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ORIGINAL ARTICLE

Hypoxia and Time of Useful Consciousness in Hypobaric Chamber at 25,000 feet in Aircrew at dr. Saryanto Health Institute of Aeronautics and Space

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ABSTRACT

Introduction: Hypoxia is a condition characterized by insufficient oxygen supply to tissues which causes body tissues to fail to get adequate oxygen supply. Hypobaric hypoxia is generally recognized as the most serious physiological hazard during high-altitude flight. This puts active crew members at risk for hypoxia and so they rely on effective performance time (EPT) or time useful consciousness (TUC) to take appropriate corrective and protective actions when hypoxia occurs. This study aimed to describe TUC scores and hypoxia symptoms experienced by active flight crew at dr. Saryanto Health Institute of Aeronautics and Space in 2021. **Methods:** A descriptive research design using medical record data from 99 flight crew with simple random sampling. The variables in this study consisted of hypoxia symptoms and TUC scores. This study uses univariate analysis to see the frequency distribution of the variables of hypoxia symptoms and TUC score. **Results:** The results showed that 18.2% experienced cognitive symptoms, 4% experienced psychomotor symptoms, 16.2% experienced visual symptoms, 3% experienced psychological symptoms, 54.5% experienced non-spesific symptoms, and 37.4% did not feel any symptoms. Most of the flight crew (68.7%) had sufficient EPT/TUC scores (3-4 minutes). **Conclusion:** Active flight crews feel symptoms of hypoxia and have sufficient TUC scores.

Keywords: aircrew, hypoxia, time of useful consciousness

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INTRODUCTION

Hypoxia occurs when there is insufficient oxygen available at the tissue level to sustain proper homeostasis. This can be brought on by either low blood supply or low oxygen content (hypoxemia), which results in insufficient oxygen transport to the tissues (Bhutta, Alghoula and Berim, 2022). When experiencing hypoxia, body tissues fail to obtain an adequate supply of O2 (Chiang *et al*., 2021). Human body tissues are very sensitive and susceptible to the effects of oxygen deprivation. Hypoxia can cause pathological vasoconstriction which will cause tissue damage (Rosyanti *et al*., 2019). Hypoxemia that results from this causes a metabolic shock that damages brain function and, in cases where it gets worse, will lead to unconsciousness and, finally, death (Shaw, Cabre and Gant, 2021). One of the main effects of hypoxia is decreased mental skills, which will reduce the ability to make decisions, remember, and perform skilled motor movements (Hall and Hall, 2020). Symptoms like weariness, headaches, nausea, vertigo, and cognitive impairments can result from either insufficient or inadequate adaptation. Even after an immediate exposure to hypobaric hypoxia, this may contribute to the development of disorders connected to high altitude (Theunissen *et al*., 2022). When on an aircraft, any factor that causes a decrease in mental function or prowess can result in errors that can threaten the lives of aviators, passengers, and people on the ground (Patrão *et al*., 2013). Acute hypoxic exposure is considered one

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of the most serious personal risks of high-altitude flight (Bustamante-Sánchez *et al*., 2021). Hypobaric hypoxia is generally recognized as the most serious physiological hazard during high-altitude flight. This is because during ascent there is a drop in barometric pressure and if the crew inhales the surrounding air it will result in a drop in partial pressure and oxygen in the lungs. This will result in loss of consciousness within 12-15 seconds and death within 4-6 minutes (Davis *et al*., 2021). Based on research conducted by Kwo-Tsao Chiang *et al*. in 2020, there were 46 in-flight hypoxia events among 341 triservice military aircrews that had experience with altitude-chamber flights who participated in exercises in 2018 at the Aviation Physiology Research Laboratory (APRL), Taiwan.

Time of useful consciousness (TUC) also called Effective Performance Time (EPT) is the maximum amount of time a pilot has at a certain altitude to make sane judgments and execute them without supplemental oxygen (Federal Aviation Administration, 2023). Each individual's tolerance at altitude varies, TUC can be extended by prerespiratory O2 which increases O2 stores in the lungs, greater O2 carrying capacity in hemoglobin (Hb) and avoids physical activity during hypoxic events (Shaw, Cabre and Gant, 2021). Exercise or light physical activity prior to Aerophysiological Indoctrination and Training (AIT) implementation may shorten TUC due to decreased circulation time and increased peripheral needs leading to faster loss of O2 (Davis *et al*., 2021). According to Stuart Macleod of Australian Safety Transport in the investigation of the Cessna 208B (VH-FAY) aircraft crash in 2018, when the risk of hypoxic events increases, good risk management training is needed for flight planning so as to improve TUC. Research conducted by Sucipta, Adi and Kaunang (2018) concluded that as many as 37% of military aviators in Indonesia have a TUC of <4 minutes. A good TUC (>4 minutes) is important for flight safety, so it is necessary to conduct Aerophysiological Indoctrination and Training (AIT) using Hypobaric Chamber. Hypobaric Chamber is a tool used to recognize symptoms of hypoxia at altitude according to the profile of the exercise carried out (TNI-AU, 2020).

