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Cooper Test Performance and Total Flight Hours as Predictors of Hypoxia Tolerance Among Indonesian Air Force Pilots

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Abstract

Background: Hypoxia is a major physiological threat in military aviation that may impair cognitive performance and operational effectiveness. Physical fitness and cumulative flight experience may be associated with individual differences in hypoxia tolerance.

Objective: To evaluate the associations of Cooper Test performance and total flight hours with hypoxia tolerance among Indonesian Air Force pilots.

Methods: This cross-sectional analytical study included 142 Indonesian Air Force pilots who underwent Indoctrination and Aerophysiology Training at the dr. Saryanto Institute of Aviation and Aerospace Medicine. Secondary aeromedical data included Cooper Test scores, total flight hours, and hypoxia tolerance measured using Time of Useful Consciousness (TUC). Associations were assessed using Spearman's rank correlation and multivariable regression analyses.

Results: The mean Cooper Test score was 50.18 ± 7.80, mean total flight hours were 1,570.90 ± 1,728.50 hours, and mean TUC was 171.27 ± 53.86 seconds. Cooper Test performance was positively correlated with TUC ($r = 0.228$; $p = 0.006$), indicating that higher fitness scores were associated with longer hypoxia tolerance. Total flight hours were moderately and negatively correlated with TUC ($r = -0.482$; $p < 0.001$), indicating that greater cumulative flight experience was associated with shorter hypoxia tolerance. In multivariable analysis, both Cooper Test performance (standardized $\beta = 0.275$; $p < 0.001$) and total flight hours (standardized $\beta = -0.445$; $p < 0.001$) remained significantly associated with TUC, with total flight hours showing the larger absolute standardized coefficient.

Conclusion: Better Cooper Test performance was associated with longer TUC, whereas greater total flight hours were associated with shorter TUC among Indonesian Air Force pilots. The stronger association observed for total flight hours highlights the need to consider cumulative flight exposure alongside cardiovascular fitness in aeromedical assessment and aviation safety strategies.

Keywords: Cooper Test, flight hours, hypoxia tolerance, Time of Useful Consciousness, military pilots

Background

Hypoxia is a major physiological challenge in aviation medicine, particularly among military pilots operating at high altitudes where reduced atmospheric pressure and oxygen availability may impair cognitive performance, judgment, coordination, situational awareness, and operational effectiveness. The gradual onset of hypoxia may delay symptom recognition, allowing pilots to continue operating aircraft despite progressive functional impairment and increasing the risk of aviation incidents. Time of Useful Consciousness (TUC), defined as the duration during which an individual remains capable of performing purposeful actions after exposure to an oxygen-deficient environment before functional incapacitation occurs, is commonly used in aviation medicine as an indicator of hypoxia tolerance.[1–5]

Aerobic fitness and cumulative flight exposure may be associated with individual differences in hypoxia tolerance. Better cardiovascular fitness may enhance oxygen transport and utilization, potentially supporting physiological function during hypoxic exposure. In this study, aerobic fitness was assessed using the Cooper Test score, a fitness score derived from performance in the standardized 12-minute running test and recorded in aeromedical records, with higher scores indicating better cardiovascular fitness. The Cooper Test is commonly used as a practical field assessment of aerobic capacity and is indirectly related to maximal oxygen uptake (VO_2max).[6–8]

Total flight hours, defined as the cumulative number of hours flown throughout a pilot's aviation career, represent cumulative aviation exposure and operational experience. Repeated exposure to aviation environments and occupational stressors may be associated with physiological responses relevant to hypoxia tolerance.[3,9]

Despite the importance of hypoxia tolerance for flight safety and operational readiness, evidence on the combined association of aerobic fitness and cumulative flight exposure with hypoxia tolerance among Indonesian military pilots remains limited. Previous studies have generally examined physical fitness, hypoxic exposure, or aviation-related factors separately, leaving uncertainty regarding their simultaneous associations with TUC in an operational military aviation population. Evaluating these factors together may provide additional evidence for aeromedical assessment and the development of strategies to maintain physiological readiness. Therefore, this study aimed to evaluate the associations of Cooper Test performance and total flight hours with hypoxia tolerance, measured using TUC, among Indonesian Air Force pilots at the dr. Saryanto Institute of Aviation and Aerospace Medicine.

