Original Article

Effect of Pilot Expertise on Visual Scanning and Precision of Flight Maneuvers in Military Aviation

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Abstract: This study explored how expertise affects visual scanning strategies and the precision of flight maneuvers in military aviation. A total of 38 French Air Force pilots of three different expertise levels performed horizontal and vertical maneuvers in a flight simulator. Flight performance analysis showed that novices had larger deviations in roll, heading, and speed compared to cadets and experts, underlining the role of expertise on the precision of flight maneuvers. Eye-tracking analysis revealed that expert pilots used more efficient gaze strategies, focusing on key parameters such as pitch and power. Our results suggest that eye-tracking could significantly enhance pilot training by providing insights into expertise-specific visual behaviors. Future work will explore the use of real-time eye-tracking data to deliver immediate feedback, guiding pilots' visual focus during training.

Keywords: eye-tracking, pilot expertise, military aviation, visual scanning strategies

Navigating a military aircraft requires pilots to keep a persistent watch over the cockpit controls in order to maintain awareness of the situation and identify any imminent dangers, such as system malfunctions or approaching traffic (Dubois, 2017; Wickens & Alexander, 2009). Novice pilots are trained to effectively distribute their attention across the various instruments within the cockpit. However, the depth of their expertise is a function not only of their ability to monitor the flight instruments but also of their efficiency in prioritizing relevant information, which distinguishes them from their less experienced counterparts (Hua et al., 2022). Beyond these operational considerations, expertise also plays a fundamental role in ensuring safety by enabling pilots to anticipate and mitigate potential risks, particularly in high-stress environments where quick decision-making is critical (Kennedy et al., 2010; Schriver et al., 2008; Tolton, 2014). This efficiency is further amplified by the capacity of expert pilots to detect and prioritize diagnostic cues – critical features that indicate potential hazards or necessary actions – more proficiently than less experienced pilots (Wiggins & O'Hare, 2003). For example, expert pilots excel at identifying and categorizing essential information, such as shifts in weather patterns or system anomalies, and can swiftly distinguish between pertinent and extraneous data (Morrison et al., 2013; Pauley et al., 2009). Their ability to concentrate on diagnostic cues facilitates quicker and more accurate decision-making, even under time constraints, by minimizing cognitive load and mitigating information overload (Wiggins, 2014; Wiggins & Henley, 1997). This advanced information-processing capability is supported by various theoretical models. Ericsson and Kintsch's (1995) theory of long-term working memory suggests that experts can easily access acquired memory skills in long-term memory by means of retrieval cues in short-term memory. In addition, Haider and Frensch's (1996) information reduction hypothesis posits that experts are adept at filtering out irrelevant information, thereby reducing cognitive load. Moreover, Kundel and colleagues' (2007) holistic model of image processing elucidates that experts utilize both foveal and parafoveal vision for an initial global analysis, leading to more targeted extraction of finer details. By contrast, novices tend to have a more erratic approach to visual scanning, marked by unnecessary fixations and saccades. Their performance in dynamic situations is often inferior, which Klein's (1993) theory of recognition-primed decision attributes to their inability to quickly match current situational features with patterns stored in long-term memory (Gobet, 2011).

In an experimental context, eye-tracking technology has been instrumental in understanding various aspects of how pilots process information and adapt their visual strategies in response to cognitive load (Allsop & Gray, 2014; Allsop et al., 2017; Björklund et al., 2006; Diaz-Piedra et al., 2019; Haslbeck et al., 2012; Lounis et al., 2021; Tole

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et al., 1982) and expertise (Bellenkes et al., 1997; Fitts et al., 1950; Rayner, 1998; Wierda et al., 2012). Focusing on expertise, the seminal study by Fitts et al. (1950) was a landmark, showing that expert military pilots tended to have shorter fixations that were more frequently directed toward the flight instruments. This discovery has been the basis for further research on visual scanning strategies in aviation. For example, Bellenkes et al. (1997), Rayner (1998), and Wierda et al. (2012) have shown that expert pilots possess advanced scanning strategies, characterized by efficient information acquisition through shorter and more frequent instrument checks. Ziv (2016) corroborated these insights, highlighting that gaze behavior could distinguish between novice and expert pilots.

