How Pilots' Professional Ability Influences Their Workload in Simulated DPO and SPO Task

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Abstract. To ascertain the psychological factors needed for the pilots in SPO (single pilot operations) crew configuration, a study investigated the effects of professional ability on pilots' workload in a simulated DPO (dual pilot operations) and SPO task. 46 pilots performed approaches with low visibility using a B737 full flight simulator in DPO and SPO crew configuration respectively, and their workload measured by NASA-TLX. A pilot's psychological competency measurement tool was used to collect pilots' professional ability data. The results showed that there were significant differences detected in crew configuration regarding workload and relative indexes. Mostly, the workload in the SPO crew configuration was higher than it was in the DPO crew configuration. Meanwhile, in DPO crew configuration, as the Pilot Flying (PF), better teamwork ability was significantly correlated with a worse self-evaluated performance. In SPO crew configuration, spatial orientation ability was negatively correlated with the mental demand index and physical demand index but positively correlated with the performance index (all *p*s<0.05). These findings contribute to the selection of pilots working in future SPO aircraft while demonstrating the practical application value of the pilots' psychological competency measurement tool in safeguarding SPO flight safety.

Keywords: Single Pilot Operation, Mental Workload, Professional ability.

Introduction

Due to the improvement in reliability and automation of onboard equipment, automation has made most of the dedicated flight crew functions redundant (e.g. the radio operators, navigators, and flight engineers) (Deeker, 2004). Commercial pilot crew size has steadily decreased over the years, from five in the 1950s to two in the 1980s (Vu et al., 2018). With the development of technology, some experts have started to consider the possibility of designing a single-pilot operation (SPO) commercial aircraft (Harries, 2007). Researchers began addressing SPO as early as 2005 (Deutsch & Pew, 2005). SPO refers to the operation of a commercial transport aircraft with only one pilot, assisted by advanced onboard automation and/or ground operators providing flight support (Matessa et al., 2017). The feasibility and the safety of SPO have been extensively studied by NASA, and regardless of whether SPO is adopted in the future, exploration in this field is beneficial (Comerford et al., 2013). With the progression of SPO research, advancements in automation and other technological aspects not only facilitate the creation of enhanced air-to-ground collaborative environments but also offer guidance for addressing emergencies arising from the incapacitation of one crew member in a dual-pilot configuration. Meanwhile, potential profit also drives the implementation of SPO. A cost estimation model for possible SPO on a current one-year basis showed an operational cost saving of 1% to 7% depending on the range of flight for optimistic scenarios (Malik & Gollnick, 2016). In conclusion, the potential value of SPO is worthy of further research and exploration. On the other hand, safety constitutes the foundation of civil aviation development, and human factors represent a crucial element of blame for the occurrence of safety incidents. The implementation of the SPO implies the reduction of the original two-pilot cockpit to a single pilot, signifying a shift in the pilot's job responsibilities and an alteration in the overall workload. The stability of human factors would become uncertain. Some have argued that in SPO configuration, achieving mutual understanding with an assistant could occupy pilots' attentional resources, potentially disrupting immediate actions. (Goe & Wolter, 2014). However, some experts noted that having two pilots doubles the chances that one pilot can become unstable (Comerford et al., 2013). All in all, safety research on SPO needs to strengthen the exploration of human factors. Besides, given the changes in job responsibilities and workload resulting from SPO, there is a need to research and identify the qualities that pilots flying in SPO configuration should possess. In NASA's Single-Pilot Operations Technical Interchange Meeting, five basic configurations were discussed by participants (1. One pilot on board; 2.One pilot with automation; 3.One pilot with a ground-based team member; 4.One pilot on board, with onboard personnel serving as a backup pilot; 5.One pilot on board, with the support of an intricate, distributed team)(Comerford et al., 2013). Neis et al.(2018) comprehensively explored diverse technological and operational concepts by proposing seven configurations, encompassing a wider range of potential application scenarios and strategic choices. In many other studies, the feasibility of operating different configurations and defining roles has been progressively clarified and delineated(Harries, 2023; Matessa et al., 2017). Currently, there is no definitive consensus on crew configuration for SPO cockpits, and experiments conducted under any configuration may not fully represent all scenarios. However, each configuration has the potential for single-pilot independent operations (e.g., in cases of automation or air-to-ground data transmission equipment failure). Conducting preliminary research into these scenarios is meaningful. Tailored selection processes and training programs become essential for ensuring the safety of SPO operations. Flight professional ability is one of the psychological competencies that pilots must possess, impacting flight safety (FAA, 2020; Belobaba, 2015; Luo & Gao, 2022). At the same time, workload determines the minimum flight crew (Schmid, 2017), and is closely related to flight performance (Young & Stanton, 2002). Therefore, paying attention to the changes in workload when transitioning from a DPO configuration to an SPO crew configuration, and studying the relationship between the pilot's professional ability and workload, is of practical significance in identifying the critical psychological competencies required for SPO pilots and promoting the implementation of SPO.

