Virtual Reality for Pilot Training: Study of Cardiac Activity

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Abstract: Flight training is provided through real flights with real aircraft and virtual flights using simulators. Nowadays a third alternative way emerges which is the use of immersive virtual reality (VR) flight deck. However, the effectiveness of this technology as a training tool for pilots has not yet been fully assessed. We, therefore, conducted an experiment involving four pilots that had to perform the same traffic pattern scenario (take off, downwind, and landing) in a VR simulator and real flight conditions. We collected subjective (perceived task difficulty) and objective data (trajectory, cardiac activity). In this this preliminary study, the first descriptive results disclosed that pilots had similar flying trajectories in both conditions. As one could expect, the pilots reported higher task difficulty and exhibited higher heart rate and lower heart rate variability in the real flight condition compared to the VR one. However, similar patterns of subjective rating and cardiac activation were found across the different segments of the scenarios (landing > take off > downwind) for the two conditions. These latter findings suggest that VR offer promising prospects for training purpose but that more experiments have to be conducted following the proposed methodology.

1 INTRODUCTION

Today, air traffic is experiencing significant growth. Statistics show that the number of passengers doubles every 15 years. The International Air Transport Association (IATA) expects the number of passengers to double again by 2037. The need for professional pilots, therefore, remains high. However, there are two main barriers to flight training to keep up to this trend: the training cost and the availability of aircraft, simulators, and flight instructors. Immersive virtual reality (VR) seems to be an interesting alternative to reduce costs and get around the lack of availability of resources (aircraft, simulators, instructors). Moreover, the recent development of this technology makes the design of virtual environments such as flight simulators much more flexible (Kozak et al., 1993). The VR is already used professionally in various fields such as UAV pilot training (Postal et al., 2016), phobia treatment (Banos et al., 2002; Hodges et al., 1996), or fire fighting (Cha et al., 2012). In 2020, Varjo announced that the astronauts are preparing for the spaceflight with Boeing Starliner using the VR headsets (Varjo, 2020).

The medical field is a forerunner in the field of VR adoption, especially in surgery (Silverstein et al., 2002). For example, VR has allowed trainee surgeons to acquire skills without threatening the lives of patients, especially in laparoscopic surgery (Grantcharov et al., 2004), with positive results in terms of feelings of presence and the ability to transfer the training to the real operation. These promising results in the field of surgery and its similarities to flight, including high levels of stress, accuracy, and risk-taking (S Galasko, 2000), make VR worthy of consideration for pilot training.

However, the use of VR as an operational learning tool still presents challenges in terms of immersion, sense of presence, fatigue, and motion sickness (Labedan et al., 2018). Indeed, it is recognized that simulators do not reproduce the level of engagement that pilots may experience in real-world conditions (Gateau et al., 2018). Studies comparing VR and simulator training (Lawrynczyk, 2018) or simulator and real flight training (Hays et al., 1992), have already been conducted. A recent study (Labedan et al., 2018) with pilot instructors showed that the strong feeling of immersion, combined with good controllability of the aircraft, generates high presence levels. Another recent study (Peysakhovich et al., 2020) showed that VR is an efficient tool for learning checklists in the

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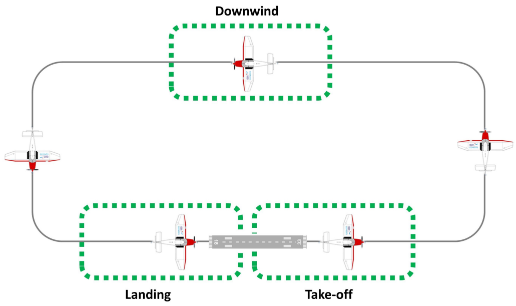

Figure 1: The flight phases considered: take-off, downwind and landing, each lasting 60 seconds.

early stages of pilot training. However, to date, no research has been found directly comparing VR and real flights, which is our goal here.