Flight crews rely on TUC to take appropriate corrective and protective action during hypoxic events so actively flying flight crew must meet the TUC requirements that can be assessed during hypobaric chamber training at 25,000 feet. The altitude of 25,000 feet was chosen to avoid decompression sickness, it is because the risk of developing decompression sickness increases significantly at altitude higher of 25,000 (Feldman and Cooper, 2023). Although rare, there is always a risk of decompression sickness in trainees during hypobaric hypoxia training. Based on a study conducted by Ercan *et al*. (2020), the overall incidence of decompression sickness was found to be 0.11% among 7,193 male subjects, which included both trainees and inside chamber observers. In addition, the TUC at this altitude is about 3-5 minutes, which is a short time for the flight crew to recognize a hypoxic state and be able to take the necessary rescue actions in the event of a respiratory air pressure drop during flight (Gunarsih, 2014). This study was conducted with the aim of knowing how the description of hypoxia and TUC symptoms in active flight crew at dr. Saryanto Health Institute of Aeronautics and Space (Lakespra dr. Saryanto) in 2021.

METHODS

This study used a descriptive conservation method where researchers wanted to see a picture of hypoxia and TUC symptoms in active flight crews at Lakespra dr. Saryanto in 2021. The research will be conducted from April 2022 to January 2023. The sampling technique in this study used the simple random sampling method. The sample of this study was 99 active flight crew at Lakespra dr. Saryanto who met the inclusion criteria, namely all male active flight crew who took part in AIT and periodic health checks and similarity tests at Lakespra dr. Saryanto. The variables in this study consisted of hypoxia symptoms and TUC scores. TUC scores is the amount of time an aircrew is able to perform flying duties efficiently in an environment with inadequate oxygen supply. The criteria for TUC scores on flight crew are divided into good (>4 minutes), sufficient (3-4 minutes), less (1-2 minutes), and very less (<1 minute). Hypoxia is a condition characterized by insufficient oxygen supply to tissues which causes body tissues to fail to get adequate oxygen supply. The symptoms are classified into five categories, namely cognitive, psychomotor, visual, psychological, and nonspecific. In this study, secondary data collection was obtained through AIT result documents to determine the description of hypoxia symptoms and TUC score results based on the results of hypoxia demonstration in hypobaric chamber. Secondary data in this study uses medical records of AIT results of active flight crews in 2021. The number of samples in this study was 99 samples with univariate data analysis. This analysis was used to describe each of the variables studied, namely TUC and hypoxia symptoms. Ethics: 460/XII/2022/KEPK.

RESULT

A total of 99 medical records of active male flight crew at Lakespra dr. Saryanto became a research sample. Medical record data will then be analyzed.

In this study, 99 flight crew members who were sampled had the oldest age of 47 years and the youngest 22 years, with most included in early adulthood aged 26-35 years, which was 52 people (52.5%) (Table 1). Most of the study sample were officers with the rank of Second Lieutenant, which was 32 people (32.3%) (Table 1).

Symptoms of hypoxia vary from individual flight crew. The symptoms are classified into five categories, namely cognitive, psychomotor, visual, psychological, and nonspecific (Smith, 2008). The flight crew felt cognitive symptoms as many as 18 people (18.2%), psychomotor as many as 4 people (4%), visual as many as 16 people (16.2%), psychological as many as 3 people (3%), nonspecific as many as 54 people (54.5%), and those who did not feel symptoms as many as 37 people (37.4%) (Table 2). Nonspesific symptoms are self-reported symptoms and do not indicate a specific hypoxia incidence, such as flatulance, weakened muscles strength, feeling floating, tingling sensation, tears, shortness of breath, chest pain, dizziness, stomachache, and a sense of warmth. Crew who did not feel symptoms of hypoxia were fewer than those who felt symptoms from all five classifications of hypoxic symptoms.

Flight crew who felt symptoms of hypoxia were mostly from the adolescence (17-25 years) and the early adult age group (26-35 years), which was 30 people (57.7%) (Table 3). Based on the results of the alternative test that the value of p value = 0.267 (>0.05). This showed that there was no significant difference in hypoxic events in each age group of active air crew at Lakespra dr. Saryanto.

