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The influence of a 12-week yoga program on military aviation pilots' decision-making capacity for operational effectiveness

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A R T I C L E I N F O

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A B S T R A C T

Military aviation demands cognitive performance, emotional stability, and resilience under pressure. Portuguese Airforce pilots face additional challenges: maintaining fitness and readiness independently, without structured exercise regimens. Yoga's capacity to enhance mindfulness makes it a promising intervention. Despite potential benefits, research on yoga's impact in military aviation remains limited. This study investigates incorporation of yoga into the training regimen of Portuguese Airforce to verify decision-making effectiveness and performance. A randomized controlled trial was conducted with 18 Portuguese Air Force pilots: Control Group ($n = 8$) followed standard military training, and Intervention Group ($n = 10$) received aditional yoga training twice a week, for 12 weeks. Assessments included Five Facet Mindfulness Questionnaire (FFMQ), Multidimensional Assessment of Interoceptive Awareness (MAIA), Aviation Safety Attitude Scale (ASAS), Risk Perception To Self (RPTS), Trail Making Test (TMT) and aviation simulator performance. Data analysis used Jamovi v2.6.13. The yoga group showed significant improvements in mindfulness (FFMQ), interoceptive awareness (MAIA), self-confidence and safety attitudes (ASAS), cognitive flexibility (TMT-B), and simulator performance (fewer flight errors). Enhancements in attention regulation, body awareness, and emotional self-regulation reflect greater readiness for stress management. Improvements in decision-making, calculated risk-taking, and operational safety suggest yoga's potential to reinforce psychophysiological resilience in high-demand environments. Yoga contributes meaningfully to enhanced performance and safety in high-pressure aviation environments. These findings may inform policy-level decisions toward integrating mandatory mind-body training programs that are cost-effective and time-efficient. The benefits observed may be applicable to Air Force teams globally, as well as commercial aviation, civil aviation, and other high-stress, high-performance domains, including elite sports.
Clinical Trial Registry number and website where it was obtained: ClinicalTrials.gov identifier NCT05821270

Introduction

Military aviation pilots undergo rigorous training and are exposed to multiple operational stressors during both training exercises and active missions (Fuentes-García et al., 2021; Johannes et al., 2017). They operate in specific environments that are characteristic of the military aviation profession (Villafaina et al., 2021; Wittels et al., 2024), this includes simultaneous physical, cognitive, and emotional demands of varying intensities during flight maneuvers, which may influence both performance and well-being (Hormeño-Holgado & Clemente-Suárez, 2019). Given the nature of their duties and the associated operational stress, there is an increasing need to identify strategies that support pilots' health and resilience (Fuentes-García et al., 2021; Hormeño-Holgado & Clemente-Suárez, 2019; Johannes et al., 2017; Santos et al., 2024).

Military aviation pilots experience stress due to combat missions, extended training schedules, exposure to high-risk scenarios, and the necessity for rapid decision-making under complex psychological,

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physiological, and environmental demands (Martin et al., 2020). In this context, stress may contribute to cognitive challenges such as diminished focus and impaired judgment (LeDoux, 2014; Moscarello & Maren, 2018; Vrijkotte et al., 2016). When prolonged, it can negatively affect physical and mental health, potentially leading to fatigue, burnout, decreased resilience, and reduced task performance (Mobbs et al., 2019; Yilmaz & Huberman, 2019; Yilmaz et al., 2021). In military aviation, performance requires not only speed, but also accuracy, sound decision-making under pressure, situational awareness, and adaptability. Operational efficiency—completing tasks effectively with minimal resources—is essential for mission success and safety, particularly in high-demanding environments (Cao et al., 2019; Lahtinen et al., 2007; Lehrer et al., 2010; Mansikka et al., 2016; Santos et al., 2022; Svensson et al., 1997).

Portuguese military pilots face additional challenges: currently, there is no standardized exercise program specifically designed for training aircraft pilots, instead pilots must maintain their fitness and readiness on their own, in order to pass standardized yearly physical exams (Santos et al., 2024). The results of this study could be pivotal in developing or refining a formal exercise program for pilots, which would, in turn, enhance future military health policies.

While the need to support the health and performance of military aviation pilots has long been acknowledged, advancements in aircraft systems and operational demands have increased the cognitive and physiological load placed on pilots (Hormeño-Holgado & Clemente-Suárez, 2019; Johannes et al., 2017; Vrijkotte et al., 2016; Wittels et al., 2024). In light of these evolving challenges, the *Departamento de Medicina Aeronáutica da Força Aérea Portuguesa* (Department of Aerospace Medicine of the Portuguese Air Force) has initiated efforts to develop a mandatory training program that promotes physical and cognitive resilience. Within this context, yoga has emerged as a potential low-cost, time-efficient intervention to complement existing training protocols.

Yoga, with its mix of physical postures, breathing techniques, and mindfulness practices, has been shown to reduce stress and improve overall well-being in different groups, including athletes and military personnel (Cushing et al., 2018; Kanthi et al., 2024; Santra, 2022; Singh, 1999; Stoller et al., 2012; Sullivan et al., 2021; Thomson et al., 2024). These circumstances provide a rationale for conducting a randomized controlled trial (RCT) to evaluate whether incorporating yoga into the training of Portuguese military pilots may support stress management, cognitive resilience, and performance, within the specific demands of their occupational context (Santos et al., 2024). Ashtanga Vinyasa Yoga is a physically demanding practice involving fluid movements (vinyasas) and synchronized breathing. It emphasizes coordination of posture, breath, and gaze, with each movement linked to an inhalation or exhalation. The practice, often referred to as "meditation in motion," requires focused attention due to the technical complexity of the postures (Dybvik & Steinert, 2021; Koncz et al., 2024; Thrower et al., 2023; Tsopanidou et al., 2020).

This RCT will explore the benefits of adding Ashtanga Vinyasa Yoga Supta to the training regimen of Portuguese military pilots, aiming to offer insights for future mandatory exercise programs (Santos et al., 2024). By finding effective ways to boost mental fitness and operational readiness, the study hopes to develop evidence-based results to support health and performance of military pilots in Portugal and potentially guide training protocols globally. The objective is to examine how integrating yoga into individual training routines may contribute to stress reduction and enhance decision-making capacity and overall performance among military aviation pilots. The hypothesis is that a structured yoga program will significantly lower perceived stress, enhance decision-making capacity, and improve cognitive and psychomotor performance. Additionally, it is expected that these benefits will lead to better resilience and operational effectiveness during flight missions, leading to increased flight safety.