Studies indicate that expert pilots exhibit more efficient and systematic ocular behavior patterns compared to novices during flight maneuvers (Haslbeck & Zhang, 2017; Lounis et al., 2021; Ziv, 2016). Yet, in the military domain, there is a lack of comprehensive research on the distinct ways expert and novice pilots apply their gaze behavior across the various cockpit instruments, particularly during fighter-specific flight maneuvers. This is of interest as it has implications for a better understanding of the determinants of flight performance and for the refinement of training policies. Therefore, this work aimed to add to the scientific literature on the effect of expertise on the piloting and ocular behavior of military pilots with varying levels of expertise. Participants performed a series of maneuvers executed on an SR20 flight simulator, both horizontal (left and right turns) and vertical (climbs and descents), which are typically taught during military training. This approach is particularly relevant given that significant variations in gaze behavior have been observed with task difficulty, especially among pilots in the early stages of their career (Ayala et al., 2023). The uniqueness of our research lies in the inclusion of actual pilots from the French Air Force, allowing for a nuanced analysis of expertise variation within a military population. Our research hypotheses were:

Hypothesis 1 (*H1*): More experienced military pilots will outperform their less experienced counterparts, reaching a higher maneuvering accuracy, as evidenced by superior control over trajectory, speed, and altitude during maneuvers (Fitts et al., 1950; Kasarskis, et al., 2001; Schriver et al., 2008).

Hypothesis 2 (*H2*): In addition to better maneuvering accuracy, more experienced pilots will display different scanning strategies, including more efficient information processing with shorter fixations, more frequently directed toward areas of interest (AOIs) directly linked to the ongoing maneuver (Haslbeck & Zhang, 2017; Lefrançois et al., 2021; Ziv, 2016).

Figure 1. An Air Force Captain engaged in the experiment using the experimental flight simulator. The head-mounted eye tracker is visible.

Method

Participants

A total of 38 pilots (36 male and two female pilots) from the French Air Force with varying levels of expertise participated in the study. The sample consisted of 15 novice student pilots (mean age = 24; *SD* = 1.65; mean flight hours on Cirrus SR20/22 = 10.18), 12 cadet pilots (mean age = 22.91; *SD* = 2.23; mean flight hours on Cirrus SR20/22 = 45.18), and 11 expert instructor pilots (mean age = 31.7; *SD* = 3.19; mean flight hours on Cirrus SR20/22 = 520.9). All participants had normal visual acuity. This study was conducted in accordance with established ethical standards and approved by the military hierarchy; all participants received an information letter and provided informed consent prior to participation. Ethical approval was also granted by the Ethics Committee for Research (CER) of the University of Toulouse (reference number: 2023_689, June 20, 2023).

Apparatus

Participants were equipped with a head-mounted Pertech eye tracker (Pertech, Mulhouse, France) operating at 50 Hz with a 0.25°–0.5° accuracy (Figure 1). For technical reasons, the head-mounted eye tracker was chosen because it provided sufficient accuracy and robustness for capturing gaze behavior in this study. Participants did not report any discomfort or interference while performing the tasks. Moreover, integrating an external eye tracker into the simulator would have been too complex and would have required removing it after each experiment to avoid

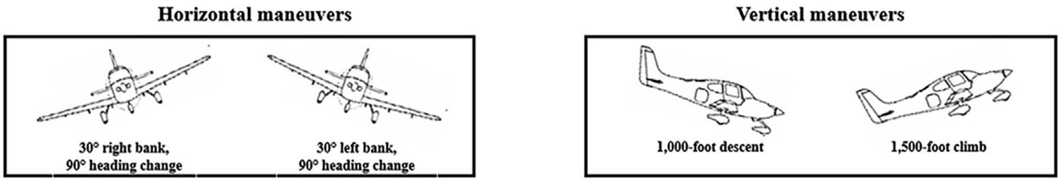

Figure 2. Aircraft maneuvers performed during the experiment. The left panel shows horizontal maneuvers with a 30° left bank and a 30° right bank, requiring a 90° change of heading. The right panel illustrates vertical maneuvers requiring either a 1,000-ft descent or a 1,500-ft climb.

disrupting the normal course of pilot training. The tasks were performed on a flight training device (FTD), which replicates the cockpit environment of a Cirrus SR20 aircraft, run by two Microsoft Windows-based computers. The first was used to display the external environment on three 23-in screens (SYNCMASTER MD230, 60 Hz, 1,920 × 1,080). This external environment was rendered by the flight simulation software Xplane 10.r36. The second computer simulated the Cirrus SR20 glass cockpit on two touchscreen monitors (IIYAMA PLT2250MTS, 60 Hz, 1,920 × 1,080). The glass cockpit (Garmin 1000) was emulated by the SIMAVIO software from the company FlyThisSim. Interaction with Xplane was achieved using Logitec G940 peripherals, which included the joystick, throttle, and rudder pedals.

Flight Task

Participants were seated in the FTD and were asked to maintain a steady flight at a constant speed (125 kt) with a north heading. As done during their usual military training, an experimenter provided instructions that participants immediately applied to complete the required maneuver and then return to a steady flight. The instructions were given using the complete phraseology used by French military instructors to ensure clarity. The maneuvers included standard turns to the left or right, optimal speed ascents ("VOM") and rapid descents ("OPS"). These maneuvers were specifically selected based on recommendations from military flight instructors, as they are commonly used in training programs to develop fundamental piloting skills.

