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VIRTUAL REALITY APPLICATION IN PILOTAGE TRAINING: A COMPARATIVE ANALYSIS OF REAL FLIGHTS

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Abstract. Virtual reality technology has been in a development trend since 1966 when it was used as a flight simulator. Since this technology emerged as a training area, has been used in the public sector for 25 years. According to the purpose of study, three main flight stages are determined. These are take-off stage, controlling air movements in traffic pattern, approach and landing stage. External and internal controls, engine start, taxi and take-off tasks are analysed under take-off stage. Climb, ascending, and cruise flight, low and normal bank turns, turns in climb and descent, speed altitude tracking tasks are analysed under controlling air movements in traffic pattern. Triangulation tracking, approach pattern, landing, and leaving the runway, taxiing tasks are analysed under approach and landing stage. Forty one pilotage students are analysed, and the findings showed a statistical difference between VR and real flight performances in Speed Altitude Tracking, Approach Pattern tasks that real flight scores were relatively higher. Additionally, a statistical difference was found between VR and Real Flight Performances related to Approach and Landing stage different from two other stages. To summarize, a significant similarity in terms of grades between VR and real flight experience was found excluding two tasks.

Keywords: virtual reality, real flight, pilotage training, flight stages, flight tasks.

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1. Introduction

The airline pilot, who is also the operation's manager, is the most crucial factor in term of pilotage. An airplane pilot also named as flight instructor who has more than 5000-hour flight experience except type rating and general training communicates with air traffic control, and dispatchers according to the rules of air traffic services by monitoring second captain as light officer and the flight crew. The pilot should be aware of all hazards that might jeopardize air safety. The study covers virtual reality (VR) technology in the usage of pilotage training. VR technology, as the foremost for the reality significant software system, has increased the development of information displays rapidly since the third industrial revolution. Since the 21st century, display technologies have properly developed from ray tubes to flat panels from liquid crystal display (LCD) to organic light-emitting diode (OLED) (Chen et al., 2018). In the 2010s, new technologies have been widespread not only for flat panels but also for more innovative systems such as next generation displays. These innovative systems provide the interaction between the user and their ambient environment (Cakmakci & Rolland, 2006). These developments are pioneers of the VR display as the field of view (FOV) by transiting the whole environment into a fast-moving virtual experience. The advanced version was designed for the users as an advanced version of a real-life experience that was produced according to the VR technology by adding tactility. This version is defined as Augmented Reality (AR). AR provides tactility not only for high-quality vision performance but also presents software like the real world with tactility digital specifications. The optical technology improvements and the user's experience increased the number of AR and VR display examples (Zhan et al., 2020). Virtual reality (VR) technology has been used in training for over 50 years, although the awareness is in low level. Despite cheap prices, several shortcomings arose in the technology level and logistics related to distribution of these products globally (Kavanagh et al., 2017). This technology was not new because the first VR application was manufactured in 1966 as a flight simulator. Afterward, it emerged in the United States in the training area of the Air Force (Page, 2000). Besides, VR technology has taken place in the public sector for approximately 25 years. In 1991, the specialized arcade game series took a position in the market by Virtuality Group Company (Kushner, 2014; West, 1995). This game series was not successful and continued with different versions for only two years (West, 1995).

Besides, SEGA also produced a head-mounted display (HMD) related to VR in 1993. Some game studios worked on this software, but they never released it to the market (Horowitz, 2004). In July 1995, Nintendo launched a new game system named Virtual Boy on the market. It was a VR-based system, and all samples related to monochromatic HMDs were evaluated as a commercial fall and sales were stopped fewer than six months after their release date. Between 1966 to the first decade of 21st century, commercial VR systems has not become successful due to the low level of awareness (Kushner, 2014), however, some investigations related to the usage of VR in training area earned positive findings. They are increasing experiences time-on-task (Huang et al., 2010; Johnson et al., 1998), pleasure (Apostolellis & Bowman, 2014; Ferracani et al., 2014), motivation (Cheung et al., 2013; Jacobson & Holden, 2005; Sharma et al., 2013), deep learning, and retention with a long-term period. Although the emergence of these positive outcomes, VR systems have never earned their common acceptance in the training sector until 2010 (Huang et al., 2010; Rizzo et al., 2009). To sum up, the introduction section includes information about VR technology with descriptive specific samples. Additionally, in the literature review section, the development of VR products, and the usage of VR technology samples are defined in detail historically.

2. Literature review

VR and AR are the primary cutting-edge technological developments available today, and they have significant potential to enhance the training system. Training industry has a chance to use technology-enhanced learning due to growing usage of AR and VR (Tan et al., 2022). Additionally, allowing trainers to tailor their learning methods to each trainer's unique learning style, AR and VR expose trainers to immersive digital experiences that are not possible to replicate through traditional methods (Phakamach et al., 2022). This helps trainers better engage with complex environment different than the real environment (Sun et al., 2023). These equipments not only make learning more immersive, but they also give trainers the chance to conduct virtual field excursions and deliver simulations without real usage (Seidametova et al., 2021). Furthermore, the application of AR and VR technologies can close the knowledge gap between conventional training and practical experience, offering observable advantages for the professional strategies (Al-Ansi et al., 2021).

