Relationship of fatigue, physical fitness and cardiovascular endurance to the hypoxic response of military pilots in Indonesia

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Abstract. Even with pressurized aircraft cabins, hypoxic conditions present a continual threat for pilots. The purpose of this study was to determine the risk factors associated with hypoxia for Indonesian military pilots. This cross-sectional study consecutively recruited 120 military pilots who carried out education and aerophysiology exercises during June 2017 at Saryanto Institute for Medical and Health Aviation and Aerospace, Jakarta, Indonesia. The subjects exercised in a hypobaric chamber simulating an altitude of 25,000 ft (7600 m), and their response to hypoxia were characterized by time of useful consciousness (TUC). Multivariate logistic regression was used to analyze relationships between TUC with a cutoff of <4 min and parameters of fatigue, physical fitness, cardiovascular endurance (VO₂max), and characteristics of the pilots. Fatigue, physical fitness, and VO₂max did not show a statistically significant relationship with TUC (p > 0.05). Total flight hours and smoking habits were found to be the main factors affecting TUC. The subjects with more than 1000 flight hours were at 2.6 times higher risk to have TUC <4 min (odds ratio 2.65; 95% confidence interval 1.21–5.78; p = 0.014). Compared with the non-smokers, the smokers showed a 63% lower risk of TUC <4 min (odds ratio 0.37; 95% confidence interval 0.14–0.95; p = 0.039). In summary, fatigue, physical fitness, and cardiovascular endurance were not associated with a hypoxic response characterized by TUC <4 min, but total flight hours ≥1000 increased the risk of TUC <4 min and being a smoker reduced the risk.

1. Introduction

Most recent plane crashes and serious incidents during flight operations in Indonesia have occurred in the Papua region. Over the last decade, there have been 25 plane crashes and 33 serious incidents described as “near misses.” It has been suggested that the plane crashes in Papua are related to the region's exact geography south of the equator; its mountainous topography and climate vary greatly from those in the rest of Indonesia. A range of high mountains 650 km long runs through the center of the island of Papua. This includes the Jayawijaya Mountains, known for having the three highest
peaks, which are continually covered in snow: Jayawijaya at 5030 m (15,090 ft), Trikora at 5160 m (15,480 ft), and Yamin at 5100 m (15,300 ft) [1].

Even with pressurized cabins, hypoxic conditions present a continual risk for aircraft pilots. The effects of hypoxia begin to be observed at a height of 1500 m (5000 ft), with decreased vision, especially at night. Symptoms, which include impaired cognitive ability and concentration, become more pronounced with increased elevation and can affect the performance and ability of pilots while flying aircraft [2]. During flights in the mountainous region of Papua, pilots are repeatedly exposed to low partial oxygen pressures. Some may not realize how often they are likely to experience hypoxia (insidious hypoxia) and the resulting risk of unsafe behavior and action. Military pilots perform daily flying tasks, sometimes including emergency operations, as well as out-of-flight tasks; together, these contribute to varying levels of fatigue and cardiac vascular endurance, which can affect the decline in the pilot's performance. It is therefore important to establish the hypoxia risk factors for military pilots, especially risks related to fatigue, physical fitness, and cardiovascular endurance. The aim of this study was to investigate the factors that affected the hypoxic response of Indonesian military pilots, characterized by time of useful consciousness (TUC) at 25,000 ft, including fatigue, physical fitness, and cardiovascular endurance, as well as demographic and work-related parameters.

2. Methods
The study protocol was approved by the Health Research Ethics Committee, Faculty of Medicine, Universitas Indonesia-Cipto Mangunkusumo Hospital. This cross-sectional study was conducted in June 2017. The subjects were enrolled by consecutive sampling from military pilots who were undergoing education and aerophysiology exercises (the ILA course) at Saryanto Institute for Medical and Health Aviation and Aerospace. The inclusion criteria were that they were active military pilots undergoing education and aerophysiologic exercises (the ILA course) at Saryanto Institute for Medical and Health Aviation and Aerospace. The inclusion criteria were that they were active military pilots who were undergoing the ILA, met the physical requirements of the ILA (in terms of hemoglobin level, spirometry, and a normal chest X-ray), and who were willing to participate and signed the consent form. Pilots who did not pass the sinus examination were excluded. All the subjects were provided written informed consent.