The maneuvers included the following:

- Horizontal maneuvers (Figure 2, left panel) with a turn of 90°, maintaining a 30° bank turn (left or right), and constant altitude and airspeed.
- Vertical maneuvers (Figure 2, right panel) with climbs performed at 115 kt, with an altitude increase of 1,000 ft, and descents at 150 kt, with an altitude decrease of 1,500 feet. Heading had to be maintained constant.

Procedure

After a brief introduction to the study, participants read detailed instructions and then completed a demographic questionnaire, which included their flight hours on the Cirrus SR20/22. Following the briefing, participants spent 5 min in the FTD for practice.

After a familiarization phase, which involved a brief session of steady flight followed by horizontal and vertical maneuvers (similar to those in the test phase) to allow participants to get accustomed to the simulator, they were equipped with the eye-tracking system, and an eight-point calibration of the eye-tracker was performed. The calibration points were located on the primary flight display (PFD), positioned near key instruments such as engine power, bank angle, speed, altitude, and heading, among others. The flight began immediately afterwards, with the same weather conditions (clear skies and no wind) for all participants. Before each experimenter instruction, the stability of the flight was checked. Once all parameters were within the tolerance zone – ensuring level wings and a constant airspeed – the experimenter instructed the next maneuver. The flight consisted of a total of 20 maneuvers (five of each type illustrated in Figure 2), presented in a random order.

Data Analysis

Data Synchronization and Preprocessing

Flight parameters and eye-tracking data were synchronized post hoc. Firstly, fixation filtering was conducted using the open-source Gazealytics software (Chen et al., 2023). The threshold for detecting a fixation on an AOI (Figure 3) was established at 100 ms, in line with the guidelines set by Salvucci and Goldberg (2000). Secondly, synchronization of fixation and maneuver data was achieved through a temporal alignment process using timestamps. Each maneuver was distinctly identified by its start and end timestamps, enabling a function to accurately filter and align the ocular data within these specific temporal boundaries. Consequently, this allowed for a precise determination of fixations occurring during each maneuver. Fixations not aligning with the predefined AOIs within these maneuvers were systematically classified as "Other."

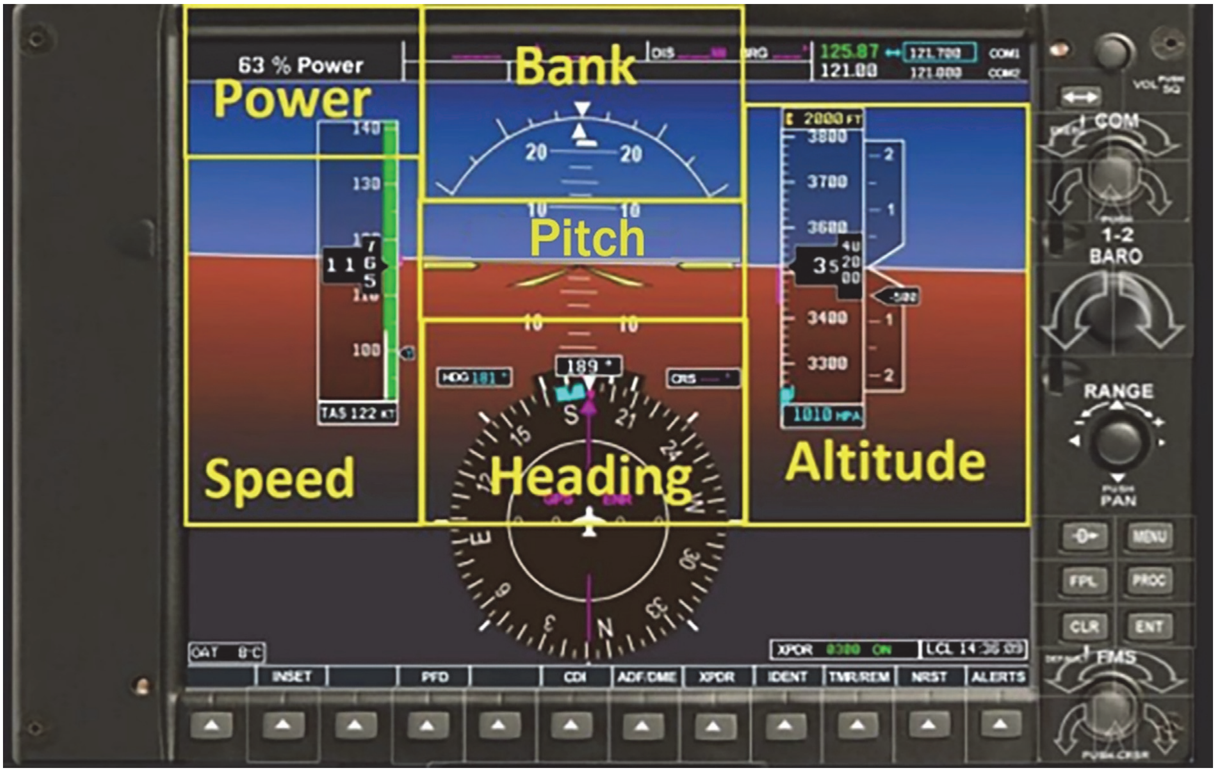

Figure 3. The six areas of interest within the primary flight display cockpit used for the analysis.