From second decade of 21st century, the technologies of VR, AR, and mixed reality (MR) have advanced significantly because of increases in processing power. The phrase "extended reality" technology has garnered a lot of interest because of encompassing VR, AR, and MR technologies more broadly. It covers an immersive, fully artificial, computer-simulated image and environment with real-time interaction in accordance with a developed VR technology (Khor et al., 2016).

Nowadays, aircraft cockpits include safer processes with improved and well-planned interfaces. Due to these interfaces, the production expenses and the finalized costs reached the highest level. These complicated developments measure the cycles that change the old processes as higher expenses. So, these measures can affect the design of innovative products. The general outcomes of these products include already perfect interfaces. The knowledge about these interfaces should create new innovative products as soon as possible. Hence, the flight deck designation provides the interfaces of human-machine improvements on human factors feedback, including ergonomics, usage ability, and cognitive perspective in the design processes of manufacturing the products (Reuzeau & Nibbelke, 2004). The improvement of these products increased the human factor assessment strategies and their designations. They should be selected cautiously to interrelate with vital resources (Kelly, 2004). Firstly, it is essential to specify the proper simulation level adherence of the design maturity and improvement stage. Secondly, the human factor strategy needs to be determined (Oberhauser & Dreyer, 2017). The methods for nominative inquiries are NASA-TLX and SART, while the other collected inquiries are physiological variables such as gaze behavior and heart rate. The assignment of integration ratios related to time and error needs a wide selection of applications to compose strategically successful outcomes. In civil aviation, cockpit and cabin crews, engineers, and maintenance personnel need to train with experience in particular areas. The efficiency of these areas in terms of evaluation and feedback is related to the vigorous experiments. Hence, the assessment of subject matter experts (SME) includes minor samples, which turns to operational strategies for the suggested resolution (Reuzeau & Nibbelke, 2004).

When the past studies were examined, Dreyer et al. (2014) explained the feasibility of the flight technology system and the stages that can be applied to this system. Additionally, Aslandere et al. (2014) evaluated the simulation stages by applying the human-machine display interface, optic examination, and following systems related to the interior design of the VRFS. This stage consists of a virtual cockpit, outside visual, and pilot capability. Some of the required hardware components are used in this VR system as flight control panels. VR prepares almost the same environment as the real one, and the assumed components create the mixed model. All these constituents are maintained within the systematic VR structure (Quigley, 2009; Quigley et al., 2009). The system ensures the management of these hardware elements, flight indicators as external hardware and software components without fail (Oberhauser & Dreyer, 2017). Therefore, the VR system evaluates the design process related to engineering, cockpit visuals, and human-machine interface elements (Oberhauser et al., 2015, 2016).

These processes include various flight stages suitable for the cockpit and deal with challenging elements arising from the virtual framework. So, it is revealed that the simulator flights are compared to whether the actual flight scores are similar or not. The study points out that this system can be successfully performed by evaluating the pilot's situational awareness decision-making processes and flight performance. In the acceleration of flight stages and adaptation for different types of aircraft, the processes should be used in harsh weather conditions. The VFRS system ensures the best planning of human factors engineering in the early stages of the application process. In particular, after the pilot training that ends with the PPL and ATPL licenses, getting aircraft-type training provides training practice for students. Therefore, trying different aircraft types at type training will increase the situational awareness, knowledge, and ability of a student pilot. The compliance of actual flights related to the simulator ones provides easy practice and nearly has no cost except for the first purchase. Despite all the positive assessments, the primary issues include the measurement of performance and workload according to actual, and simulator flights. When applying VR, the most accurate scoring is based on actual, and simulated flights with the correct valuation. The reason why this research was designed is related to the evaluation of all flight stages to ensure the practice of actual and simulator flights. So, it is needed to evaluate the positively developing applications in VR technology. In addition to the above information, the master's thesis that was written by Hélène sought out whether VR is a potential tool for piloting training. According to the thesis, VR applications can also perform in marketing purposes in the retail sector, surgical training in the health sector, psychology, and psychotherapy, in marketing and promotional activities, planning, management, and entertainment activities in the tourism sector, and training activities in defense and public safety and related fields (Trinon, 2019).

Furthermore, VR simulators that use pilot training can categorize full-flight simulators with realistic mobility. They are also fixed-based simulators with similar features to full flight simulators, but without motion features that include only one software. ASL Airlines took part in research to use the VR application in pilot training due to the purchase costs of these simulators. According to this research, they were not portable and cheap for flight training programs in small companies, so the costs of purchasing this service are relatively expensive. Besides this information, VR equipment like gloves and headset (a device like VR glasses) with sensors detect finger movements in the simulator. According to these sensors elements such as fluidity, interaction, and sensitivity features can be used. These features have been tested by the technical pilots of ASL. These tests have revealed additional adjustments for the VR applications, which are a potential tool in pilotage training (Trinon, 2019). Another study focuses on human factors engineering in cockpit design with VR concepts using VR glasses and other motion tracking systems. Cockpits are safety-critical products with advanced and well-researched user interfaces. Production costs and final product prices are high due to high-quality standards for both hardware and software. The development of human-machine interfaces in cockpit design requires feedback in terms of human factors (usability, ergonomics, etc.) in the early stages of design (Reuzeau & Nibbelke, 2004).