Literature Review

The Effects of SPO Crew Configuration on Pilots

Regarding the effects of SPO crew configuration on pilots, many experts have conducted research. Considering the effects on workload, there is a negative impact of SPO crew configuration on pilots. Bailey et al. (2017) found significant increases in workload for SPO, compared to DPO, with subjective assessments of safety and performance being significantly degraded. Faulhaber (2019) illustrated that workload might be problematic mostly during abnormal situations in SPO scenarios. Lachter and Battiste (2014) examined the effects of separating the pilots on crew interaction, they found that there was no impact on real-time workload, but a significantly higher post-simulation workload showed in SPO than it was in DPO.

From the view of pilots' performance, the effects of SPO are inconsistent. Some experts found there was no impact on pilots' performance. Ligda et al. (2015) set three configurations (DPO, SPO without collaboration tools, and SPO with collaboration tools), and analyzed pilots' events solving and aircraft state data, no configuration impact on pilots' performance was found. Lachter and Battiste (2014) found no impact of separation on pilots' ultimate decisions, although there was a common preference for face-to-face communication. Bailey et al. (2017) found in all cases they set, the pilots were able to overcome the failure mode effects in all crew configurations (nominal two-crew, reduced crew operation, and single-pilot operation). However, the negative impacts of SPO were examined in some research. Faulhaber and Friedrich (2019) found higher fixation frequencies, shorter average dwell durations, and a more frequent transition between different areas of interest during SPO. In another eye-tracker experiment, Faulhaber et al. (2022) compared the scanning behavior of pilots with or without PM (pilot monitoring), and they found a lower efficient scanning behavior when without PM. Additionally, some experts believe that SPO might lead to better pilot performance. In a DPO configuration, two individuals are prone to noticing the same issues, sharing similar vulnerabilities, and being influenced by the same distractions and illusions. Conversely, automation can capture information that differs from the co-pilot's perspective, providing supplementary and supportive information for the pilot (Comerford et al., 2013). Some studies also support this viewpoint, finding that individuals often exhibit better objective performance when working separately (Wichman, 1970; Williams, 1977; Chen et al., 2013).

Currently, there is no conclusive evidence regarding the impact of SPO on pilots' performance, and the results are subject to various factors such as experimental design. However, in general, workload is likely to be negatively affected. Simultaneously, in conjunction with relevant regulations, pilots' workload is a critical factor in determining the minimum flight crew size (Schmid, 2017). Therefore, to investigate the key psychological competencies that pilots need to possess under the SPO configuration, using workload as an indicator and studying the impact of professional ability on it could provide practical insights.

Measurements of Professional Ability

Humans have a limited operational envelope and require specific information to do their job. They are limited in memory (Baddeley, 1998), endurance, and other abilities such as computation. If the human is required to perform outside of this envelope or without sufficient information, they will fail (Schutte et al., 2007). Regarding the ability pilots need to be equipped, eight categories of pilot capabilities were proposed by the International Civil Aviation Organization (ICAO): application of procedures and compliance with regulations, communication, flight path management-automation, flight path management-manual control, leadership and teamwork, problem solving and decision-making, situation awareness and management of information, workload management (ICAO, 2013). The ninth competency on the European Aviation Safety Agency's (EASA) list is "knowledge". Based on this, EASA suggested that psychological assessments cover cognitive abilities, personality traits, operational and professional competencies, and social competencies following the crew resource management principles (EASA, 2018). Six categories—English language proficiency, basic ability, composite abilities, operational abilities, social-interpersonal abilities, and personality traits—were put forth in the Guidance Material and Best Practices for Pilot Aptitude Testing (PAT) created by the International Air Transport Association (IATA, 2019). The Professionalism Lifecycle Management System (PLM) was put forth by the Civil Aviation Administration of China (CAAC) in 2020 as a recommended course of action to enhance the post-competency of Chinese civil aviation pilots, and pilot competency and mental health are two essential parts in psychological competency dimension (CAAC, 2020).