Variable Analysis

Due to the non-normality of our data (evaluated with the Shapiro–Wilk test), we used nonparametric tests for our analyses. A series of Kruskal–Wallis tests were conducted to compare both the flight parameters and the ocular metrics among pilots of different levels of expertise. Post hoc Dunn tests, corrected using the Bonferroni method, were then employed to further explore these significant findings.

Flight Parameters: For each maneuver, discrepancies between actual flight parameters (four distinct types) and prescribed instructions were quantified using root mean square errors (RMSEs) to estimate flight accuracy. RMSE was calculated by taking the square root of the average squared deviations between actual and target values for each flight parameter, quantifying the precision of pilots in relation to the instructions. Key flight parameters and their units of measurement are detailed in Table 1. We examined flight metrics directly related to task execution, specifically focusing on RMSE for roll, pitch, altitude, and speed during horizontal maneuvers (left and right turns considered together), and pitch, heading, altitude, and speed during vertical maneuvers (climbs and descents).

Ocular Metrics

In order to further our understanding of the differences in scanning strategies between experts and novices, a detailed analysis of eye movements in relation to the different maneuvers was carried out. Eye metrics were calculated, encompassing fixation duration, fixations per minute, and percentage of dwell times on AOI (power, speed, heading, horizon, bank, altitude and pitch; Figure 3). The dwell time metric corresponds to the total time spent within an AOI, encompassing all fixations until the observer exits it. These metrics were distinctly analyzed across different types of flight maneuvers (horizontal maneuvers, climbs, descents; Figure 2) and among pilot groups of varying expertise (novices, cadets, experts).

Results

Due to calibration issues with the eye-tracking device, data from four novice student pilots and one cadet pilot were excluded from the analyses. The final sample comprised 33 participants, distributed evenly across the three expertise groups.

Flight Parameters

Horizontal Maneuvers

We found a significant main effect of expertise on roll deviation, $\chi^2(2) = 9.10$, $p < .011$, $\eta^2 = .229$ (left panel, Figure 4),

Table 1. Flight parameters and their respective unit of measurements

Flight parameter	Measurement unit	Description	Vertical maneuvers	Horizontal maneuvers
Roll	Degrees	Angle of inclination of the aircraft around its longitudinal axis relative to the horizon		x
Heading	Degrees	Direction in which the aircraft's nose points relative to magnetic north	x	
Speed	Knots	Aircraft's velocity relative to the surrounding air	x	x
Altitude	Feet	Vertical distance between the aircraft and the Earth's surface	x	x
Pitch	Degrees	Angle of the aircraft's nose elevation or depression relative to the horizontal plane	x	x

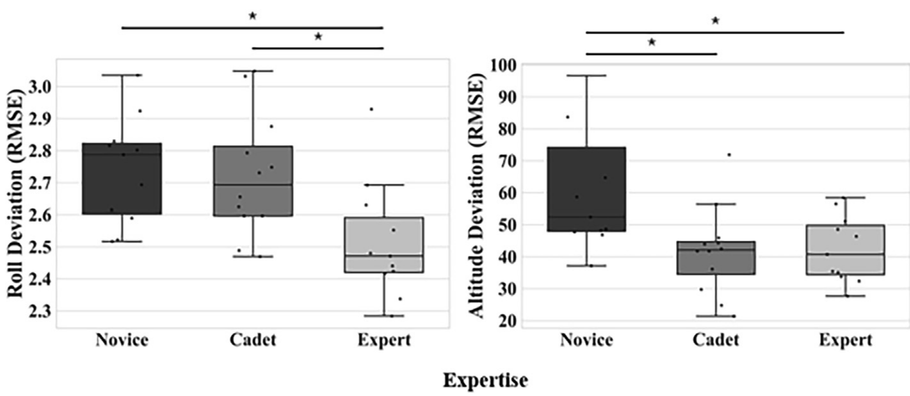

Figure 4. Roll and altitude during the horizontal maneuvers (turns) according to the level of expertise. The dots represent the data for each participant. RMSE = root mean square error.

with novices having a higher deviation than cadets and experts (p = 0.014 and p = 0.018, respectively). We found a significant main effect of expertise on altitude deviation, $\chi^2(2) = 9.52$, $p = .009$, $\eta_p^2 = 0.243$ (right panel, Figure 4), with novices having a higher deviation than cadets and experts (p = .014 and p = .037, respectively). The analyses of the horizontal maneuvers did not show any significant results (all $p > .05$).