Oberhauser and Drayer (2017) used different methods to analyze human factors in cockpit design with a VR concept. After the simulator experiences, subjective surveys such as NASA-TLX (NASA Payload Index) and SART (Situational Awareness Rating Technique) were applied to users. In addition, it is possible to have information about the gaze behavior, the number of glances and transitions, and the pilot workload by using eye-tracking. Therefore, data based on gaze behavior emerges as a method for obtaining visual data for the cockpit. Physiological data such as heart rate, which can easily be measured with a pulse sensor attached to the ears of the pilots, and psychological concepts such as mental load and effort can also be evaluated (Jorna & Hoogeboom, 2004). Thus, a suitable environment will provide human-machine development in the interfaces of the cockpit design's early stages with both subjective and objective methods (Oberhauser & Drayer, 2017).

"Design and Development of the F-16 Combat Pilot Training System: First Views" was presented at the conference named "Advances in Human Dynamics for Progress in Contemporary Societies" about Portuguese Air Force's F16 pilots "Joint Helmet Mounted Cueing System" during flight. The collected data had great importance, so pilots could see possible hazards and warnings. This importance has increased because the high costs of actual flights cannot be practiced by trainers enough (Raposo et al., 2021). In VR, there is no contact with the actual environment, and data completely transfers to the hardware used for VR so that the user is not confused with the environment contact. Also, VR hardware can be used in any environment. In conclusion, the necessity of using a VR flight simulator that can transmit data with higher efficiency, accuracy, and more varied shapes and colors has emerged from the interviews with the pilots and the related research (Martins et al., 2020). In the semi-structured interviews with the pilots, open-ended questions are asked to trainers, and a prototype is prepared according to the features, which is a result of diversified interface reviews. These prototypes have been tested so that pilots can understand the features and environment related to the interface (Raposo et al., 2021). The requirements of this usage test are as follows:

VR hardware should be developed by adding both cockpit and airplane views, the provided data must be accurate, additionally, speed, altitude, and time should be evaluated in terms of the performance level. The most basic requirement for the interface; is for the simulation to be as close as possible to actual flight visualizations through VR glasses, developing the color scale by adding new colors rather than the green color that are used in other simulations sush as in night vision, implementing the comparison of data suitable for this mode, adding suitable data to unlikely emergencies and extraordinary situations in the simulator, and developing the tactile senses (Trinon, 2019).

3. Data and methodology

Flight evaluations started with taxiing, which is one of the real training flight tasks. During taxiing, the speed, heading and whether the aircraft left the taxiway or not were evaluated. Afterwards, the students were expected to take off, during which time, maintaining the runway centerline, speed tracking, and the rotation technique were observed. Then, the students were expected to climb along the runway line, then join the traffic pattern, and make a pattern by obeying the visual references. In the meantime, the student's speed altitude tracking and the extent to which he/she followed the visual references were evaluated. Afterwards, the students participate in the approach and configuration were observed. Then, the student made the landing and during this landing, the place where he/she put the wheel on the runway and the speed altitude were monitored. Finally, it was expected to leave the runway and park the aircraft in a suitable parking area. All evaluations in VR flights were applied according to the checklist and SOP (standard operating handbook) procedures of Diamond Aircraft DA20 aircraft suitable for the procedures in real flights.

In the study, real flight term is used for physical flights, and VR flight term is related to the usage of 4K view that were obtained by virtual reality glasses and computer system. In real flights, the recording time was taken as 01:00 block time (between chock-in and chock-out time-period). In 01:00 block time, 00:45 minutes is related to flight, and 00:15 minutes is related to taxi stages. In VR flights, the recording time was taken between 4 minutes 18 seconds to 9 minutes 6 seconds with an average of 7 minutes 12 seconds in the same aerodrome, and route planning of real flights. The selected 11 flight stages include the most basic flight movements, and they were analyzed under 3 main titles according to the stages of flight. These stages are mentioned below.

3.1. Take-off stage

1. External and Internal Controls: It is the setting of the necessary systems before the aircraft engine start and requesting permission from the tower for engine start.
2. Engine Start: It is the safe starting of the aircraft engine and then checking the working engine values.
3. Taxi and Take-off: Bringing the aircraft safely to the runway and waiting point in line with the ground markings. Then, it is to request take-off permission from the tower, and wheel off (or take-off) by maintaining the centre line of the runway.

3.2. Controlling air movements in traffic pattern

1. Climb, Ascending, and Cruise Flight: It is the transition of the aircraft to level flight after reaching the target altitude by following the appropriate speed values after cutting the wheels.
2. Low and Normal Bank Turns: It is related to turn by giving the required bank angle to participate in the square tour and maintaining the distance to the runway.
3. Turns in Climb and Descent: In case of climbing and descending, it is to turn by maintaining the required distance.
4. Speed Altitude Tracking: It is providing the coordination between the straight flight speed of the aircraft by maintaining the altitude of the square altitude +1000 feet during the square tour.

3.3. Approach and landing stage

This stage starts when an aircraft descends below 5,000 feet above ground level (AGL) with the aim to direct an approach and ending when the aircraft safely leaves the landing runway, or the pilot directs a go around and ascends the aircraft above 5,000 feet AGL enroute to destination airport.