Evaluating the effectiveness of virtual reality as a solution for pilot training requires being able to compare this type of learning to that carried out in real flight. An interesting perspective for such a comparison is to measure subjective and objective indicators of the mental effort of pilots in both virtual and real flight situations. Cardiac activity, in particular, is a possible indicator for cognitive load (Meshkati, 1988), even in operational conditions (Scannella et al., 2018). A similar approach had already been carried out to compare simulators to virtual reality (Lawrynczyk, 2018). This study even showed a slightly higher heart rate in virtual reality than in a flight simulator.

The present study focuses mainly on the collection and analysis of heart activity parameters, in reality, and VR, with student pilots in training. Finally, we confronted these objective results with subjective results concerning the difficulty perceived by the pilots to perform the different flight phases of the chosen scenario (Fig. 1).

2 MATERIALS AND METHODS

2.1 Participants

Four private pilot licence (PPL) student pilots from ISAE-SUPAERO, Toulouse, France, took part in the experiment (all males, 20-21-year-old, mean flight hour experience: 15 hours). All reported normal vision and hearing as attested by their flight medical certificate. No participants had a history of heart or neurological disease and, as required by aviation regulations, no participants were taking any psychoactive substances or medication. The pilots signed a consent form before the experiment.

2.2 Flight Scenario

The experimental scenario consisted of several standard traffic patterns on runway 33 of Toulouse-Lasbordes Aerodrome (France). This exercise has the advantage of being particularly formalized in terms of flight procedures and of being reproducible (Dehais et al., 2019; Scannella et al., 2018).

In both environments (virtual reality and real flights), the scenario was the same: the pilots made three patterns without stopping the plane with a go-around between each pattern, until the last one with a complete stop of the aircraft on final landing. We focus on three specific phases of the standard traffic pattern:

- Take-off (from maximum power setting or touch-and-go);
- Downwind (in the middle of the return path);
- Landing (before touchdown).

We cropped each phase recordings to 60 seconds to directly compare the results to a previous study performed in similar conditions (Scannella et al., 2018).

2.3 Measures

2.3.1 Electrocardiogram

The electrocardiograms (ECG) were acquired with a Faros 360 eMotion device with three electrodes at a sampling rate of 500 Hz. A conductive gel was applied to improve signal quality. The raw data were recorded and stored via the LabRecorder software of the LabStreamingLayer (LSL). In addition to the raw ECG signal, the Faros system provided R-R intervals data using a built-in R-detection algorithm.

2.3.2 Flight Parameters

During the virtual reality flights, the Aerofly FS2 simulator flight parameters were streamed, recorded, and stored via the LSL LabRecorder. For the real flights, an ILevil 2-10-AW acquisition unit was used to collect the trajectory (via GPS), accelerations, altitude, and speed (with available static and dynamic pressure inputs). Similarly, these data were recorded and stored via the LSL LabRecorder. This acquisition unit had to be mounted in the aircraft's cargo area at a specific location that guaranteed the accuracy of the attitude data (roll, pitch, and yaw). These parameters were then used to automatically identify the three flight phases of interest.

2.3.3 Questionnaire

The pilots filled out a subjective questionnaire to evaluate the perceived difficulty during the different phases (take-off, downwind, landing) in both environments (virtual reality and real flight). The questionnaire used a visual analog scale from 1 (very easy) to 7 (very difficult).

2.4 Environments

2.4.1 Virtual Reality

We used the VRtigo flight simulator at ISAE-SUPAERO (Labedan et al., 2018). This simulator is composed of the following elements:

- Aerofly FS2 flight simulation software (IPACS);
- An identically reproduced environment (Toulouse-Lasbordes aerodrome, DR400 cockpit, some buildings used by the pilots for visual cue, etc.; Fig. 2);
- The 6-axis motion platform MotionSystems PS-6TM-150 (features table 1);
- Conventional controls: stick, rudder, throttle, and flap lever;
- A cockpit, including the controls and a pilot's seat;
- A virtual reality headset (HTC Vive);
- An Alienware "VR ready" Laptop computer.