The pilots' hypoxic response was measured as TUC while they exercised in a hypobaric chamber with a simulated altitude of 25,000 ft (7600 m). At this altitude, the average TUC is 3–5 min [3]. In the present study, the subjects were divided into two categories: TUC ≥ 4 min and TUC < 4 min.

Fatigue was classified using the IFRC questionnaire administered before the subjects started the ILA. The fatigue scores were divided into mild (31–60), moderate (61–90), and severe (91–120) [4]. For this study, physical fitness was considered to be the ability of the subjects to perform their daily work activities efficiently without experiencing significant fatigue and still to have energy reserves to perform other activities. It was classified as sufficient or good [5]. Cardiovascular endurance was indicated by VO₂max values measured at the start of the ILA. The VO₂max values were classified according to the subject's age as sufficient, moderate, or good [6].

Each subject's total flight hours as a military pilot prior to the ILA was calculated, and the subjects were divided into those with <1000 h and those with ≥1000 h. The subject's rank was classified as either a middle-ranking officer or a lower-ranking officer, and the subjects were divided according to their duration of military service as <10 years or ≥10 years. The average number of flights per day over the previous 30 days was also calculated.

Smoking habits were assessed with the Brinkman index (the number of cigarettes smoked per day multiplied by the number of smoking years), and the subjects were divided into non-smokers, light smokers, and heavy smokers. Each subject's age at the start of the ILA was obtained from the date of birth on his ID card and categorized as <30 years or ≥30 years. The amount of physical exercise undertaken each week was categorized according to whether or not the subject met the recommendation of ≥75 min/week of exercise at a vigorous intensity [7]. Body mass index (BMI) was calculated as body weight (in kg) multiplied by the square of the height (in m) and categorized according to BMI threshold in Indonesia as normal (≤25 kg/m²) or overweight (>25 kg/m²).
The analysis included descriptive statistics of each parameter followed by bivariate analysis, calculating odds ratios (ORs) with 95% confidence intervals (CIs) for the likelihood of the subject having TUC <4 min. A p-value of 0.05 was considered statistically significant. Parameters with $p < 0.025$ in the bivariate analyses were included in multiple multivariate logistic regression analyses, calculating ORs with 95% CIs for the likelihood of the subject having TUC <4 min. The statistical analyses were performed using SPSS 20.

3. Results
During the data collection period in June 2017, 120 pilots underwent the hypoxia simulation at low pressurized airspace (RUBR) of Saryanto Institute for Medical and Health Aviation and Aerospace, Jakarta. All met the inclusion criteria and were willing to participate. The number of subjects enrolled was greater than the estimated required sample size of 106 subjects. Table 1 summarizes their median age, length of service, and flight hours, and Tables 2 and 3 show how the subjects were distributed between the various demographic and work-related categories, respectively.

| Table 1. Median age, length of service, and total flight hours ($N=120$). |
|---------------------------------|-----------------|
| Median (Range)                  |                 |
| Age, y                          | 29 (21–54)      |
| Length of service, y            | 8 (1–32)        |
| Total flight hours, h           | 588 (50–6236)   |

| Table 2. Subject distribution for the demographic categories ($N=120$). |
|----------------------|-----|---|
|                      | n   | % |
| Age                  |     |   |
| <30 years old        | 61  | 50.8|
| ≥30 years old        | 59  | 49.2|
| Rank                 |     |   |
| Middle-ranking officer| 25  | 20.8|
| Lower-ranking officer| 95  | 79.2|
| Body mass index      |     |   |
| Normal               | 76  | 63.3|
| Overweight           | 44  | 36.7|
| Length of service    |     |   |
| <10 years            | 71  | 59.2|
| ≥10 years            | 49  | 40.8|
| Physical fitness     |     |   |
| Sufficient/good      | 93  | 77.5|
| Excellent            | 27  | 22.5|