1. Triangulation Tracking: It is the monitoring of some geographical shapes on the earth to ensure that the pilot candidates do not go beyond the distance limits during the square tour.
2. Approach Pattern: When approaching the landing phase, pilot candidates adjust themselves according to the runway and altitude.
3. Landing: Pilots do a visual approach and landing safely on the runway.
4. Leaving the Runway and Taxiing: After landing, the aircraft slows down safely and leaves the runway by following the directions on the ground (Diamond Aircraft Industries Inc., 2012).

A Bayesian approach was adopted to compare the performance of participants in two different flight conditions: Virtual Reality (VR) and Real Flight. Given the ceiling effects observed in the initial analysis using frequentist methods, Bayesian statistics were employed to better capture the potential differences between the two conditions while incorporating prior knowledge and accounting for uncertainty in the estimates. To compare the task-based flight performance between the VR and Real Flight conditions, a Bayesian paired-samples analysis was utilized. This method allows for the incorporation of prior information, and it generates posterior distributions, which provide a more comprehensive understanding of the uncertainty surrounding the differences between the two groups. This analysis was chosen due to its ability to handle potential ceiling effects by estimating the posterior distribution of the difference in means, rather than relying on point estimates and p-values alone. Statistical analyses were performed by using the pymc3 package of Python programming language (Salvatier et al., 2016).

4. Findings

In the history of VR usage, the design and specifications of VR simulators, and the usage of interface applications, are very effective and powerful tools, especially for flight-measuring performance in pilotage training (Raposo et al., 2021). In the study, it was benefited from three airports located in Turkey that are also used by Atlantic Flight Academy in pilotage training. These are Çorlu, Edremit, and Bursa Yenişehir Airports. In all airports, the comparisons were applied according to VR, and real flight experience by applying an analysis for 41 pilotage students. If a student flew at Çorlu Airport in real life, he/she flew at the same airport in VR. To gain the best outcome, after the student finished the PPL (Private Pilot License) flights, the VR flights were completed in the same aerodrome, and technological environment suitable for real flight experience. Some of the figures about VR flight images are:

Figures between 1 to 15 were obtained from BAP.2021.03.07 Scientific Research Project (Bahcesehir University, 2021) for the purpose of showing sample scenes

Figure 1. Çorlu Airport Cruise Phase

Figure 2. Çorlu Airport Landing Phase

Figure 3. Çorlu Airport Take Off Phase

Figure 4. Edremit Airport Take Off Phase

Figure 5. Edremit Airport Cruise Phase (VR)

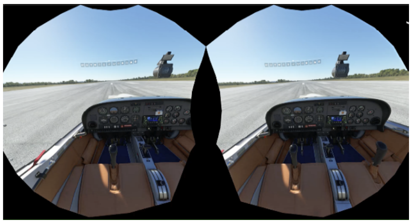

Figure 6. Çorlu Airport Take Off Phase (VR)

Figure 7. Çorlu Airport Landing Phase (VR)

Figure 8. Çorlu Airport Cruise Phase (VR)

Figure 9. Bursa Yenişehir Airport Take Off Phase

Figure 10. Bursa Yenişehir Airport Landing Phase

Figure 11. Bursa Yenişehir Airport Cruise Phase

Figure 12. Edremit Airport Cruise Phase

Figure 13. Edremit Airport Landing Phase

Figure 14. Edremit Airport Take Off Phase (VR)

Figure 15. Edremit Airport Cruise Phase (VR)

including three airports that were analyzed by virtual reality equipment. Two pilots who have ATPL license were evaluated the outcomes of real flights and VR flights by benefiting the Atlantic Flight Academy Real Flight Grades. With an average of 7 minutes 12 seconds visual recording for 41 students in 4K view were taken by using virtual reality glasses and computer system to obtain the best outcome to compare with the real flights that were completed in contracted flight school Atlantic Flight Academy (BAP.2021.03.07 Scientific Research Project).

All the figures were obtained by using the VR Simulator. The analysis was applied to 41 students and all of them flight in Atlantic Flight School Academy, which is a partnership of the Bahcesehir University. All figures were obtained from the airports located in Turkey.

According to the Figures as mentioned above, the same three airport were selected, which were the same as the real flights' airports to create the same environment. Figure 1 shows Çorlu Airport cruise phase. Figure 2 shows Çorlu Airport landing phase. Figure 3 shows Çorlu Airport take off phase. Figure 4 shows Edremit Airport take off phase. Figure 5 shows Edremit Airport cruise phase with VR equipment. Figure 6 shows Çorlu Airport take off phase with VR equipment. Figure 7 shows Çorlu Airport landing phase with VR equipment. Figure 8 shows Çorlu Airport cruise phase with VR equipment. Figure 9 shows Bursa Yenişehir Airport take off phase. Figure 10 shows Bursa Yenişehir Airport landing phase. Figure 11 shows Bursa Yenişehir Airport cruise phase. Figure 12 shows Edremit Airport cruise phase. Figure 13 shows Edremit Airport landing phase. Figure 14 shows Edremit Airport take off phase with VR equipment. Figure 15 shows Edremit Airport cruise phase with VR equipment. VR equipment figures were analyzed according to the usage of high resolution (4K) virtual reality glasses by using full motion of finger and feet configurations, the other figures were analyzed by using the computer system.