The interest of this platform is that the pilots evolve in the same environment (real and virtual). This homogeneity between environments was essential for the comparison.

Table 1: Features of the 6-axis moving platform.

Parameters	Values
Heave	-106.9mm +117.1mm
Pitch	-25° +25.6°
Roll	+/-26°
Yaw	+/-22.5°
Surge	-100mm +121mm
Sway	-99.5mm +121mm

2.4.2 Real Flights

The aircraft used during the experiments was an ISAE-SUPAERO Robin DR400 with 160 HP. The same aircraft is used by the students during their training at the PPL (Fig. 4).

Figure 2: DR400 cockpit reproduced identically; real (top) and virtual (bottom).

Figure 3: VRtigo : the virtual flight simulator.

Figure 4: DR400 used during the experiment.

2.5 Experimental Protocol

2.5.1 Real Flights

For each real flight, three people were present on the plane: the participant in the front left seat, a flight instructor (FI) acting as a safety pilot on the right front seat, the experimenter in the back seat. They first received a briefing, then completed their pre-flight inspection, before finally receiving the ECG electrodes. LSL's Matlab Viewer application displayed ECG data in real time, which was necessary to ensure data consistency throughout the flight. The first data check was performed between engine start and taxi. In a nominal case, these checks lasted 20 seconds. The data recordings began during the aircraft's first take-off and ended during the last landing. The experimenter in the rear seat monitored the ECG and flight data throughout the flight to ensure that the data collected was consistent. All four flights were conducted on sunny days, in CAVOK (Ceiling and Visibility OK) conditions (no obstructing cloud ceilings and visibility greater than 10 km). There was sometimes a strong crosswind (16 G 24 kt, 30° off-axis, meaning a wind at 16 knots, gusting to 24 knots, direction 30° off the runway axis). Temperatures rose to 36°C in the cockpit on the ground. The flight experience was approved by the European Aviation Safety Agency (2403 2424 2487-EASA 0010011661).

2.5.2 Virtual Reality

The virtual reality flights were conducted in a temperature-controlled room. Three people were inside the room:

- the participant (on the VRtigo platform),
- the experimenter monitoring ECG data and aircraft configuration,
- the safety technician that controls the correct functioning of the moving platform (ready to interrupt the simulation at any time by pressing an emergency stop button).

The weather conditions were CAVOK, and no wind was programmed. The recordings were switched on and off at the same time as the real flights.

2.6 Data Analyses

2.6.1 Electrocardiogram

The electrocardiogram (ECG) data were processed both in terms of time period (HR: Heart Rate) and heart variability (HRV: Heart Rate Variability). HR and HRV are indicators generally used to report on the mental workload and stress of the pilot (without, however, distinguishing between the two sources of variation) (Scannella et al., 2018; Togo and Takahashi, 2009). Usually, studies report an increase of HR and a decrease of HRV (i.e. lower variability) as task demand gets higher (Scannella et al., 2018; Togo and Takahashi, 2009; Durantin et al., 2014).

Concerning the HRV, there are several metrics to study it in the time domain. Some of these metrics, for example the SDNN (Standard Deviation of the Normal R-R intervals), are more suitable for long-term analysis. The SDNN analysis would require several hours of recording for a correct analysis (Ismail, 2012). Others metrics, like RMSSD (Root Mean Square of the Successive Differences of the R-R intervals) are meanly used for short-term analysis. In our case (60 seconds flight phases), the RMSSD seemed the most suitable as it requires only a few minutes of recording (Ismail, 2012), and is the most commonly used in this kind of analysis. The use of HR and HRV requires only the recording of R-R intervals. From a technical point of view, this is convenient because the R peaks are the easiest to detect and almost insensitive to noise. The R-R intervals of the raw ECG signal were detected using the built-in QRS detection algorithm of the KubiosHRV software. To eliminate missed R peaks, false positives, and noise, the KubiosHRV software's *strong* filter was applied to the acquired raw data set. We then plotted the average HR (in beats per minute) and HRV (RMSSD, in ms) values in the 60-second windows of each of the three phases for each pattern.