Vertical Maneuvers: Descents

For the descents, we found a significant main effect of expertise on heading deviation, $\chi^2(2) = 10.10$, $p = .006$, $\eta_p^2 = 0.261$ (Figure 5), with novices having a higher deviation than cadets (p = .005). The analyses of the descents did not show any significant results (all $p > .05$).

Vertical Maneuvers: Climbs

For the climbs, we found a significant main effect of expertise on speed deviation, $\chi^2 = 7.64$, $p = .021$, $\eta_p^2 = 0.182$ (left panel, Figure 6), with novices having a higher deviation than cadets (p = 0.022). Similarly, heading deviation also showed a significant main effect of expertise, $\chi^2 = 9.13$, $p = .011$, $\eta_p^2 = 0.230$ (right panel, Figure 6), with novices having a higher deviation than cadets and experts (p = .015 and p = .049 respectively). The analyses of the climbs did not show any significant results (all $p > .05$).

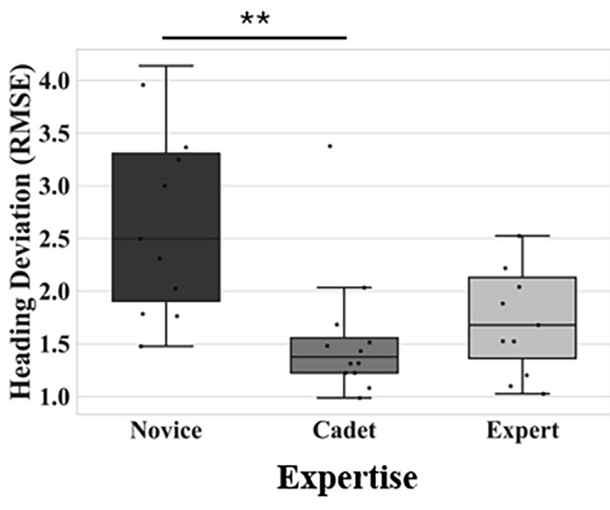

Figure 5. Heading deviations (RMSE) during the descents according to the level of expertise. The dots represent the data for each participant. RMSE = root mean square error.

Ocular Metrics

Fixation Duration and Fixations per Minute

Regarding the average fixation duration and the number of fixations per minute, no significant effects of expertise were found for any type of maneuvers (all $p > .05$; mean fixation duration: 306 ms).

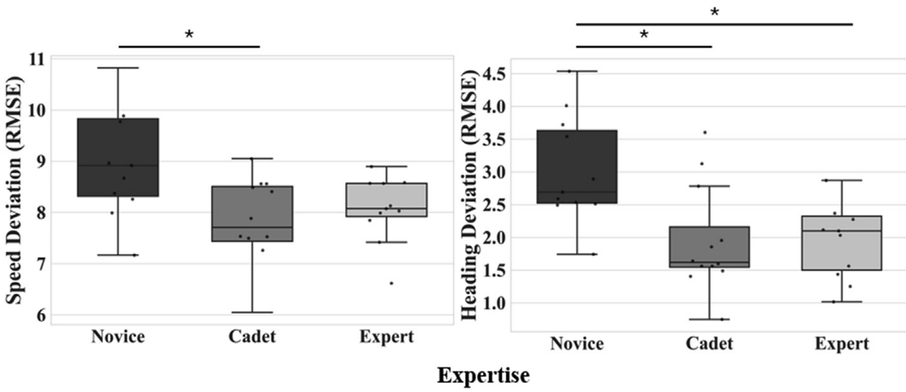

Figure 6. RMSE for speed and heading during climbs according to the level of expertise. The dots represent the data for each participant. RMSE = root mean square error.

Percentage of Dwell Time per AOI

Horizontal Maneuvers

The three most gazed AOIs were altitude (novices: 30.9%; cadets: 30.8%; experts: 28.9%), followed by heading (novices: 29.5%; cadets: 28.9%; experts: 26.1%), and bank (novices: 16.2%; cadets: 15.9%; experts: 20.2%). This is consistent with the objective of the maneuver, which was to keep altitude constant, perform a turn of 90° exactly, and keep an exact bank of 30°. The analyses of the effects of expertise on the percentage of dwell time during horizontal maneuvers did not show any significant results (all $p > .05$).

Vertical Maneuvers: Descents

For the descents, the three most viewed AOIs were altitude (novices: 41.4%; cadets: 40.8%; experts: 34.2%), followed by speed (novices: 24.8%; cadets: 22.6%; experts: 20.5%), and pitch (novices: 9.2%; cadets: 15.3%; experts: 22.1%). This is consistent with the maneuver instructions, requiring pitching down and reaching a specific altitude while maintaining a target speed.