Methods

Sample

All professional military pilots from the 2021 and 2022 Tirocinium classes at the Portuguese Air Force Academy took part in this study. Sample size calculation is shown in Fig. 1.

One pilot was excluded from the control group ($n = 8$) due to significant lifestyle changes during the three-month timeframe, including alterations in diet, exercise, and smoking habits.

Intervention

Over 12 weeks, the Control Group ($n = 8$) attended the standard "Masters in Military Aeronautics: Aviator Pilot Specialist" course. Meanwhile, the Yoga Intervention Group ($n = 10$) took the same course plus two additional 1-hour yoga classes per week. Participants were instructed to maintain their regular routines. The yoga sessions were customized based on the pilots' work schedules and tailored to address challenges identified by the pilots and referenced in the literature and detailed by Santos et al., (Santos et al., 2024) in their methods article.

To minimize potential observer bias (Hawthorne Effect), a delayed intervention design was implemented. All participants were informed that the yoga program would be made available to everyone, with the control group receiving the same training immediately after the initial 12-week study period. This approach promoted a sense of fairness and reduced differential expectations between groups, helping to support internal validity despite the inherent challenges of blinding in behavioral interventions.

Data collection

Pilots completed a work scenario in a flight simulator (Epsilon - SEPS TB30), involving both visual and instrument flight conditions. Flight maneuvers followed a set sequence with randomized emergency activation times. Performance was measured by the correct identification of the emergency and the actions taken by the pilots. The study focused on the number of mistakes made (out of 35 steps identified in Fig. 2, including not performing or incorrectly performing the steps) and the type of mistakes (ranked by severity, with the simulator shutting down if the pilot's life would be at risk or the aircraft would be in danger of being severely damaged).

The study also employed several validated tools to measure various outcomes related to stress, mindfulness, interoceptive awareness, safety attitudes, and risk perception:

1. Five Facet Mindfulness Questionnaire (FFMQ): This questionnaire assesses mindfulness through five facets: observing, describing, acting with awareness, non-judging of inner experience, and non-reactivity to inner experience. The FFMQ has demonstrated strong construct validity in both meditating and non-meditating samples (Baer et al., 2008; Carpenter et al., 2019).
2. Multidimensional Assessment of Interoceptive Awareness (MAIA): This tool measures interoceptive awareness, including aspects such as noticing, not-distracting, not-worrying, attention regulation, emotional awareness, self-regulation, body listening, and trusting. The Portuguese version of MAIA has been validated and found to have strong psychometric properties (Machorrinho et al., 2019).
3. Aviation Safety Attitude Scale (ASAS): This scale measures pilots' attitudes towards aviation safety, providing insights into their perceptions and potential hazardous attitudes. It is an established tool in the field of aviation psychology (Hunter, 2005).
4. Risk Perception To Self (RPTS): This measure assesses pilots' perceptions of risk and their tolerance for it, crucial for understanding decision-making under pressure. It has been widely used in research on aviation safety (Hunter, 2002).

Sample Size for Frequency in a Population

Population size(for finite population correction factor or fpc)(*N*):	19
Hypothesized % frequency of outcome factor in the population (*p*):	50%+/-5
Confidence limits as % of 100(absolute +/- %)(*d*):	5%
Design effect (for cluster surveys-*DEFF*):	1

Sample Size(*n*) for Various Confidence Levels

ConfidenceLevel(%)	Sample Size
95%	19
80%	18
90%	18
97%	19
99%	19
99.9%	19
99.99%	19

Equation

Sample size n = $[DEFF*Np(1-p)]/[(d^2/Z^2_{1-\alpha/2}*(N-1)+p*(1-p)]$

Fig. 1. Sample Size results from OpenEpi, Version 3, open source calculator—SSPropor.

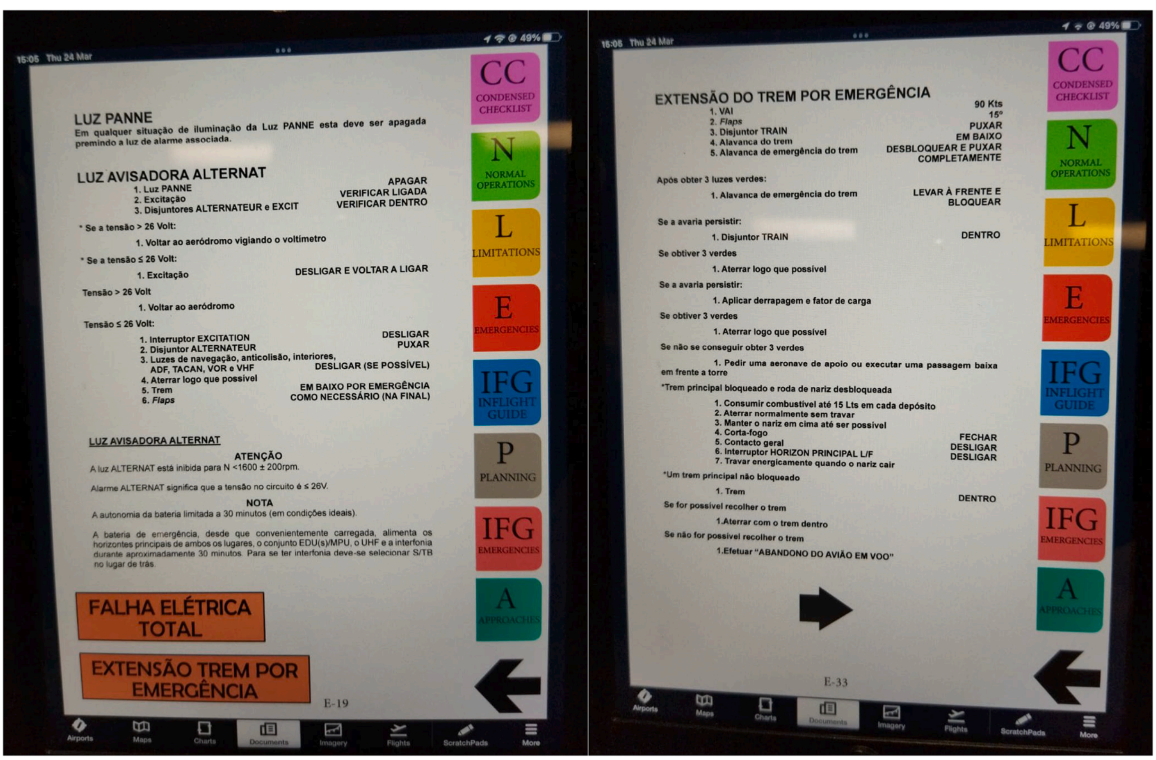

Fig. 2. The emergency response manual has step-by-step instructions for dealing with alternator failure emergency, shown on pages 1 (left) and 2 (right) in Portuguese language. Pilots need to follow these steps and report to the control tower in English. There are 33 steps to follow and 35 possible performance errors, with not following a step being counted as an error, as well as not reporting to the control tower and taking too long to land the plane, being countes as errors as well.