3 RESULTS

The results were evaluated and displayed using Microsoft Excel and Matlab software. In the graphs that will follow and that allow to compare the real flights with the virtual reality, we have respected the following color code for better readability: the real-world

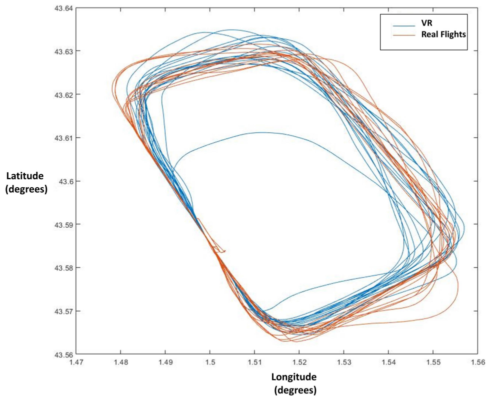

Figure 5: Cumulative trajectories in virtual reality (blue) and real flights (orange).

results are depicted in orange, and the virtual reality results are depicted in blue.

3.1 Flight Parameters

The flight parameters have not been fully exploited for the moment. They were used in this study for the extraction of the three flight phases by the analysis of the following parameters: longitude, latitude, altitude, heading, and power. We then only visually checked the trajectories to verify their coherence between real and virtual reality flights (Fig. 5).

3.2 Subjective Measures

The results of the questionnaire evaluating the difficulty felt to carry out the three phases of flight (Take-off, Downwind, Landing) can be found in Figure 6.

3.3 Cardiac Activity

The Figures 7 and 9 represent the comparative balance between the real world and virtual reality measurements of average HR (heart rate) and average HRV (heart rate variability). The abscissa corresponds to the three phases of flight: Take-off, Downwind, Landing.

4 DISCUSSIONS

4.1 Subjective Measures

The answers to the questionnaire (fig. 6) disclosed that in both environments (real and virtual), the pilot students experienced, on average, a lower level of difficulty in carrying out the downwind phase. They thus found that the phases close to the ground (take-off and landing) were the most difficult, with higher reported difficulty for the landing. Such findings are consistent with previous experiments (Scannella et al., 2018; Dehais et al., 2008).

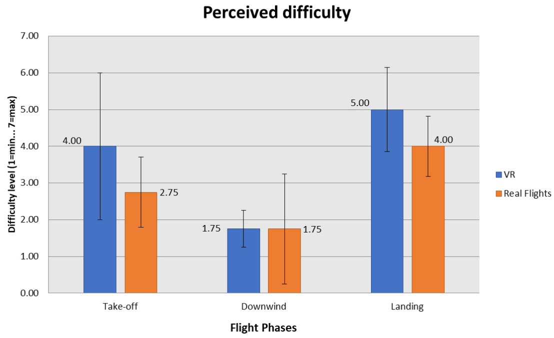

Figure 6: Difficulty felt for the realization of the flight phases (1:very easy ... 7:very difficult).

Looking now in more detail at the difference between real and virtual reality (Fig. 6), our participants reported a similar level of difficulty in the downwind leg. On the other hand, each of the phases close to the ground (take-off and landing) was found to be more difficult to achieve in virtual reality than in the real condition. One reason could rely on a lower level of experience when using the VR simulator than the real airplane. Another reason could be related to some limitation of the virtual reality simulator noted during a previous study (Labedan et al., 2018). In particular, the low graphic resolution of the VR headset negatively impacts pilots' ability to read the value of the speed. They also experienced difficulty to grasp and interact with the throttle and flap lever. We also noted, during post-flight discussions with the pilots, that the sensations during the phases of flight close to the ground, essentially the landing, were not completely realistic, even with the 6-axis moving platform. The ground effects were not simulated realistically enough, which may have disturbed the pilots to flare the plane during landing.

