1,595h) and simulated flight (mean of 490h) (see S6 of supplementary materials for more information)

Our results indicate that further studies should be made on comparing the stress of tasks in simulated flight versus real flight, and detecting the lack of arousal situations in highly demanding tasks when physical integrity may be compromised. And if these situations are indeed detected, research should focus on determining whether they can be explained by fatigue or level of skills rather than a lack of motivation or overconfidence.

The results of this study indicate that wearing the wristband during the instruction phase in the simulator is advisable, so that stress levels can be obtained in real-time to predict performance on highly demanding tasks and thus individualize the training sessions depending on stress levels and demands of the task.

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