5. Trail Making Test (A and B versions – TMTA and TMTB, respectively) –is a neuropsychological assessment used to evaluate cognitive abilities, particularly visual attention, task switching, processing speed, and executive function. It consists of two parts: TMT-A in which the individual is asked to connect a series of 25 numbered circles in sequential order (1–2–3, etc.) as quickly as possible with a purpose to Measure processing speed, visual scanning, and attention. TMT-B in which the individual connects circles by alternating between numbers and letters in sequence (1-A-2-B, etc.) until completion, with the purpose of Assessing cognitive flexibility, task switching, and executive function. The time taken to complete each part and the number of errors is recorded. Longer completion times and more errors indicate possible cognitive impairment (Bowie & Harvey, 2006).

By using these tools, the study aims to comprehensively assess the impact of a 12-week yoga program on the decision-making capacity of these Portuguese military pilots.

Data analysis

We used Jamovi (Desktop version 2.3.16) to generate descriptive statistics for both the intervention and control groups. Normality was assessed using the Shapiro-Wilk test, where p-values greater than 0.05 indicated normal distribution, and p-values lesser than or equal to 0.05 indicated non-normal distribution (Ho et al., 2019; McGough & Faraone, 2009; Sullivan & Feinn, 2012). For normally distributed data, we conducted independent (for between group comparisons) and paired (for within group comparisons) samples T-Tests (Student's t) and calculated effect sizes (Cohen's d). For non-normally distributed data, we used the Wilcoxon rank test (Wilcoxon W) and calculated effect sizes using Rank Biserial Correlation (for both between and within group comparisons, due to the small sample size). Significance was set at the conventional threshold of 0.05 (Ho et al., 2019; McGough & Faraone, 2009; Sullivan & Feinn, 2012).

Results

Performance

The descriptive statistics for performance (Table A in the Supplementary Material) shows that data is not normally distributed.

Data in Table 1 shows significant results between groups before the intervention for performance, regarding: 1. Number of Errors between groups after the intervention; and 2. Time (of emergency for completion of the task). It also shows a medium effect size for 1. Number of Errors within the yoga group. The performance time considered in this study was the total period of time that each pilot spent inside the flight simulator, from habituation to recovery, including all the flight simulator maneuvers.

Data in Fig. 3 shows significant differences found in Number of Errors (NE).

Five facet mindfulness questionnaire (FFMQ)

FFMQ descriptive statistics (Table B in the Supplementary Material) show that data is normally distributed.

Data in Table 2 shows significant results for Aware Actions and Non-Judgmental Inner Critic, both within the yoga group. Table 2 also shows medium effect sizes for Observation between groups after the intervention; Description within the yoga group; and Non-Reactivity between groups before the intervention.

Data in Fig. 4 shows significant differences found in FFMQ for Observation and Fig. 5 shows significant differences found in FFMQ for Aware Actions.

Multidimensional assessment of interoceptive awareness (MAIA)

MAIA descriptive statistics (Table C in Supplementary Material) show that data is not normally distributed.

Data in Table 3 shows significant results for Noticing within the yoga group and between groups after intervention; Attention Regulation and Body Listening both within the yoga group. Table 3 also shows medium effect sizes for Non-Distracting within the yoga group; Not-Worrying within the control group; Attention Regulation, Emotional Awareness and Trust between groups after the intervention.

Table 1
Comparison within and between groups for performance variables.

		Performance Wilcoxon and Rank biserial correlation				
				Statistic	p	Effect Size
1. Number of errors	Whithin group	Control group before	Control group after	21.0	0.270	0.500
		Intervention group before	Intervention group after	46.5	0.057	0.691
	Between group	Control group before	Intervention group before	19.5	0.389	0.393
		Control group after	Intervention group after	34.5	0.025	0.917
2. Time to complete the flight simulator emergency	Whithin group	Control group before	Control group after	26.00	0.313	0.444
		Intervention group before	Intervention group after	25.00	0.846	−0.091
	Between group	Control group before	Intervention group before	33.0	0.039	0.833
		Control group after	Intervention group after	18.0	1.000	0.000

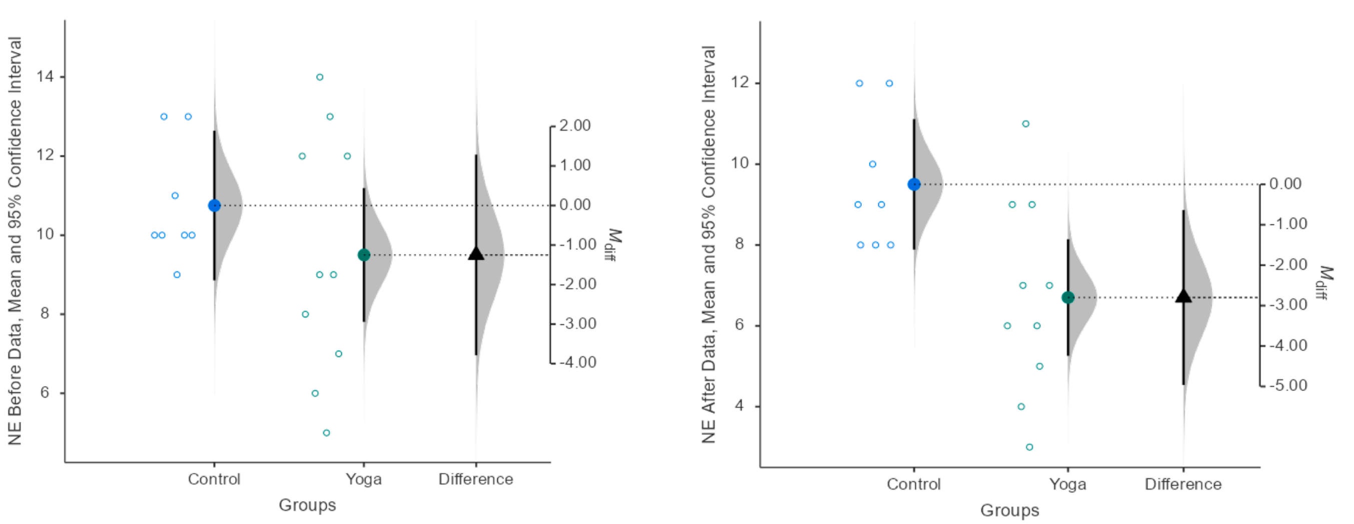

Fig. 3. Significant differences found in Number of Errors (NE) comparison between groups before and after the 12-weeks.