4.2 Cardiac Activity

4.2.1 HR

As far as the real flights were concerned, the HR analyses showed that the closer the plane was to the ground, the higher the HR was, with a maximum for landing (orange in figure 7). Indeed, the mean HR in real flight was 6.3% higher (take-off) and 8.3% higher (landing) than during the downwind phase. These results were consistent with previous findings reported during a traffic pattern experiment in real flight con-

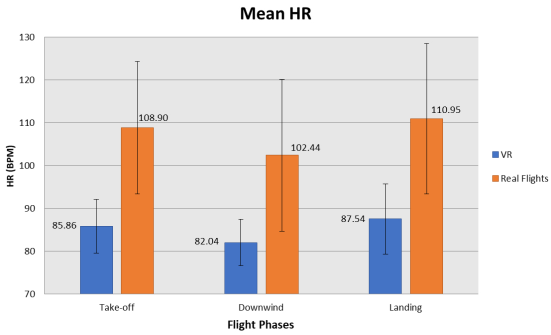

Figure 7: Mean HR (Real flights and VR).

ditions (Scannella et al., 2018). For virtual reality flights, it was interesting to note that the comparison of these three phases was of the same order of magnitude as for real flights with respectively an increase of 4.66% (take-off) and 6.71% (landing) compared to the downwind phase, with a maximum for landing. In both environments (virtual and real), the HR of the downwind phase was, therefore, lower than that of the other two phases and maximum for landing. We also noted, both in VR and in real flight, that the evolution of the HR following the three flight phases tended to be similar.

The HR analysis also revealed a gap between virtual reality and real flights (fig. 7). The HR was higher in real flight by about 27%, 25%, and 27% respectively for take-off, downwind, and landing compared to virtual reality (fig. 8). This result could be interpreted as a lack of feeling of immersion experienced by participants in the VR condition. However, it is important to mention that the real flights were performed with crosswinds, especially for two of the pilots (16 G 26 kt at 30° from the runway axis). The crosswind induced in return higher mental demand (constant correction of trajectories). These aerological differences conditions could thus explain this difference between VR and reality findings.

4.2.2 HRV: The RMSSD Parameter

The analysis of the mean RMSSD during the real fight condition (orange bars in Figure 9) disclosed higher values in downwind than during the take-off and landing phases, with a minimum for landing. These results for real flights were again similar to (Scannella et al., 2018). The results in virtual reality (Fig. 9, the blue bars), followed a similar law than in real flight but with higher average RMSSD in downwind than during the take-off and landing phases, and a minimum for landing. Again, these results seem to suggest that the real flight condition induced higher mental demand and psychological stress than in the simulated condition.

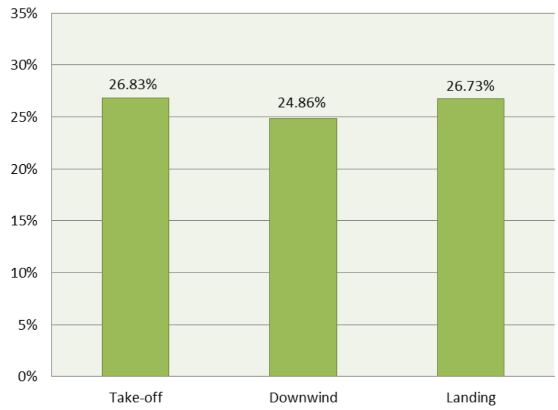

Figure 8: Percentage increase in mean HR between virtual and real flights, by flight phase.