We found a significant main effect of expertise for power, $\chi^2(2) = 6.593$, $p = .037$; $\eta_p^2 = 0.256$ (Figure 7); however, post hoc comparisons did not reveal any significant differences (all $p > .05$). We also found a significant main effect of expertise for pitch, $\chi^2(2) = 8.523$, $p = .014$; $\eta_p^2 = 0.123$ (Figure 7), with novices having a lower percentage of dwell time on this AOI than experts ($p = .011$). The analyses of the descents did not show other significant results (all $p > .05$).

Vertical Maneuvers: Climbs

For the climbs, the three most viewed AOIs are consistent with the descents, as the maneuver is quite similar, with altitude (novices: 38.6%; cadets: 36.5%; experts: 32.0%), followed by speed (novices: 23.1%; cadets: 26.5%; experts: 19.4%), and pitch (novices: 11.0%; cadets: 17.1%; experts: 21.5%). This is consistent with the maneuver instructions, requiring pitching up and reaching a specific altitude while maintaining a target speed.

We found a significant main effect of expertise for power, $\chi^2(2) = 7.52$, $p = .023$; $\eta_p^2 = 0.185$ (Figure 7), with novices having a higher percentage of dwell time on this AOI than cadets ($p = .011$). We also found a significant main effect of expertise for pitch, $\chi^2(2) = 6.592$, $p = .037$; $\eta_p^2 = 0.143$ (Figure 7), with experts having a higher percentage of dwell time on this AOI than novices ($p = .011$). The analyses of the climbs did not show other significant results (all $p > .05$).

Discussion

Our study investigated the impact of expertise on flight performance and ocular behavior among military pilots, utilizing an SR20 flight simulator during maneuvers. This research sheds light on the variations in flight parameter management and ocular behavior among pilots of different expertise levels within the French Air Force.

Expertise and Flight Performance

The results show that novices were significantly outperformed by more experienced pilots during the different flight maneuvers. During horizontal maneuvers, novices deviated more in terms of roll and altitude. During vertical maneuvers, novices also performed worse, deviating more in heading during climbs, compared to cadets and experts. These results clearly evidence the expected finding that novices have poorer accuracy during these complex military flight maneuvers, thus validating Hypothesis 1. Our observations are consistent with the findings of