Table 2
Comparison within and between groups for FFMQ variables.

		FFMQ Student's t and Cohen's d				
				Statistic	p	Effect Size
1. Observation	Whithin group	Control group before	Control group after	−0.183	0.860	−0.065
		Intervention group before	Intervention group after	−1.422	0.189	−0.450
	Between group	Control group before	Intervention group before	−0.823	0.423	−0.390
		Control group after	Intervention group after	−2.422	0.028	−1.149
2. Description	Whithin group	Control group before	Control group after	0.219	0.833	0.077
		Intervention group before	Intervention group after	−2.005	0.076	−0.634
	Between group	Control group before	Intervention group before	−0.197	0.846	−0.0934
		Control group after	Intervention group after	−1.510	0.150	−0.7165
3. Aware actions	Whithin group	Control group before	Control group after	1.29	0.238	0.456
		Intervention group before	Intervention group after	−2.58	0.030	−0.817
	Between group	Control group before	Intervention group before	0.246	0.809	0.117
		Control group after	Intervention group after	−2.919	0.010	−1.385
4. Non-judgmental inner critic	Whithin group	Control group before	Control group after	−0.119	0.909	−0.042
		Intervention group before	Intervention group after	−2.589	0.029	−0.819
	Between group	Control group before	Intervention group before	1.19	0.250	0.566
		Control group after	Intervention group after	−1.01	0.325	−0.481
5. Non-reactivity	Whithin group	Control group before	Control group after	0.595	0.570	0.211
		Intervention group before	Intervention group after	−0.647	0.534	−0.205
	Between group	Control group before	Intervention group before	−1.20	0.247	−0.570
		Control group after	Intervention group after	−1.83	0.086	−0.867

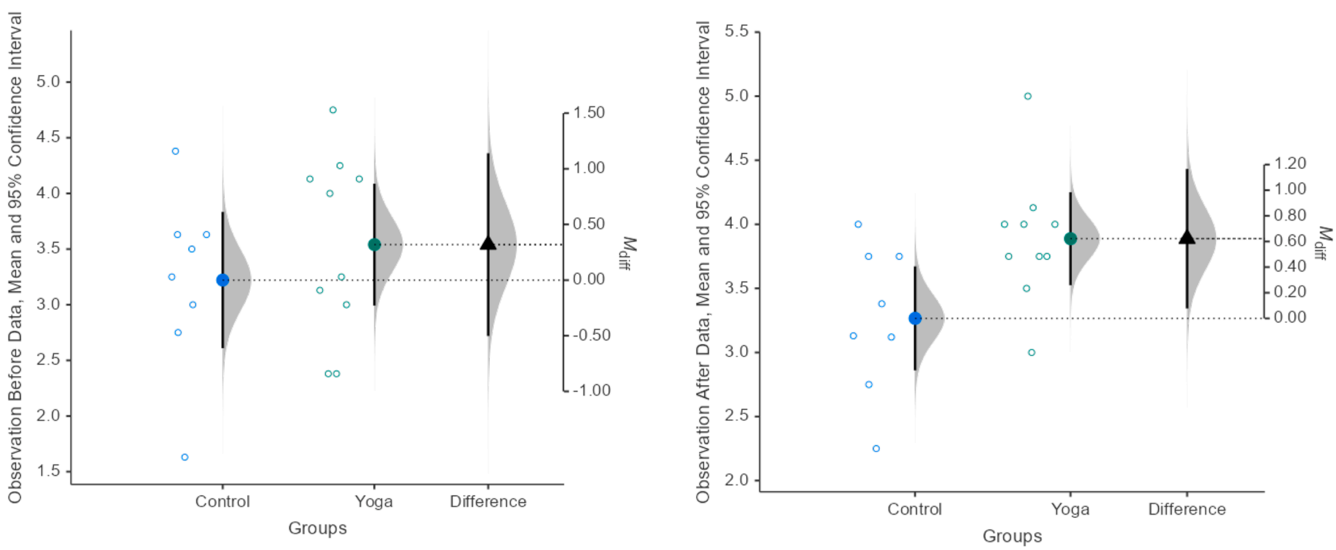

Fig. 4. Significant differences found in FFMQ: Observation comparisons between groups before and after the 12-weeks.