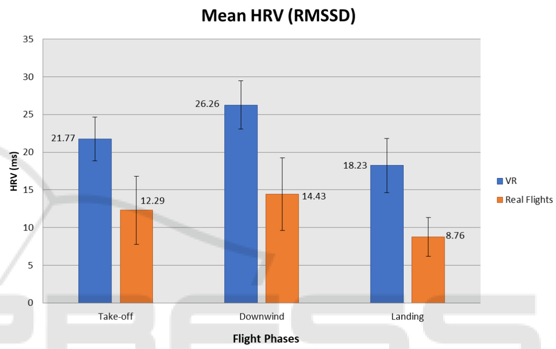

Figure 9: Mean HRV (real flights and VR).

The analysis of the RMSSD (Fig. 9) also revealed a gap between real flights and virtual reality. The RMSSD values were on average 56%, 54%, and 48% lower in reality than in VR. This is also in line with the results of the HR analysis, but with a stronger (and reversed) lag.

4.3 Motion Sickness

None of the pilots reported motion sickness after using the VRtigo platform during the experiments. Our sample of pilots was too small, so this result will need to be confirmed on larger samples in future experiments.

4.4 Conclusions and Perspectives

This preliminary study provided encouraging results for the use of virtual reality as a training tool for pilots. Though we had only four participants, the subjective and physiological findings were consistent with previous real flights experiment (Scannella et al., 2018; Dehais et al., 2008). Indeed, during the three flight phases studied (take-off, downwind, landing), the physiological parameters (HR and HRV) and the subjective data (difficulty felt) evolved in the same way. Then, similarly to (Gateau et al., 2018), higher physiological responses were found in real flight compared to simulated conditions. However, comparisons between real and virtual reality flights disclosed that these physiological responses followed a similar pattern between the two conditions.

This study thus mainly contributed to the implementation of an experimental protocol and the acquisition of experience for real flight and VR measurements. The future experiments will also be conducted with an eye tracker in both conditions to compare the pilot's scan pattern. Indeed, pilot's attention is a key issue for flight safety (Peysakhovich et al., 2018; Dehais et al., 2008; Dehais et al., 2020) and there is a need to measure to what extent VR can affect it. For instance, we plan to use portable eye tracking system both in the VR environment (Tobii eye tracking VR system) and real flight environment (Tobii pro glasses 2). Our goal is to perform basic eye movement (fixation and saccades) as well area of interest (AOIs) based analyses to compare pilot's scanning in the two conditions. Moreover, flight parameters will also be studied more closely to provide other performance metrics (eg. comparison of the moments of action on flap management according to the flight phases, maintaining speed and altitude, ...). Eventually, other subjective measures (stress, mental workload, fatigue) should be collected in the future to better interpret the findings.

In order to achieve an almost perfect simulation, the problem of the hard-to-read anemometer will have to be solved. This can be a modification of the flight simulator or a higher resolution helmet (expensive). The ground texture will have to be richer if future research requires flying under VFR navigation.

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REFERENCES

Banos, R., Botella, C., Perpina, C., Alcaniz, M., Lozano, J., Osma, J., and Gallardo, M. (2002). Virtual reality treatment of flying phobia. *IEEE Transactions on Information Technology in Biomedicine*, 6(3):206–212.

Cha, M., Han, S., Lee, J., and Choi, B. (2012). A virtual reality based fire training simulator integrated with fire dynamics data. *Fire Safety Journal*, 50:12 – 24.

Dehais, F., Causse, M., and Pastor, J. (2008). Embedded eye tracker in a real aircraft: new perspectives on pilot/aircraft interaction monitoring. In *Proceedings from The 3rd International Conference on Research in Air Transportation. Fairfax, USA: Federal Aviation Administration*.

Dehais, F., Duprès, A., Blum, S., Drougard, N., Scannella, S., Roy, R. N., and Lotte, F. (2019). Monitoring pilot's mental workload using erps and spectral power with a six-dry-electrode eeg system in real flight conditions. *Sensors*, 19(6):1324.