| Table 3. Subject distribution for the work-related categories ($N=120$). |
|----------------------|-----|---|
|                      | n   | % |
| Total flight hours   |     |   |
| < 1000 hours         | 68  | 56.7|
| ≥ 1000 hours         | 52  | 43.3|
| Number of flights per day |   |   |
| 1                     | 49  | 40.8|
| 2                     | 47  | 39.2|
| 3                     | 24  | 20.0|
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Table 3. Continue

| Aircraft type          | n  | %  |
|------------------------|----|----|
| Rotary wing            | 39 | 32.5 |
| Fixed wing             | 81 | 67.5 |
| Instrument rating      |    |    |
| Helicopter             | 39 | 32.5 |
| Transport aircraft     | 41 | 34.2 |
| Fighter aircraft       | 40 | 33.3 |

Table 4 summarizes the distribution of the subjects according to the physical health-related categories. The vast majority of subjects met the recommended level of weekly exercise. Most did not smoke, but those who did were all classified as light smokers (Brinkman index, 1–599). Of the 120 subjects, 44 (37%) had TUC <4 min.

Table 4. Subject distribution for physical health-related categories and time of useful consciousness.

| Physical exercise                  | n  | %  |
|------------------------------------|----|----|
| Below recommended level            | 18 | 15.0 |
| As recommended                     | 102| 85.0 |
| Smoking habit                      |    |    |
| Non-smoker                         | 86 | 71.7 |
| Light smoker                       | 34 | 28.3 |
| Fatigue                            |    |    |
| Mild                               | 101| 84.2 |
| Moderate                           | 19 | 16.8 |
| VO$_2$ max classification          |    |    |
| Sufficient                         | 42 | 35.0 |
| Moderate                           | 50 | 41.7 |
| Good                               | 28 | 23.3 |
| Time of useful consciousness       |    |    |
| ≥4 min                             | 76 | 63.3 |
| <4 min                             | 44 | 36.7 |

Table 5 shows the analysis of the relationships between the demographic characteristics and whether the subjects had TUC <4 min. The subjects older than 30 years (OR 2.54, 95% CI 1.18–5.46) and those with length of service ≥10 years (OR 2.85, 95% CI 1.32–6.15) were significantly more likely to have TUC <4 min.

Table 5. Relationship of demographic characteristics with time of useful consciousness.

| Time of useful consciousness |       | Hard odds ratio | 95% confidence interval | P    |
|------------------------------|-------|-----------------|-------------------------|------|
|                             | ≥4 min (N = 76) | <4 min (N = 44) |                         |      |
| n                            | %     | n               | %                       |      |
| Age                          |       |                 |                         |      |
| <30 years                    | 45    | 73.8            | 16                      | 26.2 | 1.00 | Reference |
| ≥30 years                    | 31    | 52.5            | 28                      | 47.5 | 2.54 | 1.18–5.46 | 0.016 |
| Rank                         |       |                 |                         |      |
| Middle-ranking officer       | 13    | 52.0            | 12                      | 48.0 | 1.00 | Reference |
| Lower-ranking officer        | 63    | 66.3            | 32                      | 33.7 | 0.55 | 0.23–1.34 | 0.186 |
Table 5. Continue

| Time of useful consciousness | Hard odds ratio | 95% confidence interval | P   |
|-----------------------------|-----------------|------------------------|-----|
| ≥4 min (N = 76)             | <4 min (N = 44)  |                       |     |
| n                           | n               |                        |     |
| 45                          | 31              | 59.2                   | 40.8| 1.00 Reference |
| 31                          | 13              | 70.5                   | 29.5| 0.61 0.28–1.35 0.218 |

Body mass index

Normal

Overweight

Length of service

<10 years

≥10 years

Physical fitness

Enough and good

Excellent

Table 6 shows the analysis for the work-related characteristics. The subjects with more than 1000 flight hours were significantly more likely to have TUC <4 min (OR 2.78, 95% CI 1.18–5.46).