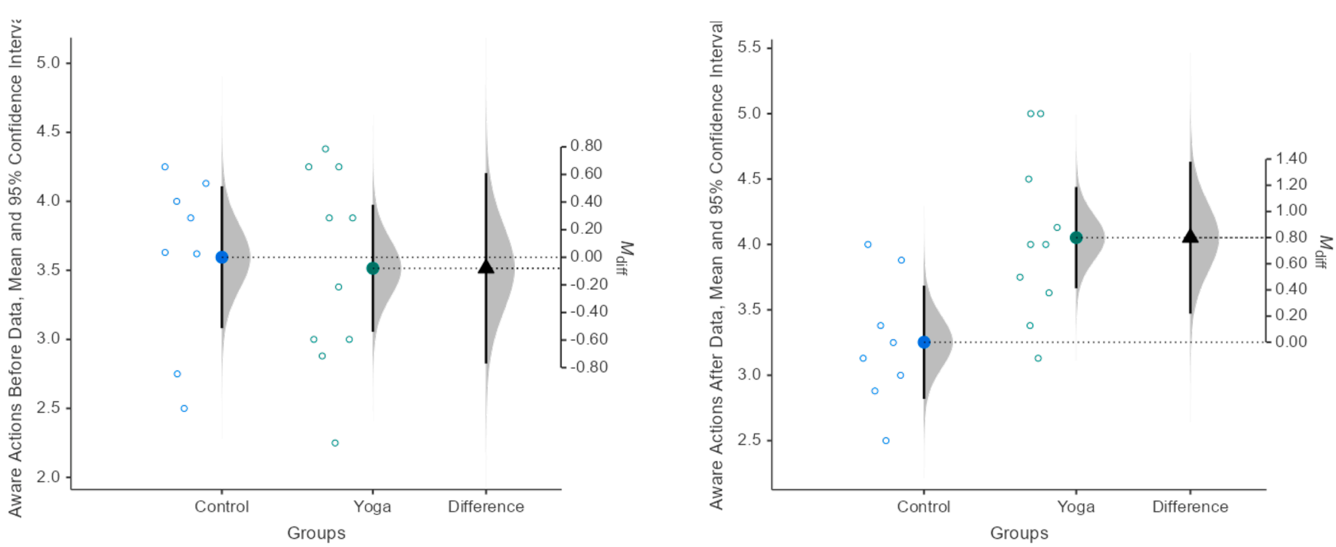

Fig. 5. Significant differences found in FFMQ: Aware Actions comparisons between groups before and after the 12-weeks.

Table 3
Comparison within and between groups for MAIA variables.

		MAIA Wilcoxon and Rank biserial correlation				
				Statistic	p	Effect Size
1. Noticing	Whithin group	Control group before	Control group after	15.50	0.865	0.107
		Intervention group before	Intervention group after	0.00	0.006	−1.00
	Between group	Control group before	Intervention group before	18.00	1.000	0.00
		Control group after	Intervention group after	1.50	0.024	−0.917
2. Not-Distracting	Whithin group	Control group before	Control group after	12.0	0.833	0.143
		Intervention group before	Intervention group after	10.0	0.153	−0.556
	Between group	Control group before	Intervention group before	15.0	0.726	−0.167
		Control group after	Intervention group after	12.5	0.483	−0.306
3. Not-Worrying	Whithin group	Control group before	Control group after	27.00	0.233	0.500
		Intervention group before	Intervention group after	24.00	0.904	0.067
	Between group	Control group before	Intervention group before	24.00	0.441	0.333
		Control group after	Intervention group after	8.50	0.892	0.133
4. Attention Regulation	Whithin group	Control group before	Control group after	18.00	0.554	0.286
		Intervention group before	Intervention group after	4.00	0.019	−0.855
	Between group	Control group before	Intervention group before	17.00	0.673	0.214
		Control group after	Intervention group after	8.50	0.207	−0.528
5. Emotional Awareness	Whithin group	Control group before	Control group after	22.00	0.622	0.222
		Intervention group before	Intervention group after	12.00	0.234	−0.467
	Between group	Control group before	Intervention group before	15.00	0.933	0.071
		Control group after	Intervention group after	7.00	0.148	−0.611
6. Self-Regulation	Whithin group	Control group before	Control group after	18.50	1.000	0.028
		Intervention group before	Intervention group after	24.50	0.858	0.089
	Between group	Control group before	Intervention group before	14.50	0.671	−0.194
		Control group after	Intervention group after	9.50	0.256	−0.472
7. Body Listening	Whithin group	Control group before	Control group after	10.00	1.000	−0.048
		Intervention group before	Intervention group after	4.50	0.037	−0.800
	Between group	Control group before	Intervention group before	25.00	0.360	0.389
		Control group after	Intervention group after	8.50	0.397	−0.393
8. Trust	Whithin group	Control group before	Control group after	25.00	0.362	0.389
		Intervention group before	Intervention group after	15.00	0.726	−0.167
	Between group	Control group before	Intervention group before	11.00	0.670	−0.214
		Control group after	Intervention group after	5.00	0.076	−0.722

Fig. 6 shows significant differences found in MAIA for Noticing.

Aviation safety attitude scale (ASAS)

ASAS descriptive statistics (Table D in Supplementary Material) show that data is not normally distributed.

Data in Table 4 shows significant results for Self-Confidence, Risk Orientation and Safety Orientation within the yoga group. It also shows medium effect sizes for Self-Confidence between groups both before and after the intervention and Risk Orientation between groups before the intervention.

Risk perception to self (RPTS)

RPTS descriptive statistics (Table E in Supplementary Material) show that data is not normally distributed.

Data in Table 5 shows no significant results.

Trail making test version A (TMTA) and trail making test version B (TMTB)

TMT descriptive statistics (Table F in Supplementary Material) show that data is normally distributed.

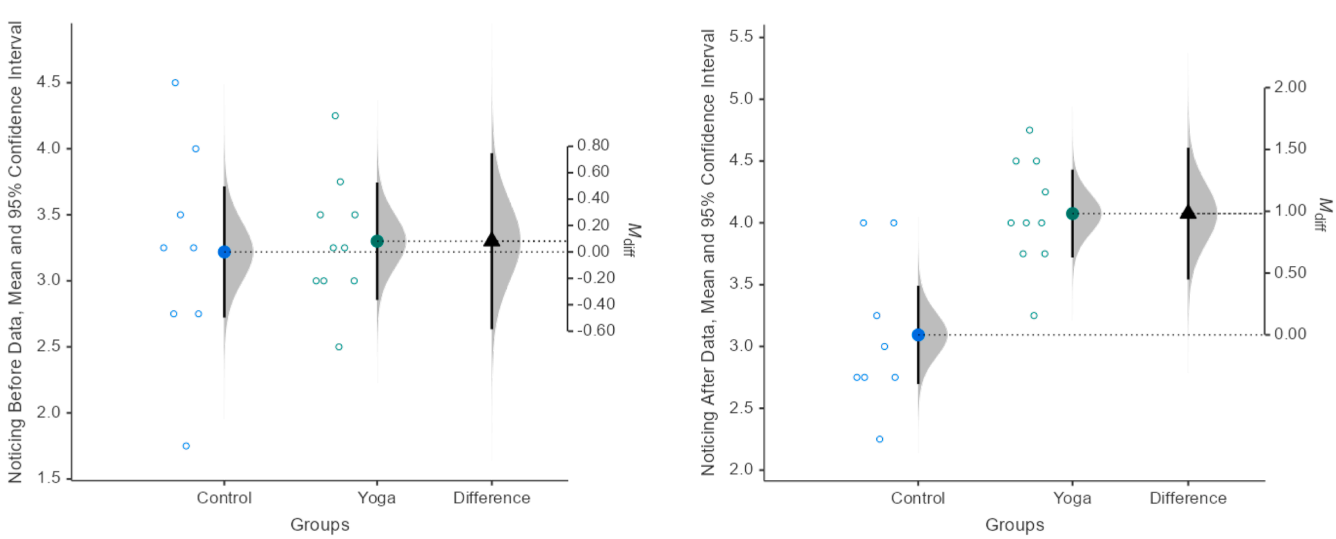

Fig. 6. Significant differences found in MAIA: Noticing comparisons between groups before and after the 12-weeks.