Based on the demand for pilot selection and training, numerous studies have examined the structure of basic cognitive abilities and pilot evaluation. The collaboration and communication skills of pilots have received increased attention. However, there is a lack of tools to measure and integrate the data on both ability, personality, and mental health status at the same. Combining with professional characteristics of airline transport pilots and the requirements of PLM, a study has established a measurement framework, specifying the measurement metrics (Zhang et al., 2022). Meanwhile, Wang et al. (2023) provided a complete process and algorithm for psychological competency evaluation with supporting software and hardware. The evaluation tool, grounded in occupational adaptability psychology and mental health considerations, focused on six dimensions: general cognitive ability, operational and professional ability, social-interpersonal ability, personality traits and attitude, mental quality, and mental state. It has certain applicability and can be widely applied. Therefore, to investigate the relationship between the pilot's professional ability and workload, the operational and professional ability module in this tool would be adopted to value pilots' professional ability.

Method

Participants

A total of 46 pilots (all males owning commercial pilot licenses) from an airline participated in this experiment. They were aged from 23 to 36 (M = 30.895, SD = 4.081). Besides, The flight hours of pilots ranged between 52 and 4500 hours (M = 606.14 h, SD = 994.57 h).

Apparatus and Design

In this experiment, a B737 full flight simulator was used to design, test, and implement the flight scenario. A pilot's psychological competency measurement tool was used to measure pilots' professional ability. The workloads of pilots were collected using a 5-point NASA-TLX scale.

The design rationale, such as automation levels and cockpit layout, for the SPO configuration is uncertain. Although the configuration design of SPO is controversial, it is mandatory that all large commercial aircraft must be capable of operation by a single pilot from either seat (Code of Federal Regulations, 2003; JAA, 2000)). That is, pilots operating a plane alone in an emergency (all auxiliary systems are down) is an essential scenario that must be considered. Therefore, our experiment design would be based on the scenario that the single pilot as a PF operates without extra assistance. We aim to analyze the potential psychological factors required for pilots in the SPO configuration by evaluating their workload. In this experiment, the independent variables were crew configuration (DPO/SPO) and pilot professional ability, and the dependent variables were pilot workload. An approach task under low visibility was designed with slight turbulence and calm wind. The participants performed an ILS land (CAT I) with PM (trained flight instructors) in DPO and without the assistance of PM in SPO, respectively. The initial configuration of the aircraft was the same for each scenario: The aircraft was in a freeze mode aligned for the final approach at 6 nm from the runway. Autothrust and autopilot were engaged so that the aircraft was in a stable position when participants took over to land manually. NASA-TLX scale was used to measure the workload of each approach task. The pilot's psychological competency measurement tool would be used to collect pilots' professional ability data.