Table 6. Relationship of work-related characteristics with time of useful consciousness

| Time of useful consciousness | Hard odds ratio | 95% confidence interval | P   |
|-----------------------------|-----------------|------------------------|-----|
| ≥4 min (N = 76)             | <4 min (N = 44)  |                       |     |
| n                           | n               |                        |     |
| 50                          | 18              | 73.5                   | 26.5| 1.00 Reference |
| 26                          | 50              | 50.0                   | 50  | 2.78 1.18–5.46 0.008 |

Numbers of flight per day

1

2

3

Type of Aircraft

Rotary wing

Fixed wing

Instrument Rating

Helicopter

Transport aircraft

Fighter aircraft

Table 7 shows the analysis for the physical health-related characteristics. The subjects who smoked were significantly less likely to have TUC <4 min than those who did not smoke (OR 0.34, 95% CI 0.34–0.87).

Table 8 shows the subjects with more than 1000 flight hours were at 2.65 times greater risk of having TUC <4 min compared with the subjects with total flight hours less than this. In addition, the subjects with a smoking habit were 63% less likely to have TUC <4 min when compared with the non-smokers.
Table 7. Relationships of physical health-related characteristics with time of useful consciousness.

| Time of useful consciousness | Hard odds ratio | 95% confidence interval | p |
|------------------------------|-----------------|-------------------------|---|
| ≥4 min (N = 76)              |                 |                         |   |
| Physical exercise            |                 |                         |   |
| Deficient                    | 14 77.8        | 4 22.2                  | 1.00 | Reference |
| As recommended               | 62 60.8        | 40 39.2                 | 2.26 | 0.69–7.35 | 0.168 |
| Smoking habit                |                 |                         |   |
| Non-smoker                   | 49 57.0        | 37 43.0                 | 1.00 | Reference |
| Light smoker                 | 27 79.4        | 7 20.6                  | 0.34 | 0.34–0.87 | 0.022 |
| Fatigue                      |                 |                         |   |
| Mild                         | 62 61.4        | 39 38.6                 | 1.00 | Reference |
| Moderate                     | 14 73.7        | 5 26.3                  | 0.57 | 0.19–1.70 | 0.307 |
| VO₂₃max classification       |                 |                         |   |
| Sufficient                   | 26 61.9        | 16 38.1                 | 1.00 | Reference |
| Moderate                     | 35 70.0        | 15 30.0                 | 0.70 | 0.29–1.66 | 0.413 |
| Good                         | 15 53.6        | 13 46.4                 | 1.41 | 0.53–3.71 | 0.488 |

Table 8. Interconnected total flight hours and smoking with time of useful consciousness.

| Time of useful consciousness | Odds ratio | 95% confidence interval | p |
|------------------------------|------------|-------------------------|---|
| ≥4 min (N = 76)              |            |                         |   |
| Total flight hour            |            |                         |   |
| <1000 hours                  | 50 73.5    | 18 26.5                 | 1.00 | Reference |
| ≥1000 hours                  | 26 50.0    | 26 50.0                 | 2.65 | 1.21–5.78 | 0.014 |
| Smoking habit                |            |                         |   |
| Non-smoker                   | 49 57.0    | 37 43.0                 | 1.00 | Reference |
| Light smoker                 | 27 79.4    | 7 20.6                  | 0.37 | 0.14–0.95 | 0.039 |

4. Discussion

This study assessed factors associated with a hypoxic response of TUC <4 min at a simulated altitude of 25,000 ft in Indonesian military pilots. The study considered factors such as fatigue, physical fitness, and cardiovascular endurance, as well as a range of demographic and work-related parameters. The findings indicated that the pilots aged ≥30 years, and those with more than 10 years of service or more than 1000 flight hours' experience, were more at risk of having TUC <4 min, whereas those who smoked were at a lower risk.