Methods

Study Design and Participants

This analytical observational study used a cross-sectional design to evaluate the associations of Cooper Test performance and total flight hours with hypoxia tolerance among Indonesian Air Force pilots. The study was conducted at the dr. Saryanto Institute of Aviation and Aerospace Medicine (LAKESPRA), Jakarta, Indonesia, using secondary aeromedical data from pilots who underwent Indoctrination and Aerophysiology Training (ILA) between September 2024 and December 2024.

The study population consisted of Indonesian Air Force pilots who underwent aerophysiological evaluation during the study period. A total of 142 pilots with complete records of Cooper Test performance, total flight hours, and Time of Useful Consciousness (TUC) measurements were included using total sampling. Records with missing data for any of the primary study variables were excluded.

Variables and Operational Definitions

The dependent variable was hypoxia tolerance, operationally defined as Time of Useful Consciousness (TUC) measured in seconds during standardized hypobaric chamber training. TUC was defined as the interval from the removal of supplemental oxygen after reaching the target simulated altitude until the participant was no longer able to perform the predefined cognitive or psychomotor task according to the termination criteria of the ILA protocol. TUC measurement was conducted at a simulated altitude of 25,000 feet with a maximum exposure duration of 4 minutes. During hypoxic exposure, participants were instructed to perform simple math tasks, and TUC was recorded according to the standardized ILA hypobaric chamber protocol. Exposure was terminated when the time elapsed or when the participant requested termination because of hypoxia-related symptoms.

The independent variables were Cooper Test performance and total flight hours. Cooper Test performance was assessed using the standardized 12-minute running test. The distance covered during 12 minutes was converted into a fitness score according to the Indonesian Air Force Cooper Test scoring standard, considering age in the scoring. The Cooper Test score was analyzed as a continuous variable, with higher scores indicating better cardiovascular fitness.

Total flight hours were defined as the cumulative number of hours flown by each pilot throughout their aviation career up to the time of aerophysiological assessment. Data were obtained from official aeromedical records and analyzed as a continuous variable representing cumulative aviation exposure and operational experience.

Data Collection

Secondary data were obtained from aeromedical records maintained by LAKESPRA dr. Saryanto. Extracted variables included participant characteristics, Cooper Test scores, total flight hours, and TUC measurements. Data collection was conducted after institutional permission and ethical approval had been obtained.

Potential confounding variables, including age, body mass index, hemoglobin concentration, smoking status, and sleep quality, were not consistently available in the secondary aeromedical records and therefore could not be included in the adjusted statistical models.

Statistical Analysis

Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) version 25.0. Continuous variables were summarized as means and standard deviations. The distribution of continuous variables was assessed using the Kolmogorov-Smirnov test.

Because Cooper Test scores and total flight hours were not normally distributed, bivariate associations between Cooper Test performance, total flight hours, and TUC were evaluated using Spearman's rank correlation coefficient (ρ). Correlation coefficients were interpreted according to established criteria. Statistical significance was defined as a two-sided p value < 0.05.

A multiple linear regression analysis was performed to evaluate the independent associations of Cooper Test performance and total flight hours with TUC as a continuous dependent variable. Both independent variables were entered simultaneously into the regression model. Unstandardized regression coefficients (B) with 95% confidence intervals (CIs), standardized regression coefficients (β), and p values were reported. The absolute standardized β coefficients were compared to describe the relative strength of the associations between each independent variable and TUC. Because potentially relevant confounding variables were unavailable in the secondary dataset, the multivariable model was limited to Cooper Test performance and total flight hours.

Ethical Considerations

This study was approved by the Health Research Ethics Committee of the Republic of Indonesia Defense University under approval number 2408031 and the Health Research Ethics Committee of the LAKESPRA dr. Saryanto under approval number 002511. All data were anonymized before analysis to protect participant confidentiality and privacy. The study was conducted in accordance with the ethical principles of the Declaration of Helsinki.

Results

Participant Characteristics

A total of 142 Indonesian Air Force pilots with complete data on Cooper Test performance, total flight hours, and Time of Useful Consciousness (TUC) were included in the analysis. Baseline participant characteristics are presented in Table 1. The mean age of the participants was 30.23 ± 5.12 years, with a mean body mass index of 24.12 ± 2.11 kg/m² and a mean length of military service of 20.89 ± 4.54 years. Other available demographic and aeromedical characteristics are also summarized in Table 1.

The mean Cooper Test score was 50.18 ± 7.80. The Cooper Test variable represented a fitness score derived from the standardized 12-minute running test according to the scoring system used in Indonesian Air Force aeromedical records, rather than directly measured maximal oxygen uptake (VO_2max) or raw running distance. The mean total flight hours were 1,570.90 ± 1,728.50 hours, whereas the mean TUC was 171.27 ± 53.86 seconds.