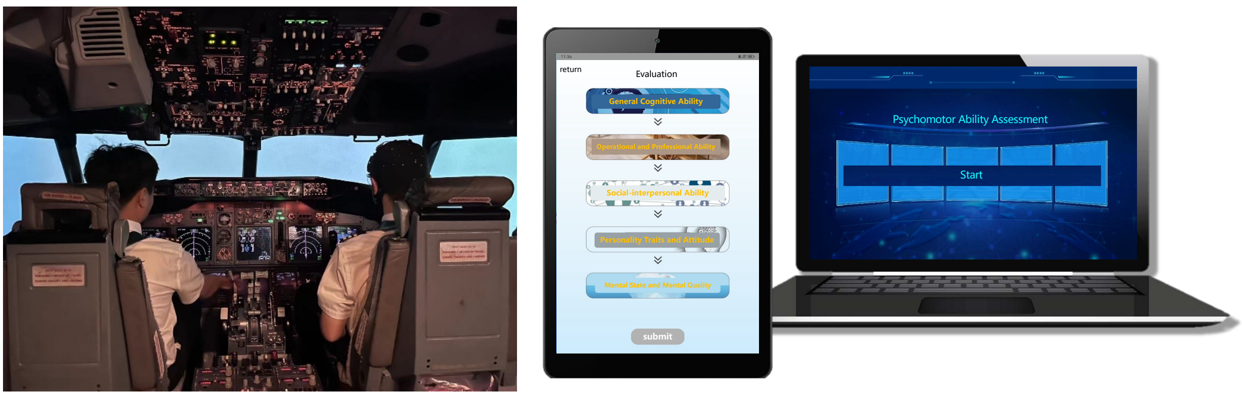

Figure 1. Apparatus (The tablet in the middle is used to assess pilots' general cognitive ability and social-interpersonal ability, while the computer on the right is primarily employed to evaluate pilots' psychomotor abilities.)

Procedure

Before the experiment, the experimental procedures, aircraft, and environment information were explained to pilots, and they signed the informed consent form and the ethical review form for the scientific experiment to allow their data to be used for academic research. Subsequently, the basic information of the pilots (such as flight hours, aircraft type, flight grade, etc.) was investigated. After the participants reported that they were ready, the experiment officially began. They would get on the full flight simulator and complete two approaches in DPO and SPO scenarios, respectively. After each scenario, pilots completed a brief post-trial questionnaire (NASA-TLX scale), and after all flights, the pilots completed a test based on the pilot's psychological competency measurement tool.

Data Analysis

Statistical analysis was performed using SPSS version 20. The Shapiro–Wilk test was used to test the normality of the data, showing non-normal results. Wilcoxon signed-rank test was then used to investigate the effects of crew configuration on the pilot's workload. Meanwhile, Spearman's correlation analysis was used to analyze the correlation between professional abilities and workload.

Results

Differential Analysis

After performing a Bonferroni-Holmes correction, the Wilcoxon signed-rank test indicated that there were significant differences detected in crew configuration regarding temporal demand and the composite workload (all *p*s<0.0071). As shown in Figure 2, pilots in the SPO crew configuration rated higher scores than they were in the DPO crew configuration in both subscales and the composite scale.

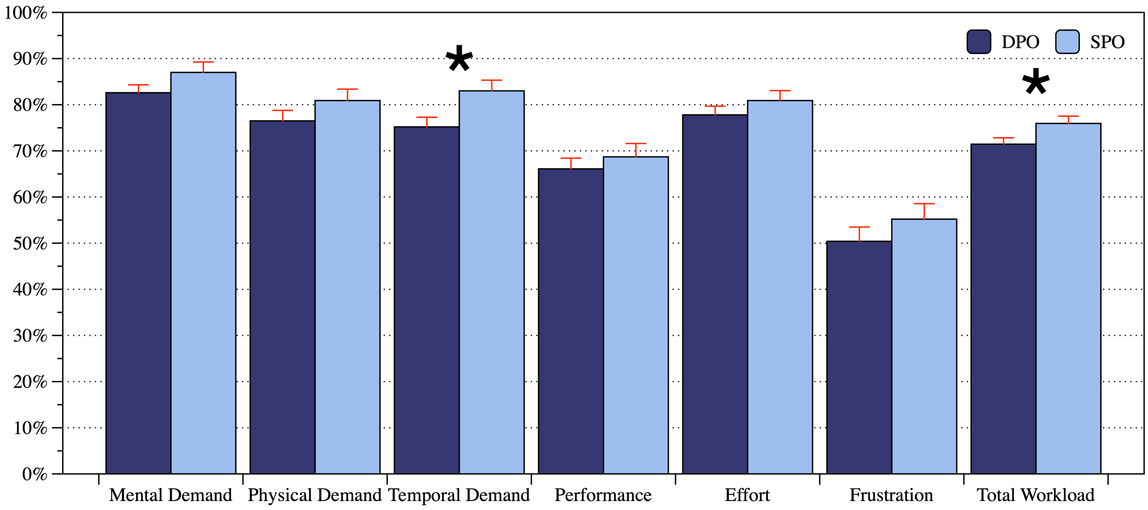

Figure 2. Bar graphs showing the NASA-TLX unweighted mean workload scores for each subscale and composite scale for the factor crew configuration. Error bars show standard errors of the mean. (* - $p < 0.0071$)

Correlation Analysis

Figure 3 shows the correlational analysis results. Using Spearman's correlation analysis, in the simulated DPO crew configuration, a positive correlation was found between teamwork ability and performance index in NASA-TLX. Meanwhile, in the SPO crew configuration, spatial orientation ability was found negatively correlated with mental demand and physical demand but positively correlated with performance index in NASA-TLX (all *p*s<0.05).