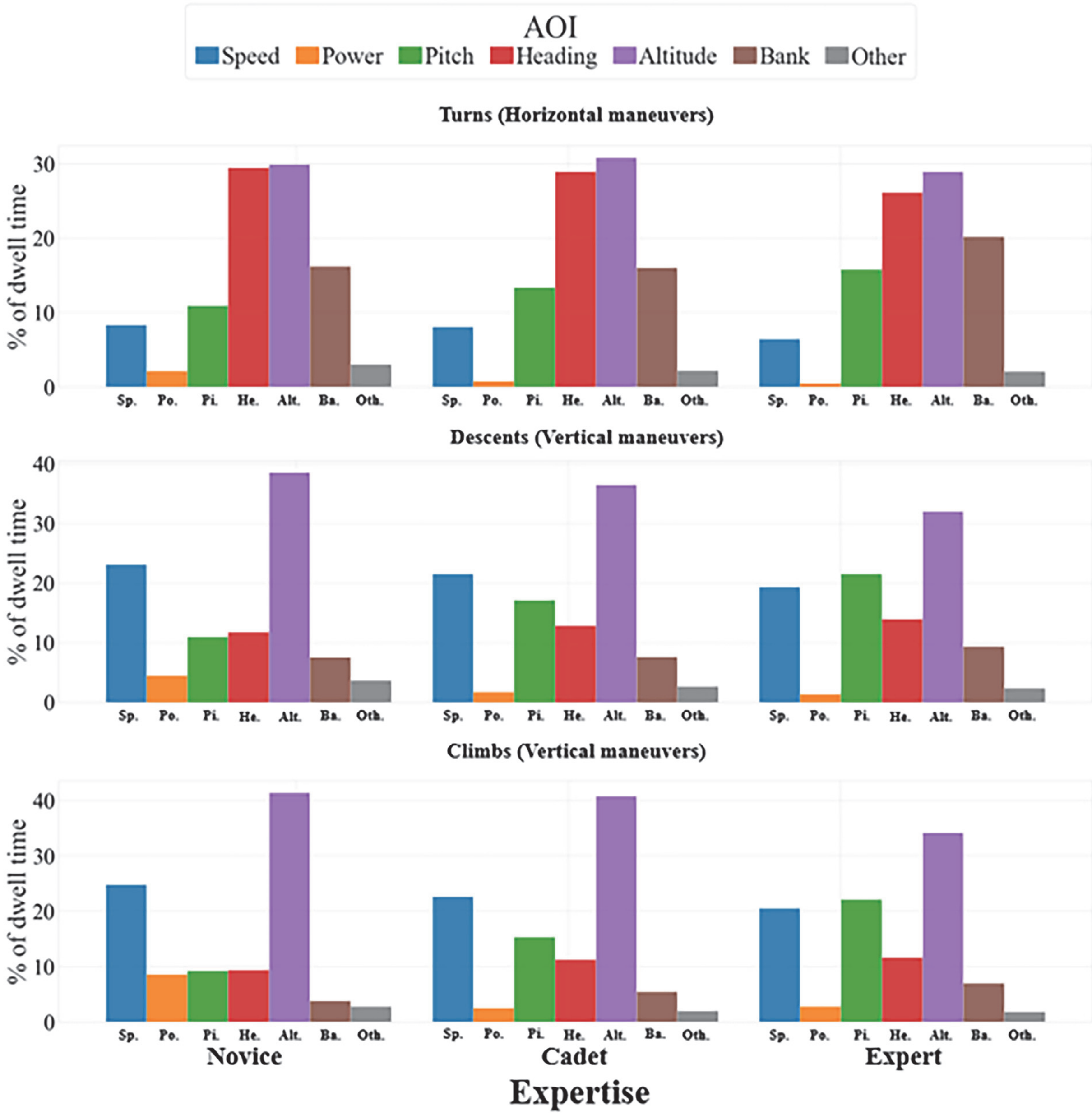

Figure 7. Percentage of dwell times on each area of interest according to the maneuver type and level of expertise. Error bars show ± 1 within-subject standard error of the mean (SEM). Sp. = speed; Po. = power; Pi. = pitch; He. = heading; Alt. = altitude; Ba. = bank; Oth. = other.

Schriver et al. (2008) and Kasarskis et al. (2001), which underscore the profound impact of pilot expertise on the mastery of flight parameters. These studies collectively illustrate how experienced pilots exhibit more precise handling of critical flight dynamics compared to their less experienced counterparts, effectively reducing the likelihood of piloting errors during complex maneuvers.

However, our findings revealed interesting nuances regarding expertise effects. In several analyses, cadets exhibited performance levels comparable to those of experts. Additionally, in two analyses, novices performed worse than cadets but not worse than experts (specifically for heading during descent and speed during climb). This suggests that, at least in a simulation context, comprehensive initial training on simulators, as part of their formal education, effectively equips cadets to perform at levels comparable to, or even slightly better than, expert pilots. This observation highlights the effectiveness and significant advantages of contemporary simulator-based training programs and underscores the importance of targeted training and prior knowledge in achieving high levels of proficiency.

Variability in Ocular Metrics: Insights Into Pilot Expertise

The general analysis of scanning strategies showed a consistent visual focus on key flight parameters aligned with the requirements of each maneuver. During horizontal maneuvers, fixations were particularly focused on heading, bank, and altitude, which is entirely consistent with the objective of the maneuver, executing a 90° turn, maintaining a 30° bank angle, and keeping a constant altitude. Similarly, for vertical maneuvers, the results were fully consistent, with more fixations on altitude, speed, and pitch, which aligns with the fact that they were required to reach a precise altitude, keep a target speed, and maintain a specific pitch for climbing or descending. These results were consistent for both descent and climb maneuvers. This is line with previous research suggesting that task demands strongly influence visual attention, with top-down processes guiding gaze behavior based on the relevance of specific flight parameters to the task at hand (Ballard & Hayhoe, 2009; Groner & Menz, 1985; Haslbeck & Zhang, 2017; Itti & Koch, 2001).

We also observed effects of expertise on eye fixations during vertical maneuvers. During descent and climbs, novices spent a lower proportion of time looking at the pitch compared to experts. This parameter is important to maintain good accuracy in keeping the target altitude and speed. Pitch also provides information on wing alignment relative to the horizon, which impacts heading control. Interestingly, while all participants generally focused on the appropriate indicators for each maneuver, experts seemed to rely more on pitch as an integrated reference rather than monitoring individual instruments separately. The fact that experts focused more on the pitch indicator, despite no explicit instructions to do so, suggests a top-down influence on their ocular behavior (Shapiro & Raymond, 1989; Xiong et al., 2016). This implies that experts recognize the importance of monitoring pitch to maintain optimal control of the aircraft, beyond just gazing at the parameters directly related to the specific maneuvers. This finding raises the possibility that experts might interpret pitch as a synthesized indicator encompassing multiple flight dynamics, such as altitude, speed, and heading. It is very likely that, by leveraging their extensive training and experience, experts can use pitch as an aggregate metric to guide adjustments in other control parameters more efficiently. While this interpretation aligns with theories of expertise, such as long-term working memory (Ericsson & Kintsch, 1995), our study did not explicitly assess whether experts adopt this approach. Future research could incorporate subjective feedback or interviews to explore how experts perceive and utilize pitch in complex flight scenarios. This interpretation is further supported by prior research on expertise and visual scanning strategies. Haslbeck et al. (2012) found that less experienced pilots conducted significantly more systematic instrument checks than their expert counterparts, suggesting that expertise refines visual attention allocation rather than simply increasing the number of fixations. Similarly, Haslbeck and Bengler (2016) demonstrated that pilots predominantly use a vertical tracking strategy, meaning they focus primarily on instruments related to altitude and pitch control, such as the attitude indicator and altitude display. This strategy helps maintain aircraft pitch but can lead to larger deviations on the glideslope, which represents the aircraft's vertical path toward the runway during an instrument landing. This finding aligns with our results, where expert pilots focused more frequently on the pitch indicator, most likely using it as a key reference point for piloting, as it provides an instant picture of the aircraft's orientation and gives clues about its energy state (e.g., a negative pitch may suggest a loss of speed) or vertical motion. This suggests that expertise makes gaze behavior more strategic, potentially improving decision-making in dynamic flight environments. We also found an effect of expertise on the fixations oriented to power during climbs, with novices focusing more on power compared with cadets. Despite this increased fixation on power, novices had greater speed deviations during climb, indicating that these fixations are likely related to difficulties in adjusting power rather than an attempt to gaze more on the speed indicator to minimize deviations. In other words, these increased fixations on speed did not benefit the novices' performance.