Table 1. Baseline characteristics of the study participants

Variable	Value
Age, years	30.23 ± 5.12
Body mass index, kg/m²	24.12 ± 2.11
Length of military service, years	20.89 ± 4.54
Cooper Test score	50.18 ± 7.80
Total flight hours, hours	1,570.90 ± 1,728.50
TUC, seconds	171.27 ± 53.86

Normality Analysis

The distribution of continuous variables was assessed before inferential analysis. The results of the normality tests are presented in Table 2. Because Cooper Test scores and total flight hours were not normally distributed, nonparametric correlation analysis using Spearman's rank correlation coefficient was performed.

Table 2. Normality test results

Variable	Statistical test	p-value	Interpretation
Cooper Test score	Kolmogorov-Smirnov	<0.0002	Non-normal

Variable	Statistical test	p-value	Interpretation
Total flight hours	Kolmogorov-Smirnov	<0.0001	Non-normal
TUC	Kolmogorov-Smirnov	0.0922	Normal

Correlation Analysis

Spearman's rank correlation analysis demonstrated a weak positive correlation between Cooper Test performance and TUC ($\rho = 0.228$; $p = 0.006$), indicating that higher Cooper Test scores were associated with longer TUC. In contrast, total flight hours showed a moderate negative correlation with TUC ($\rho = -0.482$; $p < 0.001$), indicating that greater cumulative flight hours were associated with shorter TUC. The results of the bivariate correlation analysis are presented in Table 3.

Table 3. Correlation between independent variables and hypoxia tolerance

Variable	Correlation coefficient (r)	p-value	Interpretation
Cooper Test score	0.228	0.006	Weak positive correlation
Total flight hours	-0.482	<0.001	Moderate negative correlation

Multivariable Analysis

Multiple linear regression analysis was performed to evaluate the independent associations of Cooper Test performance and total flight hours with TUC. The regression results are presented in Table 4.

Cooper Test performance was positively associated with TUC after adjustment for total flight hours ($B = 1.891$; 95% CI, 1.00 to 2.78; standardized $\beta = 0.275$; $p < 0.001$). Total flight hours were negatively associated with TUC ($B = -0.014$; 95% CI, -0.019 to -0.009; standardized $\beta = -0.445$; $p < 0.001$).

The absolute standardized regression coefficient was larger for total flight hours than for Cooper Test performance ($|\beta| = 0.445$ vs. 0.275), indicating a stronger association between total flight hours and TUC within the fitted regression model. However, this finding should not be interpreted as evidence of a causal influence because of the cross-sectional study design.

Table 4. Multiple linear regression analysis of factors associated with Time of Useful Consciousness

Variable	B	95% CI	Standardized β	p-value	VIF
Cooper Test score	1.891	1.00 to 2.78	0.275	0.00003	1.120
Total flight hours	-0.014	-0.019 to -0.009	-0.445	0.00002	1.120

Discussion

The present study evaluated the associations of Cooper Test performance and total flight hours with hypoxia tolerance, measured using Time of Useful Consciousness (TUC), among Indonesian Air Force pilots. Cooper Test performance showed a weak positive correlation with TUC, whereas total flight hours demonstrated a moderate negative correlation. Both variables remained significantly associated with TUC in the multivariable regression model, with total flight hours showing a larger absolute standardized regression coefficient than Cooper Test performance. These findings indicate that better aerobic fitness was associated with longer hypoxia tolerance, whereas greater cumulative flight exposure was associated with shorter TUC. However, because of the cross-sectional design, these associations should not be interpreted as evidence of causal relationships.

The positive association between Cooper Test performance and TUC is physiologically plausible. Higher aerobic fitness is generally associated with more efficient cardiovascular function, oxygen delivery, and peripheral oxygen utilization, which may support physiological performance during acute hypoxic exposure. Individuals with better aerobic capacity may also demonstrate more effective ventilatory and cardiovascular responses when oxygen availability decreases. The observed positive correlation between Cooper Test performance and TUC therefore supports the potential relevance of maintaining cardiovascular fitness among military pilots. Nevertheless, the correlation was weak, suggesting that aerobic fitness alone explains only a limited proportion of the individual variability in hypoxia tolerance and that other physiological, environmental, and occupational factors may also contribute.