Dehais, F., Juaneda, S., and Peysakhovich, V. (2020). Monitoring eye movements in real flight conditions for flight training purpose. In *1st International Workshop on Eye-Tracking in Aviation*.

Durantin, G., Gagnon, J.-F., Tremblay, S., and Dehais, F. (2014). Using near infrared spectroscopy and heart rate variability to detect mental overload. *Behavioural brain research*, 259:16–23.

Gateau, T., Ayaz, H., and Dehais, F. (2018). In silico vs. over the clouds: on-the-fly mental state estimation of aircraft pilots, using a functional near infrared spectroscopy based passive-bci. *Frontiers in human neuroscience*, 12:187.

Grantcharov, T. P., Kristiansen, V. B., Bendix, J., Bardram, L., Rosenberg, J., and Funch-Jensen, P. (2004). Randomized clinical trial of virtual reality simulation for laparoscopic skills training. *British Journal of Surgery*, 91(2):146–150.

Hays, R. T., Jacobs, J. W., Prince, C., and Salas, E. (1992). Flight simulator training effectiveness: A meta-analysis. *Military Psychology*, 4(2):63–74.

Hodges, L., Watson, B., Kessler, G., Rothbaum, B., and Opdyke, D. (1996). Virtually conquering fear of flying. *IEEE Computer Graphics and Applications*, 16(6):42–49.

Ismail, A. (2012). *Intérêt de la variabilité du rythme cardiaque comme marqueur de risque*. PhD thesis.

Kozak, J. J., Hancock, P. A., Arthur, E. J., and Chrysler, S. T. (1993). Transfer of training from virtual reality. *Ergonomics*, 36(7):777–784.

Labedan, P., Dehais, F., and Peysakhovich, V. (2018). Evaluation de l'expérience de pilotage d'un avion léger en réalité virtuelle. In *ERGO'IA*.

Lawrynczyk, A. (2018). *Exploring Virtual Reality Flight Training as a Viable Alternative to Traditional Simulator Flight Training*. PhD thesis, Carleton University.

Meshkati, N. (1988). Heart rate variability and mental workload assessment. In Hancock, P. A. and Meshkati, N., editors, *Human Mental Workload*, volume 52 of *Advances in Psychology*, pages 101 – 115. North-Holland.

Peysakhovich, V., Lefrançois, O., Dehais, F., and Causse, M. (2018). The neuroergonomics of aircraft cockpits: the four stages of eye-tracking integration to enhance flight safety. *Safety*, 4(1):8.

Peysakhovich, V., Monnier, L., Gornet, M., and Juaneda, S. (2020). Virtual reality versus real-life training to learn checklists for light aircraft. In *1st International Workshop on Eye-Tracking in Aviation*.

Postal, G. R., Pavan, W., and Rieder, R. (2016). A virtual environment for drone pilot training using VR devices. In *2016 XVIII Symposium on Virtual and Augmented Reality (SVR)*. IEEE.

S Galasko, C. (2000). Competencies required to be a competent surgeon. *Annals of the Royal College of Surgeons of England*, 82:89–90.

Scannella, S., Peysakhovich, V., Ehrig, F., Lepron, E., and Dehais, F. (2018). Assessment of ocular and physiological metrics to discriminate flight phases in real light aircraft. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 60(7):922–935.

Silverstein, J. C., Dech, F., Edison, M., Jurek, P., Helton, W., and Espat, N. (2002). Virtual reality: Immersive hepatic surgery educational environment. *Surgery*, 132(2):274 – 277.

Togo, F. and Takahashi, M. (2009). Heart rate variability in occupational health —a systematic review. *Industrial Health*, 47(6):589–602.

Varjo (2020). A new era in astronaut training. *https://varjo.com/boeing-starliner*. Accessed: 2020-10-22.