Based on the Bayesian analysis of mean differences between Virtual Reality (VR) and Real Flight performance across various flight stages in Table 1, credible intervals were calculated to estimate the magnitude and uncertainty of these differences. In the Take-Off Stage, the posterior mean difference for "External and Internal Controls" was 0.07 with a 95% credible interval of [–0.01, 0.16], suggesting that while VR scores tended to be slightly higher, the true difference might be negligible. Similarly, for "Engine Start," the mean difference was 0.10, but the credible interval [–0.02, 0.22] indicates uncertainty about the presence of a substantial difference. For the task "Taxi and Take-off," the mean difference was –0.07 with a wider credible interval of [–0.32, 0.17], suggesting no clear evidence of a difference.

In the Controlling Air Movements in Air Traffic Pattern Stage, most tasks showed no strong evidence of a difference between VR and Real Flight performances, as the credible intervals all included zero. For "Speed Altitude Tracking," however, a clear difference was observed with a mean difference of –0.41 and a credible interval of [–0.67, –0.16], indicating that real flight scores were significantly higher than VR scores with 95% probability.

In the Approach Pattern, a significant difference was found in the "Approach Pattern" task. The posterior mean difference was –0.39 with a 95% credible interval of [–0.66, –0.12], indicating that real flight performances were notably superior to VR. The credible interval does not include zero, providing strong evidence that the difference between VR and real flight for this task is meaningful.

Significant differences were found in the Approach and Landing Stage and Evaluation Time, where Real Flight outperformed VR in task performance and required significantly more time for evaluation in Table 2. Other stages, such as Take-Off, Controlling Air Movements, and General Evaluation, did not show strong evidence of performance differences between VR and Real Flight, as the credible intervals included zero, indicating uncertainty in these comparisons.

In the real flight evaluation method, points are given as 1, 2, 3 and 4 out of 4. The reason why pilot candidates get high scores in real flights is due to their own high per-

Table 1. Grade comparison of task-based flight stages

–	–	Mean Difference VR-Real Flights	
	–	Mean, Variance	95% Credible Interveal
Take-off stage	External and Internal Controls	0.07, 0.002	–0.01; 0.16
	Engine Start	0.10, 0.004	–0.02; 0.22
	Taxi and Take-off	–0.07, 0.015	–0.32; 0.17
Controlling air movements in air traffic pattern	Climb, Ascending and Cruise Flight	–0.02, 0.014	–0.26; 0.21
	Low and Normal Bank Turns	0.05, 0.012	–0.17; 0.27
	Turns in Climb and Descent	–0.10, 0.011	–0.30; 0.11
	Speed Altitude Tracking	–0.41, 0.016	**–0.67; –0.16**
Approach and landing stage	Triangulation Tracking	–0.24, 0.017	–0.50; 0.02
	Approach Pattern	–0.39, 0.019	**–0.66; –0.12**
	Landing	–0.17, 0.028	–0.50; 0.16
	Leaving the Runway and Taxiing	–0.17, 0.011	–0.37; 0.03

Table 2. Grade comparison of general flight scores

–	Mean Difference VR-Real Flights	
	Mean, Variance	95% Credible Interveal
Take-off stage	0.03, 0.004	–0.09; 0.16
Controlling air movements in air traffic pattern	–0.12, 0.009	–0.31; 0.06
Approach and landing stage	–0.24, 0.010	**–0.44; –0.04**
General evaluation	–0.12, 0.005	–0.27; 0.02
Evaluation time (minute)	–52.82, 0.028	**–53.15; –52.49**

formance. In addition, if they receive a score such as 1, 2 in real flight, the relevant flight training sortie must be repeated. Due to the narrowness of the evaluation scale, the score given to the students can be interpreted as ceiling. Since simulation technologies are difficult to access and costly, the aim in the study is to try primary 11 tasks of the flight with VR simulations before starting real flights, thus increasing the performance of the students. In addition, pilots were not given any time for practice. This factor was caused pilots to get low scores. The pilots were not accompanied by any instructor pilots or supervisors. Therefore, the pilots may or may not have seen their mistakes themselves. Therefore, their scores were low. The evaluation period is applied to the students approximately the duration of 1 traffic pattern activity. In real flights, students apply six of these tasks in their 1-hour flights. The focus of the research is on how the VR flights of the students compare with their real flights. Duration is only considered as a supporting factor.

Figure 16 compares the mean scores of different flight stages between VR and real flight performances. The stages are categorized as take-off, controlling air movements in traffic pattern, and approach and landing. In speed altitude tracking, triangulation tracking, and approach pattern, real flight scores are higher than VR flights. In landing task, real flight scores are slightly higher than VR flights. According to other 7 tasks, the scores are nearly same between real and VR flights.

External and Internal Controls: Both VR and real flights have similar mean scores, indicating a close similarity in performance.

Engine Start: The mean scores are very close for VR and real flights, showing minimal difference in this task.

Taxi and Take-off: Both tasks show nearly identical performance levels for VR and real flights.

Climb Ascending and Cruise Flight: Scores are highly similar between VR and real flights.

Low and Normal Bank Turns: Minimal difference between VR and real flight scores.

Turns in Climb and Descent: Both VR and real flights show a similar performance.

Speed Altitude Tracking: There is a noticeable difference, with real flight scores being higher than VR scores.