Overall, Hypothesis 2 is partially validated, with an effect of expertise on the distribution of fixations across the cockpit, but without an effect on the mean fixation duration or fixation frequency per minute. This partial validation underscores the complexity of visual attention mechanisms and suggests that further research is needed to fully understand the impact of expertise on ocular behavior in different dynamic flight environments.

Finally, it is important to note that while our results indicate that more experienced pilots do not exhibit significantly different outcomes compared to novices on all ocular measures, they nevertheless demonstrate superior performance in a significant portion of flight metrics. This observation suggests that flight expertise, and its influence on ocular behavior, does not follow a simple pattern, as evidenced by the numerous theoretical frameworks attempting to explain expertise (Ericsson & Kintsch, 1995; Haider & Frensch, 1996; Klein, 1993; Kundel et al., 2007). It highlights the complexity of aviation skills and the ability of experienced pilots to maintain high performance levels, even with different ocular strategies.

Limitations

As mentioned, cadets sometimes had a relatively similar performance to experts. These two groups of participants may not be very different in terms of their level of performance. While civilian aviation experts may accumulate over 10,000 flight hours, our experts had approximately 500 hr on the Cirrus SR20/22. This reflects the operational realities of flying this particular aircraft, primarily used in a training context. Furthermore, incorporating more demanding flight situations, varying weather conditions, and unexpected emergency scenarios could help reveal more pronounced behavioral and visual scanning differences between the expertise groups. This approach is supported by studies such as those by Lounis et al. (2021) and Ayala et al. (2023), which demonstrated that novice pilots respond differently to challenging tasks compared to experienced pilots, both in terms of performance and visual strategies.

Surprisingly, no effect of expertise was found on mean fixation duration or fixation frequency per minute. While previous studies (Bellenkes et al., 1997; Fitts et al., 1950) have shown that expertise typically results in shorter fixation durations and higher fixation frequencies, our findings diverge from these results. This may be due to the highly dynamic nature of the task in our study. These maneuvers required continuous monitoring of key flight parameters, such as altitude and heading, to maintain the required flight conditions as instructed. In this context, pilots may have needed to maintain a more sustained focus on the instruments to meet the task demands, unlike in other studies where brief glances suffice, in the present study, a more sustained focus was necessary for effective information extraction. Interestingly, fixation durations were quite short across all participants, typically around 300 ms, suggesting a uniform rapid scanning across different expertise levels. A "ceiling effect" in our simulation could explain the surprising results.

Conclusion

Our study has shed light on the influence of expertise on flight performance and ocular behavior among military pilots using an SR20 flight simulator. The results demonstrate that more experienced pilots exhibit higher maneuver accuracy, with experts employing more effective visual scanning strategies. Importantly, our study shows that expert pilots, unlike novices and cadets, focus more on critical instruments such as the pitch indicator, indicating advanced top-down control and a deeper understanding of flight dynamics. While no significant differences were found in fixation frequency metrics, expertise appears to manifest in the strategic allocation of attention rather than fixation rapidity. This research contributes to the literature on military piloting, emphasizing that proficiency in aviation requires both technical skill and adaptability to varied contexts. These findings highlight the value of simulator-based training and eye-tracking technology in understanding expertise development and improving pilot training through targeted interventions and optimized visual strategies (Sellberg et al., 2022). Future research should explore these dynamics in more complex and realistic settings to refine our understanding of expertise in military aviation.

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Authorship

Quentin Vantrepotte: Data Curation, Formal Analysis, Writing – Original Draft, Visualization; Cyril Camachon: Conceptualization, Methodology, Data Collection, Funding Acquisition, Writing – Review & Editing; Mickael Causse: Writing – Review & Editing; Emilien Dubois: Conceptualization, Methodology, Data Collection, Data Curation.

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