Total flight hours showed a moderate negative association with TUC and remained negatively associated with hypoxia tolerance in the multivariable model. Pilots with greater cumulative flight hours tended to have shorter TUC values. This finding should be interpreted cautiously because total flight hours may represent not only cumulative aviation exposure but also differences in age, duration of military service, aircraft type, operational workload, and other occupational characteristics. One possible explanation is cumulative fatigue or long-term aviation-related physiological stress; however, this interpretation remains hypothetical and should be confirmed in future longitudinal studies. Repeated exposure to occupational stressors, irregular work schedules, circadian disruption, and demanding flight environments may be associated with physiological changes relevant to hypoxia tolerance, but the present study cannot determine whether these factors explain the observed association. Furthermore, repeated hypoxic exposure may produce different physiological responses depending on exposure intensity, duration, recovery periods, and individual susceptibility. Therefore, the negative association between total flight hours and TUC should not be interpreted as evidence that greater flight experience directly causes reduced hypoxia tolerance.

The larger absolute standardized regression coefficient observed for total flight hours compared with Cooper Test performance suggests that cumulative flight exposure showed a stronger statistical association with TUC within the fitted regression model. However, this comparison does not establish that total flight hours is a causal determinant of hypoxia tolerance or that it is clinically more important than physical fitness. Residual confounding may partly explain the observed association because relevant factors such as age, body composition, hemoglobin concentration, smoking status, sleep quality, fatigue, and duration of military service were not available for adjustment. Future studies should evaluate whether the association between total flight hours and TUC persists after accounting for these potential confounders.

From an aeromedical perspective, the findings suggest that assessment of hypoxia tolerance may benefit from considering both physical fitness and cumulative aviation exposure. Maintaining adequate aerobic fitness remains relevant for physiological readiness, while pilots with extensive cumulative flight exposure may warrant continued periodic aeromedical evaluation and standardized hypoxia-awareness training. Nevertheless, the present findings should not be used to establish specific screening thresholds or changes in flight eligibility because the study was observational and did not evaluate prospective clinical or operational outcomes. Longitudinal studies incorporating standardized TUC protocols and relevant physiological and occupational covariates are needed before specific aeromedical recommendations can be established.

Strengths and Limitations

This study has several strengths, including the use of objective aeromedical records, standardized assessments of physical fitness and hypoxia tolerance, and the simultaneous evaluation of Cooper Test performance and cumulative flight exposure among Indonesian military pilots. The study also provides evidence from a population that remains underrepresented in aviation medicine research.

Several limitations should be acknowledged. First, the cross-sectional design precludes causal inference and does not establish the temporal relationship between flight exposure, physical fitness, and hypoxia tolerance. Second, the use of secondary data limited the availability of potentially important confounding variables, including age, body composition, hemoglobin concentration, smoking status, sleep quality, fatigue, and duration of military service. Third, total flight hours may reflect multiple correlated occupational characteristics and should not be interpreted as an isolated physiological exposure. Finally, the study was conducted at a single aeromedical institution and included Indonesian Air Force pilots, which may limit the generalizability of the findings to other military and civilian aviation populations.

Recommendations

Future longitudinal and multicenter studies should investigate changes in hypoxia tolerance over time and determine whether the observed associations persist after adjustment for demographic, physiological, and occupational confounders. Studies should incorporate standardized hypobaric chamber protocols and detailed measures of age, body composition, hemoglobin concentration, smoking status, sleep quality, fatigue, military service duration, aircraft type, and operational exposure. Further research is also needed to determine whether Cooper Test performance and cumulative flight exposure can contribute to prospective risk stratification or individualized aeromedical surveillance.

Conclusion

Better Cooper Test performance was associated with longer Time of Useful Consciousness (TUC), whereas greater total flight hours were associated with shorter TUC among Indonesian Air Force pilots. Total flight hours showed a stronger statistical association with TUC than Cooper Test performance within the fitted regression model. However, these findings should be interpreted as associations rather than causal relationships because of the cross-sectional study design and potential residual confounding. The findings support the importance of maintaining cardiovascular fitness and monitoring cumulative flight exposure as part of aerophysiological readiness and aviation safety programs. Further longitudinal studies incorporating relevant demographic, physiological, and occupational factors are needed to clarify these associations and their potential implications for aeromedical practice.

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Author Contributions

All authors act as the guarantor of the manuscript. BWB is the main investigator of this study. NL, HM, PP, and AW participated in the conception, data acquisition, data interpretation, writing of the study, data analysis, and statistical analysis of the study.

Conflict of Interest

The authors declare no conflict of interest.

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