Triangulation Tracking: Scores are slightly higher for real flights.

Approach Pattern: Real flight scores are higher compared to VR flights.

Landing: The scores are relatively close, with showing a slight advantage for real flights.

Leaving the Runway and Taxiing: VR and real flights show nearly identical scores.

Figure 17 compares the general flight scores and evaluation time between VR and real flight performances. The categories include take-off stage, controlling air movements in traffic pattern, approach and landing stage, general evaluation, and evaluation time. In approach and landing stage, and evaluation time (minute), there are significant differences, and real flight scores are higher than VR flights. In controlling air movements in traffic pattern, and general evaluation, real flight scores are slightly higher than VR flights. In take-off stage, the scores are nearly same between real and VR flights.

Take-Off Stage: The mean scores are nearly identical, indicating similar performance in both VR and real flights.

Controlling Air Movements in Traffic Pattern: Scores are very close, with real flights showing a slight advantage.

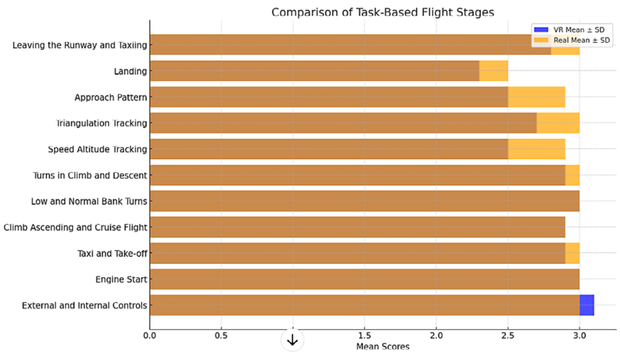

Figure 16. Comparison of task-based flight stages

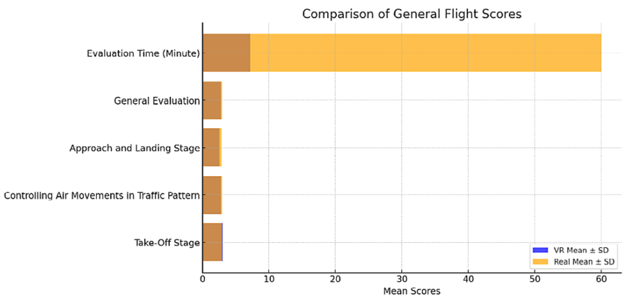

Figure 17. Comparison of general flight scores

Approach and Landing Stage: There is a notable difference, with real flight scores being higher than VR scores.

General Evaluation: The scores are quite similar, with real flights showing a slight advantage.

Evaluation Time (*Minute*)*:* There is a significant difference in evaluation time, with real flights taking substantially longer than VR flights.

5. Conclusions

VR enables the technological application of real-life experience in a virtual space similar to reality by repeating as much as necessary nearly in the same environment in terms of real life. Therefore, it is significant to use VR-related equipment to perform VR flight experiences with lots of practice. So, the current rules applied in real flight trials will increase the training qualification experience of various aircraft types. This study focuses on the implementation methods that are determined for using technologically advanced VR hardware in benchmarking flights by benefiting from VR equipment. Actual flights improve students' cognitive abilities by increasing difficulties in different scenarios (planning, route selection, weather conditions, etc.). Besides, VR flights can improve students' cognitive abilities nearly the same level under different scenarios according to the usage of Microsoft Flight Simulator Premium Deluxe 40th Anniversary Edition.

Especially at the end of real flights, scoring the processes is significant to obtain outcomes from VR hardware in the same environment at real flights. So, this hardware can perform nearly the same scoring in terms of real flights, increasing the pilotage students practice related to the 2 main purposes. The primary purpose is to show how VR experience can enhance the knowledge and skills for pilotage students by observing them. The secondary purpose is to develop the VR system for pilotage students according to the new enhancements in real flight experiences. Correspondingly, students can benefit from this system related to future technology in pilotage training. Besides, the other students who are interested in this area can use this technological system. The importance of this study is to evaluate and configure the need for information and communication technology that is related to future VR. The increasing interest in this technology can be carried out under sustainability criteria. The effective usage of cognitive skills will increase the training qualification with experience in various aircraft types. The study analyses the capabilities of a VR Flight Simulator (VRFS) with the comparison of real flights that are carried out in flight school. The pilot's reaction time, deviation from the optimum flight routes, emergency procedures in unexpected situations, and advanced technology are evaluated by creating different operational scenarios. This evaluation aims to compare the statistical diversity of the flight routes, solve the altitude problem, fly under severe weather conditions, and plan routes during the control process. Although performing safe and effective flight duties seems easy in VR technology, it can be determinant for demonstrating possible situations during flight time and indicate the importance of human factors in terms of VRFS.