Table 4
Comparison within and between groups for ASAS variables.

	ASAS Wilcoxon and Rank biserial correlation					
				Statistic	p	Effect Size
1. Self-Confidence	Whithin group	Control group before	Control group after	19.00	0.447	0.357
		Intervention group before	Intervention group after	2.50	0.021	−0.889
	Between group	Control group before	Intervention group before	18.50	0.106	0.762
		Control group after	Intervention group after	8.00	0.182	−0.556
2. Risk Orientation	Whithin group	Control group before	Control group after	20.00	0.352	0.429
		Intervention group before	Intervention group after	3.00	0.014	−0.891
	Between group	Control group before	Intervention group before	29.00	0.137	0.611
		Control group after	Intervention group after	8.50	0.752	−0.190
3. Safety Orientation	Whithin group	Control group before	Control group after	20.50	0.779	0.139
		Intervention group before	Intervention group after	2.50	0.012	−0.909
	Between group	Control group before	Intervention group before	22.00	0.624	0.222
		Control group after	Intervention group after	7.50	0.310	−0.464

Table 5
Comparison within and between groups for RPTS variables.

	RPTS Wilcoxon and Rank biserial correlation					
				Statistic	p	Effect Size
RPTS	Whithin group	Control group before	Control group after	20.0	0.844	0.111
		Intervention group before	Intervention group after	38.0	0.308	0.382
	Between group	Control group before	Intervention group before	15.0	0.742	−0.167
		Control group after	Intervention group after	14.0	0.641	−0.222

Table 6
Comparison within and between groups for TMT variables.

	TMT Student's t and Cohen's d					
				statistic	p	Effect Size
TMTA	Whithin group	Control group before	Control group after	2.043	0.080	0.722
		Intervention group before	Intervention group after	1.869	0.094	0.591
	Between group	Control group before	Intervention group before	−0.932	0.365	−0.442
		Control group after	Intervention group after	−1.340	0.199	−0.636
TMTB	Whithin group	Control group before	Control group after	2.3017	0.055	0.814
		Intervention group before	Intervention group after	2.7879	0.021	0.882
	Between group	Control group before	Intervention group before	−0.295	0.772	−0.140
		Control group after	Intervention group after	−0.368	0.718	−0.174

Data in Table 6 shows significant results for TMTB within the yoga group. It also shows medium effect sizes for TMTA within both the yoga and the control group and for TMTB within the control group.

Discussion

The Performance data reflect the actions of pilots during the simulated task: overall, the Number of Errors decreased over time in both groups, with a more pronounced improvement observed in the yoga group. While the control group showed no statistically significant change in Number of Errors before and after the 12-weeks, the yoga group demonstrated a near-significant reduction with a large effect size, suggesting a meaningful improvement in Performance. Between-group comparisons revealed no initial difference; however, after the intervention, the yoga group committed significantly fewer errors, with a very large effect size. This supports the hypothesis that the yoga practice may enhance aspects of cognitive functioning, such as attention, focus, or stress regulation, particularly under high-pressure scenarios like emergency flight tasks. In terms of task duration, the Time to complete the activity showed modest improvements in both groups, but none reached statistical significance. Initially, the yoga group performed significantly faster than the control group, as indicated by a large effect size. After the intervention, however, no significant time differences were observed between the groups, with effect size analysis showing equivalence. These findings suggest that although the yoga intervention reduced errors, it did not accelerate performance. Importantly, this indicates that the improved effectiveness in decision-making did not come at the cost of additional processing time. In practical terms, enhanced operational performance can be achieved without extending the duration required for task execution.

Most FFMQ facets increased in the yoga group after the intervention, indicating potential benefits of the program on various dimensions of mindfulness. The Observation facet showed a significant post-intervention difference between groups, with a large effect size, suggesting enhanced awareness of internal and external experiences in the yoga group. The Description facet revealed a near-significant improvement in the yoga group, with a medium-to-large effect size, reflecting a greater ability to articulate internal experiences. For Aware Actions, the yoga group showed significant improvement, both within-group and between-group, with large and very large effect sizes respectively, highlighting increased mindfulness in daily activities. These results suggest that the yoga intervention meaningfully enhanced intentionality and attention to present-moment actions. In the Non-Judgmental Inner Critic domain, the yoga group experienced a significant increase, with a large effect size, indicating greater self-acceptance and reduced critical self-evaluation after the intervention, becoming more accepting of their thoughts, emotions, and sensations, rather than reacting negatively or critically to them. For Non-Reactivity, while the change did not reach statistical significance, a large effect size was observed, suggesting that yoga may support better regulation of automatic responses to internal experiences. These trends, especially when paired with medium effect sizes in Observation and Description, suggest the potential for broader improvements with larger samples or longer interventions in future studies. Collectively, these findings indicate that yoga may improve pilots' ability to maintain mindful awareness, reduce impulsivity, and manage internal experiences without judgment—skills essential for performance under pressure. This aligns with findings from other mindfulness interventions: increases in Awareness have been observed in Kundalini Yoga for individuals with generalized anxiety disorder (Diamond et al., 2024), while improvements in Awareness, Non-Judgment, and Non-Reactivity were found in military cadets undergoing mindfulness-based stress reduction (Chen et al., 2024). Non-Reactivity, a facet positively affected in this study, is linked to mitigation of the negative mental and physical effects to combat-exposed personnel, creating resilience (Nassif et al., 2023). The FFMQ thus proves to be a valuable tool for comparing yoga-related mindfulness outcomes across both military and civilian populations and may help guide personalized mindfulness-based interventions to address specific deficits (Bravo et al., 2018; Kelsven et al., 2024; Nassif et al., 2023).