The association between older age and hypoxic response is consistent with previous reports that vital pulmonary capacity peaks at age 20 and begins to decline as age increases [8]. In addition, older people experience a decrease in VO₂₃max. The finding for length of service in this study may be related to the relationship with age; the pilots with longer employment were likely to be older.

The subject's rank, BMI, and level of physical fitness would be expected to have an association with TUC <4 min. Proportionately fewer of the lower-ranking officers than middle-ranking officers had TUC <4 min; this may have been because the lower-ranking officers tended to be under 30 years
and to have better vital pulmonary capacity than the middle-ranking officers, most of whom were older than 30 years. This result is in accordance with research by Gunarsih et al. that showed that TUC decreased with age [9]. Proportionately fewer pilots with BMIs indicating overweight had TUC <4 min. This contrasts with the common expectation that people who are obese would be more at risk because of decreased lung function due to pulmonary restriction caused by abdominal fat accumulation or central obesity (a ventilation–perfusion mismatch) [10]. In contrast to our results, the study by Gunarsih et al. found that TUC decreased with higher BMI [9]. In the present study, it was possible that the pilots did not have central obesity so abdominal fat did not cause pulmonary restriction.

TUC <4 min in this study appeared to be more likely among the pilots with excellent physical fitness rather than those with sufficient or good fitness. This was in accordance with the theory that people with high levels of physical fitness tend to have high oxygen consumption and so would be susceptible to hypoxia. The result was also consistent with that obtained in the study by Perdana, where there was no relationship between the level of physical fitness and TUC on air force patients [11].

In this study, there was no significant relationship with TUC <4 min for the number of flights per day or the type of aircraft transport rating. This may be due to bias in the number of flights per day. Pilots can fly 1–3 times a day in the same portion alternately between the pilots. In addition, transport planes normally have a pressurized cabin, so the pilot is rarely exposed to hypoxic conditions.

A greater proportion of the pilots flying fixed wing aircrafts had TUC <4 min compared with those flying helicopters. This may be because the fixed wing pilots usually flew in pressurized cabin conditions so that their resistance and adaptation to the hypoxic environment was less, leaving them more susceptible to hypoxia [11]. This could also apply to fighter pilots.

This study showed no relationship of fatigue or VO2max with TUC <4 min. There may have been bias arising from VO2max being measured on a different day to that of the RUBR exercise, allowing the possibility that it may have changed. Fatigue was assessed by a questionnaire, which may not have reflected the actual level of fatigue at the time of the experiment.

The pilots who met the physical exercise recommendations (≥75 min/week of vigorous exercise) appeared to be at higher risk of having TUC <4 min. This was in accordance with the notion that physical exercise increases muscle mass and capillary density thereby increasing oxygen ability by muscle [12]. This condition can lead to hypoxia vulnerability for pilots with large muscle mass.

The pilots with more than 1000 flight hours were at 2.65 times greater risk of having TUC <4 min compared with the other pilots. This may be because these pilots tended to be more experienced and so able to recognize the initial hypoxic response before they experienced hypoxic conditions, so in the RUBR exercise; they were more likely than the less-experienced pilots to wear an oxygen mask. This possibility can be biased under the actual conditions of their TUC capabilities.

The pilots who smoked were at 63% less risk of having TUC <4 min compared with the non-smokers. This contradicts the theory that smoking 20–30 cigarettes within 24 h before a flight can increase the saturation of COHb to 8–10% [10]. The result that smoking reduced the risk for TUC <4 min may be explained by a tendency for the smoker to have cell and tissue adaptations to compensate for reduced oxygen levels in the blood; however, this requires more research.