According to the findings that cover the grade comparison of task-based flight stages, a statistical difference was found between VR and real flight performances in terms of Speed Altitude Tracking, Approach Pattern tasks, and real flight scores were relatively higher than VR according to the p values ($p < 0.05$). According to the findings that cover grade comparison of general flight scores, a statistical difference was found between VR and real flight performances related to Approach and Landing Stage. Take-Off Stage and Controlling Air Movements in Air Traffic Pattern in terms of VR experience show high similarity to real flight experience. Despite the duration difference, the outcomes according to grade comparison are relatively the same excluding Approach and Landing Stage. Speed Altitude Tracking, and Approach Pattern tasks show a statistical difference between VR and real flight experience. Real flight grades are higher than VR flights in these two tasks. Approach and Landing stage show a statistical difference, however other two stages show high similarity. The average of real flight grades according to the four tasks in the approach and landing stage is higher than VR flights. In future studies, VR technology can combine with AI or augmented reality, and new observations and experiences can be obtained from all pilotage students. Especially studying pilotage and adaptation processes to nowadays technology will accelerate taking advantage of future trends. In rapidly developing VR technology, pilot performance in real flights according to the flight stages can be examined by using Augmented Reality including tactility.

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Author contributions

Corresponding Author: Investigation, writing, original draft preparation, reviewing and editing, supervision, resources, methodology, validation, software, and formal analysis.

Second Author: Conceptualization, data curation, image processing, and visualization.

Disclosure statement

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References

Al-Ansi, A. M., Garad, A., & Al-Ansi, A. (2021). ICT-based learning during Covid-19 outbreak: Advantages, opportunities and challenges. *Gagasan Pendidikan Indonesia*, *2*(1), 10–26. https://doi.org/10.30870/gpi.v2i1.10176

Apostolellis, P., & Bowman, D. A. (2014). Evaluating the effects of orchestrated, game-based learning in virtual environments for informal education. In *ACE '14: Proceedings of the 11th Conference on Advances in Computer Entertainment Technology* (pp. 1–10). ACM Press. https://doi.org/10.1145/2663806.2663821

Aslandere, T., Dreyer, D., Pankratz, F., & Schubotz, R. (2014). A generic virtual reality flight simulator. In *Virtuelle und Erweiterte Realität* (Vol. 11, pp. 1–13) (Workshop der GI-Fachgruppe Tagung Band). Shaker Verlag.

Bahcesehir University. (2021). *The usage of virtual reality system in pilotage training* (Scientific Research Project, BAP.2021.03.07). Bahcesehir University.

Cakmakci, O., & Rolland, J. (2006). Head-worn displays: A review. *Journal of Display Technology*, *2*(3), 199–216. https://doi.org/10.1109/JDT.2006.879846

Chen, H. W., Lee, J. H., Lin, B. Y., Chen, S., & Wu, S. T. (2018). Liquid crystal display and organic light-emitting diode display: Present status and future perspectives. *Light: Science & Applications*, *7*(3), Article 17168. https://doi.org/10.1038/lsa.2017.168

Cheung, S. K., Fong, S., Fong, J., Wang, W., & Kwok, L. F. (Eds.) (2013). *Hybrid learning and continuing education* (Vol. 8038). Springer. https://doi.org/10.1007/978-3-642-39750-9

Diamond Aircraft Industries Inc. (2012). *Airplane flight manual Diamond Aircraft DA20-C1*. https://encoreflight.com/wp-content/uploads/2017/06/Pilot-Operating-Handbook-Diamond-DA20.pdf

Dreyer, D., Oberhauser, M., & Bandow, D. (2014, July). HUD symbology evaluation in a virtual reality flight simulation. In *Proceedings of the International Conference on Human-Computer Interaction in Aerospace* (pp. 1–6). ACM Digital Library. https://doi.org/10.1145/2669592.2669652

Ferracani, A., Pezzatini, D., & Del Bimbo, A. (2014). A natural and immersive virtual interface for the surgical safety checklist training. In S. Göbel & W. Effelsberg (Eds.), *Proceedings of the 2014 ACM International Workshop on Serious Games* (pp. 27–32). ACM Press. https://doi.org/10.1145/2656719.2656725

Horowitz, K. (2004). *Sega VR: Great idea or wishful thinking?* Sega-16 Forum. https://www.sega-16.com/2004/12/sega-vr-great-idea-or-wishful-thinking/

Huang, H. M., Rauch, U., & Liaw, S. S. (2010). Investigating learners' attitudes toward virtual reality learning environments: Based on a constructivist approach. *Computers & Education*, *55*(3), 1171–1182. https://doi.org/10.1016/j.compedu.2010.05.014

Jacobson, J., & Holden, L. (2005). The virtual Egyptian Temple. In *Proceedings of the World Conference on Educational Media, Hypermedia & Telecommunications* (*ED-MEDIA*). Semantic Scholar. https://pdfs.semanticscholar.org/e4cb/929440177f9ea9a87ac5eacb6f4f33977e98.pdf

Johnson, A., Roussos, M., Leigh, J., & Vasilakis, C., Barnes, C., & Moher, T. (1998). The NICE Project: Learning together in a virtual world. In *Proceedings of IEEE 1998 Virtual Reality Annual International Symposium* (Cat. No. 98CB36180). IEEE. https://doi.org/10.1109/VRAIS.1998.658487

Jorna, P. G. A. M., & Hoogeboom, P. J. (2004). Evaluating the flight deck. In *Human factors for civil flight deck design* (pp. 235–275). Ashgate.

Kavanagh, S., Luxton-Reilly, A., Wuensche, B., & Plimmer, B. (2017). A systematic review of virtual reality in education. *Themes in Science and Technology Education*, *10*(2), 85–119.

Kelly, B. D. (2004). Flight deck design and integration for commercial air transport. In D. Harris (Ed.), *Human factors for civil flight deck design*. Routledge.