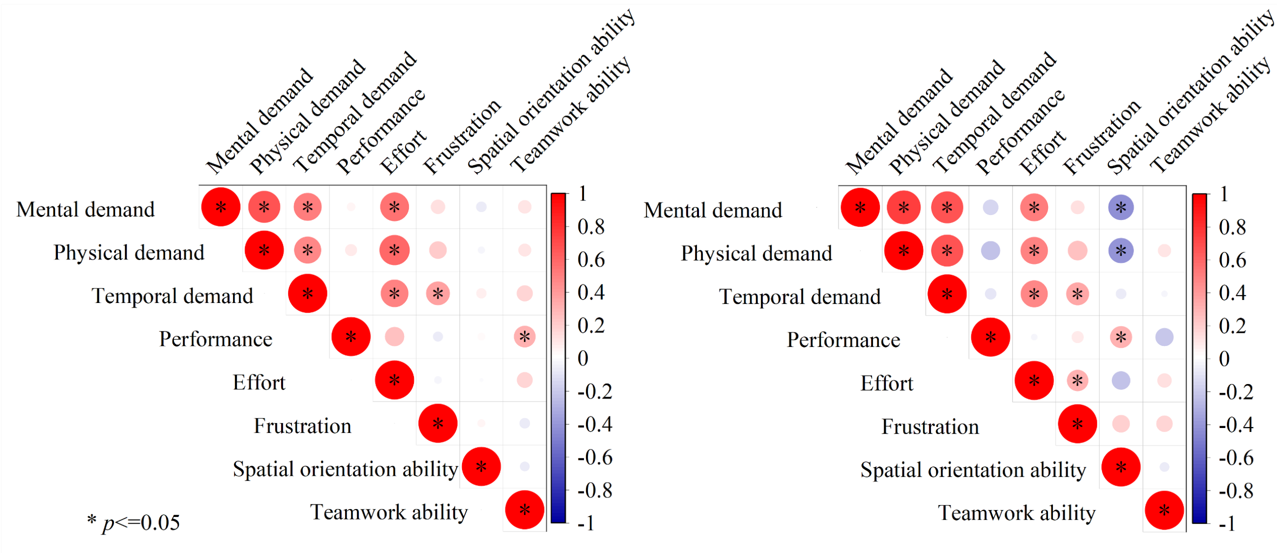

Figure 3. Bivariate Correlations Between NASA-TLX and Professional Abilities in DPO (left) and SPO (right) Configuration

Discussion

The main aim of the present study was to examine the changes in workload when transitioning from a DPO crew configuration to an SPO crew configuration and to study associations between workload and the professional ability of pilots. The study was also an opportunity to validate a pilot's psychological competency measurement tool. The analyses showed that crew configuration had a significant influence on workload, meanwhile, teamwork ability and spatial orientation ability affected workload in different crew configurations, respectively. The measurement tool for airline transport pilots' psychological competency boasts a comprehensive range of evaluation dimensions and categories, effectively discerning crucial professional abilities required by pilots across SPO and DPO scenarios.

The Effects of SPO Crew Configuration on Pilots

Based on the experimental results, we observed that the temporal demands and the composite workload of pilots operating under SPO crew configuration, were significantly higher than those in DPO crew configuration. These findings are in line with the research conducted by Bailey et al. (2017), which indicated an increase in workload in the SPO scenario. Such results are also in agreement with Faulhaber (2019), which indicated a higher workload and temporal demand in the SPO scenario with turbulence or non-standard procedures. Besides, this is coherent with a survey by Lachter and Battiste (2014), who observed a significantly higher post-simulation workload in SPO than it was in DPO.