Across the MAIA subscales, the yoga group consistently showed higher post-intervention scores, indicating improvements in interoceptive awareness. Noticing increased significantly in the yoga group, with a large effect size, and a significant between-group difference post-intervention confirmed the effectiveness of yoga in enhancing body awareness. For Not-Distracting, a non-significant trend toward improvement was observed, with a medium effect size, suggesting better sustained attention to bodily sensations. The Not-Worrying subscale showed a small, non-significant improvement in the control group, without meaningful differences between groups. In Attention Regulation, the yoga group showed significant within-group improvement, with a large effect size, reflecting better control over focus on body sensations, a key aspect of interoceptive awareness. Although the between-group difference was not significant, a moderate effect size pointed toward benefits from the intervention. A medium effect size in Emotional Awareness post-intervention suggests the yoga group may have improved their ability to connect bodily sensations with emotions, though this did not reach statistical significance. Self-Regulation did not change significantly within the yoga group, but moderate trends suggest a potential for enhanced emotional and physiological regulation through bodily cues. Body Listening significantly improved in the yoga group, with a large effect size, supporting the idea that yoga fosters better responsiveness to bodily signals. No significant between-group differences were found, though trends again favored the yoga group. In Trust, a moderate effect size indicates a possible post-intervention increase in confidence in bodily sensations in the yoga group, though not statistically significant. These findings suggest that yoga may enhance pilots' interoceptive awareness, particularly in Noticing, Attention Regulation, and Body Listening—skills that support stress management and decision-making in high-stakes environments like aviation. Large effect sizes highlight the practical relevance of these improvements, even where statistical significance was not reached. Medium effect sizes across other subscales suggest that a larger sample or longer intervention might yield additional significant gains. Since emotion regulation and stress response are linked to interoceptive processing—as shown in EEG-based studies (Allegretta et al., 2024)—enhancing body awareness through yoga may be a valuable component of broader psychological resilience strategies for pilots. Our results align with prior mindfulness research in civilian populations, where similar improvements were observed across MAIA subscales such as noticing, attention regulation, emotional awareness, self-regulation, body listening, and trust (Spaccapanico Proietti et al., 2024). This underscores the relevance of comparing different exercise-based interventions in pilot populations before establishing standardized training programs.

All three ASAS dimensions showed increased mean scores in the yoga group post-intervention, suggesting a general positive shift in safety-related attitudes. Self-Confidence significantly improved within the yoga group, with a large effect size, indicating a strong positive impact of the intervention on pilots' confidence in their abilities. Pre-intervention, a medium effect size favored the control group (non-significant), suggesting initially higher confidence. Post-intervention, the effect size shifted—though not significantly—in favor of the yoga group, suggesting that yoga helped close this gap. In Risk Orientation, the yoga group also showed a significant post-intervention increase within group, with a large effect size. This suggests a shift toward a greater acceptance or propensity for risk-taking behavior, with pilots more inclined to engage in actions that involve potential hazards. A medium effect size pre-intervention was found when comparing between groups, suggesting the control group's pilots were initially more conservative in their approach towards risk. This difference between groups diminished after the intervention. Regarding Safety Orientation, the yoga group exhibited a significant within-group improvement, reflecting stronger adherence to safety protocols post-intervention. Though between-group differences were not statistically significant, effect sizes suggest meaningful changes over time. These trends indicate that the yoga intervention may have fostered greater commitment to safe operational practices. The observed changes—especially the large within-group effect sizes—are not only statistically relevant but also practically meaningful. Enhanced Self Confidence may equip pilots to perform better under pressure, a critical factor in aviation safety. The coexistence of increased Risk Orientation and Safety Orientation suggests a more nuanced decision-making profile: calculated risk, where pilots are prepared to accept necessary risks while remaining firmly committed to safety protocols. Such dual orientation supports adaptability without compromising operational safety. It reflects a type of cognitive flexibility important for modern aviation challenges, helping pilots to act decisively while maintaining safety awareness. The yoga group's normalization in Risk Orientation post-intervention further supports this balanced profile. These findings align with literature in civilian and commercial aviation contexts. For example, higher self-efficacy has been associated with improved safety attitudes and reduced stress (Ślazyk-Sobol et al., 2021). Conversely, perceived stress negatively correlates with safety attitudes, with cognitive flexibility and job burnout mediating this relationship (Yanzeng et al., 2024). In decision-making scenarios, civilian pilots often rely on their own direct experience (He et al., 2023), reinforcing the role of Self Confidence in operational performance and in the promotion of safety behaviors. Altogether, our results suggest that yoga may enhance both psychological readiness and decision-making frameworks in pilots by improving self-confidence and aligning risk-taking behavior with strong safety attitudes. These changes could be valuable additions to aviation training programs aimed at improving resilience and reducing stress-related performance decrements.

Post-intervention RPTS scores showed a slight decrease in risk perception for both groups, with negligible change in the control group and a more noticeable, though still modest, reduction in the yoga group. These findings do not indicate a substantial shift in how pilots perceive personal risk, suggesting that yoga alone may not significantly influence this domain. Other factors—such as individual risk attitudes, external conditions (He et al., 2023), age, flight experience and qualifications (O'Hare, 2024),—may play a more decisive role in shaping risk perception. Based on these results, we propose organizing the Risk Perception to Self questionnaire into three thematic categories for more precise analysis: Environmental Conditions including uncontrollable elements such as weather and terrain, which strongly influence safety and decision-making; Pilot Condition reflecting the pilot's physical and mental state, including fatigue and stress, which are critical to in-flight decision-making; Pre-Flight Preparation and Equipment pertaining to the functionality of aircraft systems and thoroughness of checks, which are central to flight readiness and safety. Segmenting the questionnaire this way may allow future studies to better identify specific areas requiring targeted interventions, ultimately contributing to safer aviation operations and enhanced pilot decision-making.