There were some limitations to this study. Fatigue level was not measured objectively, but only from a questionnaire; there was therefore a possibility of bias compared with the subjects’ actual fatigue condition. Physical fitness and VO2max were measured on different days from the RUBR exercises so that the TUC results may not be meaningful. The study sample was determined by consecutive sampling in accordance with the inclusion criteria; the sample may therefore not have reflected the overall population of pilots. There was a possibility of recall bias in the reporting of smoking habits, physical exercise, total flight hours, and length of service; however, this was controlled by the researcher asking to see each subject's logbook and giving them time to remember when answering. This study also had specificity in the form of the relationship of fatigue, physical
fitness, and cardiovascular endurance with hypoxia characterized by TUC, which is specific to aviation.

5. Conclusions
In this study, 37% of the Indonesian military pilots had TUC <4 min while carrying out the RUBR exercise. The main factors associated with TUC were having more than 1000 flight hours of experience (which increased the risk of TUC <4 min) and being a smoker (which reduced the risk). Other factors that showed a significantly greater risk of TUC <4 min were older age and length of service.

The main factors studied were fatigue, physical fitness, and cardiovascular endurance (measured as VO$_{2\text{max}}$), but these did not show a significant relationship with TUC. However, in theory, these factors could contribute to lengthening or shortening TUC. There is a need for further research with more objective measurements for fatigue, physical fitness, and VO$_{2\text{max}}$ made on the same day as the RUBR exercises.

References
[1] Topografi Papua 2017 [cited on March 1, 2017] Available from: http://ms.wikipedia.org/wiki/papua
[2] Rainford D J, Gradwell D P 2006 Ernsting’s aviation medicine ed D J Rainford, D P Gradwell (London: Edward Arnold Ltd.)
[3] Shaver C R 2009 Hypoxia training and pilot use of supplemental oxygen above 25000 feet. (Colorado: Embry Riddle Aeronautical University)
[4] Andiningsari P 2009 Hubungan faktor internal dan eksternal terhadap tingkat kelelahan (fatigue) pada pengemudi Travel X trans trayek Jakarta-Bandung tahun 2009 (Depok: Faculty of Public Health, Universitas Indonesia)
[5] Bujuknis kesamaptaan TNI AU 2013 Petunjuk teknis tentang pembinaan jasmani (Jakarta: Department of Health, Indonesia Air Force)
[6] First beat 2014 Automated fitness level (VO$_{2\text{max}}$) estimation with heart rate and speed data (Finland: First beat technologies)
[7] McAllister R M, Laughlin M H. 2006 Vascularnitricoxide: effects of physical activity, importance for health Essays Biochem 42 119–131
[8] Rochat M K, Laubender R P, Kuster D, Braendli O, Moeller A, Mansmann U, Von Mutius E and Wildhaber J 2013 Spirometry reference equations for central European populations from school age to old age PLoS One 8 e52619
[9] Gunarsih V G, Ekasari F, Drastyawan B and Basuki B 2014 Hubungan kadar hemoglobin dan faktor-faktor lain terhadap waktu sadar efektif di kalangan calon dan awak pesawat–militar pada simulasi ketinggian 25000 kaki (Jakarta: Faculty of Medicine, Universitas Indonesia)
[10] Lad U P, Jaltade V G, Shisedo-Lad S and Satyanaryayana P 2012 Correlation between body mass indeks (BMI), body fat percentage and pulmonary functions in under weight, over weight, and normal weight adolescents J. Clin. Diagnostic Res. 6 350–353
[11] Perdana D P 2014 Hubungan antara nilai indeks samapta terhadap time of useful conciousness pada calon pasissekbang TNI AU yang melakukan ILA di Lakespra tahun 2014 (Jakarta: Indonesia Air Force)
[12] Mulyadi H and Yulieanto H 2004 Hubungan antara cardio vascular endurance dengan aerofisiologi hipoksia. Disampaikan dalam Simposium Kardiologi Penerbangan. Jakarta.