Our results may stem from the following potential factors. First is visual overload. The absence of PM may diminish the visual scanning efficiency of PF, consequently leading to an increase in temporal demand (Faulhaber et al., 2022; Faulhaber & Friedrich, 2019). Next, a lack of experience may contribute to the results. Galy et al. (2018) found that novice pilots in complex situations experience higher psychological, physical, and temporal demands than their experienced counterparts. Miller et al. (2013) observed that individuals who are not acclimated to their environment endure greater cognitive loads. Our participants are accustomed to flight with the assistance of PM. SPO represents a novel and less-experienced scenario for them, resulting in heightened temporal demands.

Notably, according to Grier's meta-analysis (2015), after percentage conversion, the workload scores for both DPO (71.45) and SPO (75.94) configurations are at a high workload level, even exceeding the 90th percentile. This indicates that approaches in marginal weather conditions are challenging for all pilots. Given the exceptionally high workload for pilots in the scenario where a single pilot assumes the duties of the second pilot flying current technology aircraft, it is entirely reasonable for the EASA eMCO concept to consider this mode only for the cruise phase.

The Effects of Professional Ability on Workload

The correlation analysis between variables revealed a negative correlation between teamwork capabilities and self-performance evaluations when pilots served as PF in a dual-crew operation configuration. In single-crew configuration, a negative correlation was also found between spatial orientation abilities and self-performance evaluations. Furthermore, pilots with higher spatial orientation abilities reported lower cognitive and physical demands during task execution.

In DPO crew configuration, pilots with stronger teamwork capabilities tended to rate their performance lower. Similarly, in SPO, pilots with higher spatial orientation abilities also rated their performance lower. This result may be related to the Dunning-Kruger effect, where individuals with lower abilities tend to overestimate their capabilities, while those with higher abilities often underestimate them (Chen et al., 2013). Capable pilots might undervalue their performance due to high self-standards and an acute awareness of the complexity of the tasks.

In the SPO scenario, there is a significant negative correlation between psychological and physical demands and spatial orientation abilities. This can be explained by considering task complexity and attentional allocation patterns. A study focusing on the spatial abilities and workload of civil aviation personnel indicated that with the growth of task complexity spatial abilities can significantly reduce workload (Yang & Zhang, 2009). Hence, in a high-workload environment like the SPO scenario, spatial abilities contribute a lot to maintaining a relatively low workload. Besides, the lack of PM would change the attentional allocation pattern of a pilot with a decrease in mean dwell durations on the external view (Faulhaber et al., 2022). And the perceived external visual cues will decrease. Hence, pilots might need to rely more on their spatial orientation ability to recognize and assess spatial relationships among ground targets, flight conditions, and their position, otherwise, there will be a need to sacrifice a portion of cognitive resources. Overall, spatial orientation ability is a key skill that enables pilots to manage high-complexity aircraft operations effectively under SPO configuration.

As for the separation of workload-sensitive professional ability, it might be caused by the crew configuration. In the SPO scenario, the absence of a PM disturbed the effects of teamwork ability on workload. At the same time, in the DPO scenario, as efficient scanning behavior has been supported by the PM to achieve the PF (Faulhaber et al., 2022), the impact of spatial orientation abilities related to vision on workload has not been highlighted.

Conclusion

Research findings suggest that the SPO scenario induces a higher workload in comparison to the DPO scenario. Furthermore, the application of a psychological competency assessment tool revealed that, in the DPO scenario, the critical competency lies in teamwork ability, while in the SPO scenario, spatial orientation ability assumes a substantial role. These competencies demonstrate a negative correlation with workload in distinct scenarios, indicating that workload-sensitive professional abilities vary between scenarios. This underscores the importance of targeted selection of pilots based on their specific task demands. Notably, this experiment is solely based on current regulatory minimum pilot requirements, indicating a prospective analysis of pilot competency needs in a possible future scenario. It does not comprehensively describe the pilot competency requirements under SPO configuration, and the related results are primarily intended to provide an approach and reference for the selection of pilots in future SPO configurations. Furthermore, our experiment was conducted in a fixed sequence, which may have influenced our results to some extent. To enhance human stability and facilitate the implementation of SPO, more comprehensive research on pilot psychological competency is needed. Simultaneously, physiological and behavioral indicators, as well as sequence effects, should be considered.

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