TMT results indicate that participants improved their performance over time, as reflected by reduced mean completion times. For TMTA, medium effect sizes were observed within both the yoga and control groups, though without statistical significance. This suggests modest improvements in visual attention and processing speed that may become significant with a larger sample or extended intervention. TMTB scores showed significant within-group improvement in the yoga group, with a large effect size. This points to a meaningful enhancement in cognitive flexibility and task-switching ability following the 12-week yoga intervention. While between-group differences were not statistically significant, the overall results support yoga's potential for improving higher-order executive functions. The absence of significant between-group effects could be attributed to small sample size or initial baseline differences. Nonetheless, these findings align with prior evidence that even subtle cognitive gains can be operationally meaningful for pilots: military aviators already show stronger cognitive profiles, particularly in verbal learning and visuospatial skills, compared to general population norms, with fewer deficits reported (Maltez-Laurienti et al., 2021). This may explain why only medium effect sizess were observed in TMTA despite functional improvements. Military training appears to cultivate these capabilities, and the yoga program demonstrates potential to further enhance them. Even slight variations in attention and coordination can influence task performance for military pilots, whose roles require sharp attention and precise motor control (Maruta et al., 2023). The TMT provides valuable insights, emphasizing the need for ongoing assessments to ensure peak operational performance. Our findings suggest that yoga could serve as a viable intervention to support mental agility and sustained operational performance.

Strengths, limitations and future perspectives

The intervention proposed is both practical and cost-effective, addressing the challenges military pilots in Portugal face in maintaining their fitness without a structured training regimen. This makes the research applicable and feasible for real-world implementation. The study included the entire population of military aviation pilots, which is difficult to access due to security restrictions and their heavy workload. This adds significant value to the research as it provides rare insights into a unique and hard-to-reach group.

One of the limitations of this study was the small sample size. However, it is important to note that we successfully included the entirety of the available population of military aviation pilots, making the sample highly representative of this specific group, as well as tested for effect sizes of the intervention on the account of the small sample. Another limitation of the study is that we only tested pilots in flight simulations rather than real flight scenarios, which is one of the safest options to test flight emergencies.

While this study focused exclusively on Portuguese Air Force pilots, it is possible that similar challenges related to the lack of a standardized exercise program could be faced by pilots in other military or commercial aviation sectors. This warrants further investigation in future studies to explore whether this issue is more widespread.

Future research should address other (safer) maneuvers and tasks during real flights, by employing robust materials and equipment capable of tolerating military aviation conditions. This would allow for the collection of data more reflective of the actual demands and realities of their profession, providing a more accurate assessment of performance under true operational stressors.

Following this rationale, in future studies it will be crucial to compare the benefits of yoga on performance with the effects of real flight as the latter may also hinder performance: Decreased SpO2, which includes moderate hypoxic exposure that a flight simulator lacks (Keeler et al., 2024); spatial disorientation, that can only be trained in a centrifuge, with galvanic vestibular stimulation or real flight, since flight simulators are most commonly used for training but offer no vestibular stimulation to the flight crew (Allred et al., 2024; Brink et al., 2024); mental fatigue from longer missions, usually involving the use of Modafinil as a countermeasure to limit the effects of fatigue in military aviation (Wingelaar-Jagt et al., 2024); poor visual conditions, countermeasured in simulated flight using a helmet-mounted display (Feltman et al., 2024).

The lack of objective physiological data or self-reports instead of objective data when completing missions should also be a target for future studies on military aviation performance. In future studies in real life settings, the use of robust armband monitors (like the Warfighter MonitorTM), electroencephalogram (EEG) signals, brain electrical activity mapping (BEAM) images or Blink-related oscillations might provide data to compare with the aviation questionnaires, self-reports and objective performance testing (Chen et al., 2024; Page et al., 2024).

Similar to our results, other military yoga programs had participants also demonstrating improved mindfulness scores and reported decreased insomnia, depression, and anxiety symptoms (Cushing et al., 2018). Programs using mindfulness to improve mental toughness showcase possible benefits for performance during boot camp, and predictable advantages for graduation rates (Saul et al., 2024). It is crucial that future research adopts homogeneous reference terms, as well as standardized military aviation questionnaires and similar tests that can serve as a direct source of comparison. This will facilitate the comparison between studies, ensuring greater consistency in the results and contributing to a better understanding of the variables being studied. Uniformity in methodologies will allow for a more accurate analysis of the effects of interventions and psychophysiological responses across different populations and contexts. Further research could explore the long-term effects of such interventions and whether similar improvements can be observed in different types of emergencies or operational contexts, as well as explore these effects in larger and more diverse populations to strengthen the evidence base.

These findings have the potential to influence policymakers to implement mandatory exercise programs for pilots. Such programs could enhance cognitive decision-making and work safety, providing practical applications that can extend beyond military aviation to commercial and civil aviation.

Conclusion

The tragic accident at the Beja AirShow on June 2, 2024, involving two aircrafts and resulting in the death of a civilian Spanish pilot and the hospitalization of a civilian Portuguese pilot, underscores the importance of research in this area to mitigate the risks that pilots face.

The performance results in the flight simulator indicate that the yoga intervention had a positive impact on reducing errors, which is crucial for safety and performance in aviation. While the intervention did not significantly affect the time to complete the task, the reduction in errors suggests improved decision-making and execution under pressure, which are critical outcomes in emergency situations.

The 12-week yoga intervention positively influenced several facets of mindfulness, interoceptive awareness, and safety-related attitudes among pilots. Significant improvements were observed in Aware Actions, Non-Judgmental Inner Critic, and Non-Reactivity, emphasizing the potential of yoga to enhance mindfulness and reduce stress-related reactions. The intervention significantly enhanced pilots' ability to notice, regulate attention, and listen to body sensations, supporting the inclusion of mindfulness practices like yoga in pilot training to improve overall performance and well-being. Furthermore, the program positively influenced pilots' self-confidence, risk orientation, and safety orientation, reinforcing its value in promoting safety in aviation environments.The data supports the notion that a structured yoga program may be beneficial for improving specific aspects of cognitive function, particularly those measured by TMTB.

Integrating mindfulness interventions into pilot training could lead to improved decision-making and adherence to safety standards, ultimately enhancing operational safety in the aviation industry.

SS designed research; SS, OF, JAP and FM conducted research; SS and CAC analyzed data; and all authors wrote the paper. SS had primary responsibility for final content. All authors read and approved the final manuscript.

Data availability

Data described in the manuscript will not be made available because of security reasons.

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During the preparation of this work the author(s) used ChatGPT in order to format the references according to JATRS guidelines. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

CRediT authorship contribution statement

Sara Santos: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Orlando Fernandes:** Writing – review & editing, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis. **Carolina A. Cabo:** Writing – review & editing, Writing – original draft. **José A. Parraca:** Writing – review & editing, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis. **Filipe Melo:** Writing – review & editing, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

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