Khor, W. S., Baker, B., Amin, K., Chan, A., Patel, K., & Wong, J. (2016). Augmented and virtual reality in surgery – the digital surgical environment: Applications, limitations and legal pitfalls. *Annals of Translational Medicine*, *4*(23). https://doi.org/10.21037/atm.2016.12.23

Kushner, D. (2014). Virtual reality's moment. *IEEE Spectrum*, *51*(1), 34–37. https://doi.org/10.1109/MSPEC.2014.6701429

Martins, N., Martin-Sanroman, J., & Suárez-Carballo, F. (2020). The design process in the improvement of the experience between a brand and its target audience through a digital product: The Lexus Portugal's used car website case study. *Advances in Science*, *Technology and Engneering Systems Journal*, *5*(5), 620–629. https://doi.org/10.25046/aj050576

Oberhauser, M., & Dreyer, D. (2017). A virtual reality flight simulator for human factors engineering. *Cognition*, *Technology* & *Work*, *19*(2), 263–277. https://doi.org/10.1007/s10111-017-0421-7

Oberhauser, M., Dreyer, D., Convard, T., & Mamessier, S. (2016). Rapid integration and evaluation of functional HMI components in a virtual reality aircraft cockpit. In *Advances in ergonomics in design* (pp. 17–24). Springer. https://doi.org/10.1007/978-3-319-41983-1_2

Oberhauser, M., Dreyer, D., Mamessier, S., Convard, T., Bandow, D., & Hillebrand, A. (2015, August). Bridging the gap between desktop research and full flight simulators for human factors research. In *International Conference on Engineering Psychology and Cognitive Ergonomics* (pp. 460–471). Springer. https://doi.org/10.1007/978-3-319-20373-7_44

Page, R. L. (2000). Brief history of flight simulation. In *SimTecT 2000 Proceedings* (pp. 11–17). Semantic Scholar.

Phakamach, P., Senarith, P., & Wachirawongpaisarn, S. (2022). The metaverse in education: The future of immersive teaching & learning. *RICE Journal of Creative Entrepreneurship and Management*, *3*(2), 75–88.

Quigley, M. (2009). ROS: An open-source Robot Operating System. In *ICRA Workshop of the Open Source Software* (ICRA). ResearchGate.

Quigley, M., Conley, K., Gerkey, B., Faust, J., Foote, T., Leibs, J., & Ng, A. Y. (2009, May). ROS: An open-source robot operating system. In *Workshops at the IEEE International Conference on Robotics and Automation* (Vol. 3, p. 5). BibSonomy.

Raposo, D., Martins, N., & Brandão, D. (2021). *Advances in human dynamics for the development of contemporary societies*. Springer. https://doi.org/10.1007/978-3-030-80415-2

Reuzeau, F., & Nibbelke, R. (2004). Flight deck design process. In *Human factors for civil flight deck design* (pp. 33–55). Ashgate.

Rizzo, A. A., Bowerly, T., Buckwalter, J. G., Klimchuk, D., Mitura, R., & Parsons, T. D. (2009). A virtual reality scenario for all seasons: *The virtual classroom*. *CNS Spectrums*, *11*(1), 35–44. https://doi.org/10.1017/S1092852900024196

Salvatier, J., Wiecki, T. V., & Fonnesbeck, C. (2016). Probabilistic programming in Python using PyMC3. *PeerJ Computer Science*, *2*, Article e55. https://doi.org/10.7717/peerj-cs.55

Seidametova, Z. S., Abduramanov, Z. S., & Seydametov, G. S. (2021, July). Using augmented reality for architecture artifacts visualizations. In *CEUR Workshop Proceedings*. KDPU. https://doi.org/10.31812/123456789/4626

Sharma, S., Agada, R., & Ruffin, J. (2013). Virtual reality classroom as a constructivist approach. In *Proceedings of the 2013 IEEE Southeastcon* (pp. 1–5). IEEE. https://doi.org/10.1109/SECON.2013.6567441

Sun, J. C. Y., Ye, S. L., Yu, S. J., & Chiu, T. K. (2023). Effects of wearable hybrid AR/VR learning material on high school students' situational interest, engagement, and learning performance: The case of a physics laboratory learning environment. *Journal of Science Education and Technology*, *32*(1), 1–12. https://doi.org/10.1007/s10956-022-10001-4

Tan, Y., Xu, W., Li, S., & Chen, K. (2022). Augmented and virtual reality (AR/VR) for education and training in the AEC industry: A systematic review of research and applications. *Buildings*, *12*(10), Article 1529. https://doi.org/10.3390/buildings12101529

Trinon, H. (2019). *Immersive Technologies for Virtual Reality – Case study: Flight simulator for pilot training* [Master's Thesis, Hec Liege, Management School].

West, N. (1995). AOU: Coin-op houses unveil '95 line-up. *NEXT Generation*, *6*(June). https://archive.org/details/nextgen-issue-006#page/n23/mode/2up

Zhan, T., Yin, K., Xiong, J., He, Z., & Wu, S. T. (2020). Augmented reality and virtual reality displays: Perspectives and challenges. *Iscience*, *23*(8), Article 101397. https://doi.org/10.1016/j.isci.2020.101397