Cognitive symptoms felt by the flight crew were mostly forgetfulness, which was as many as 16 people (88.9%). All flight crew who felt psychomotor symptoms claimed to tremble, all flight crew who felt visual symptoms felt blurred vision, and all flight crew who felt psychological symptoms felt

Table 1. Distribution of Sample Characteristics Based on Age in Active Flight Crew at Lakespra dr. Saryanto in 2021

Sample Characteristics	Frequency (N=99)	Percentage (%)
Age		
17-25 years old	26	26.3
26-35 years old	52	52.5
36-45 years old	19	19.2
46-55 years old	2	2
Ranks		
Enlisted	3	3.1
Second Lieutenant	32	32.3
First Lieutenant	20	20.2
Captain	22	22.2
Major	19	19.2
Lieutenant Colonel	2	2
Colonel	1	1

Table 2. Description of Hypoxic Symptoms in Active Flight Crew in 2021

Hypoxia Symptoms	Yes		No		Total	% Total
	n	%	n	%		
Feeling symptoms*	62	62.6	37	37.4	99	100
Cognitive	18	18.2	81	81.8	99	100
Psychomotor	4	4	95	96	99	100
Visual	16	16.2	83	83.8	99	100
Psychologies	3	3	96	97	99	100
Nonspecific	54	54.5	45	45.5	99	100
No Symptoms	37	37.5	62	62.6	99	100

*Note: each individual may feel more than one complaint in each classification of hypoxic symptoms

Table 3. Description of Age and Hypoxia Symptoms in Active Flight Crew

Age	Hypoxia Symptoms				Total	% Total	P value
	Yes		No				
	n	%	n	%			
17-25	15	57.7	11	42.3	26	100	0.267
26-35	30	57.7	22	42.3	52	100	
36-45	15	79	4	21	19	100	
46-55	2	100	0	-	2	100	

frightened. Flight crew with nonspecific symptoms mostly felt drifting and dizziness/nausea, 16 (29.6%) (Table 4).

Table 4. Description of Hypoxic Symptoms Complaints in Active Flight Crew in 2021

Hypoxia Symptoms	Yes		No		Total	% Total
	n	%	n	%		
Cognitive*	18	18.2	81	81.8	99	100
Easy to forget	16	88.9	2	11.1	18	100
Weakened thinking ability	1	5.6	17	94.4	18	100
The ability to count slows down	1	5.6	17	94.4	18	100
Sleepy	1	5.6	17	94.4	18	100
Psychomotor	4	100	95	96	99	100
Shaking	4	100	0	0	4	100
Visual	16	16.2	83	83.8	99	100
Blurred vision	16	100	0	0	16	100
Psychologies	3	3	96	97	99	100
frightened	3	100	0	0	3	100
Nonspecific*	54	54.5	45	45.5	99	100
Flatulence	8	14.8	46	85.2	54	100
Weakened muscles	9	16.7	45	83.3	54	100
Feeling floating	16	29.6	38	70.4	54	100
Tingling	13	24	41	76	54	100
Tears come out	5	9.3	49	90.7	54	100
Shortness of breath	4	7.4	50	92.6	54	100
Chest pain	1	1.8	53	98.2	54	100
Dizzy/Nausea	16	29.6	38	70.4	54	100
Stomach ache	4	7.4	50	92.6	54	100
A sense of warmth	1	1.8	53	98.2	54	100
None	37	37.4	62	62.6	99	100
Don't feel any symptoms	37	100	0	0	37	100

The criteria for TUC scores on flight crew are divided into good, sufficient, less, and very less (TNI-AU, 2020). Most flight crew had sufficient TUC scores (3-4 minutes), which was 68 people (68.7%) with the shortest TUC at 55 seconds and the longest TUC at 5 minutes (Table 5). Expected TUC scores at 25,000 feet is 3-5 minutes.

Flight crews who had sufficient TUC scores were mostly from the early adult age group (26-35 years), which was 31 people (59.7%) (Table 6). Based on the results of alternative tests, it is known that the value of p value = 0.084 (>0.05). This showed that there was no significant difference in TUC scores in each age group of active aircrew at Lakespra dr. Saryanto.

DISCUSSION

Hypoxia

Research that has been done at Lakespra dr. Saryanto with 99 medical records of active male flight crew who were sampled showed that as many as 62 people (62.6%) felt symptoms of hypoxia and as many as 37 people (37.4%) did not feel symptoms of hypoxia when carrying out hypoxic exercises in hypobaric chamber. This is in line with research conducted by Min-Yu Tu in 2020, which showed as many as 304 out of 341 people who were subjects of the study felt symptoms of hypoxia during exercise (Tu *et al*., 2020). This data is also reinforced by an

Table 5. Overview of TUC on Active Flight Crew at Lakespra dr. Saryanto in 2021

TUC	Frequency (N=99)	Percentage (%)
Good (>4 minute)	8	8.1
Enough (3-4minute)	68	68.7
Less (1-2 minute)	22	22.2
Very Less (<1 minute)	1	1
Total	99	100

Table 6. Age and TUC Overview in Active Flight Crew

Age	<4 min		3-4 min		1-2 min		<1 min		Total	% Total	P value
	n	%	n	%	n	%	n	%			
17-25	1	3.8	24	92.4	1	3.8	0	0	26	100	0.084
26-35	5	9.6	31	59.7	15	28.8	1	1.9	52	100	
36-45	2	10.5	12	63.2	5	26.3	0	0	19	100	
46-55	0	0	1	50	1	50	0	0	2	100	

analysis conducted by the United State Air Force Army (USAF) that there were 656 hypoxic events in flight involving 606 trained aircrew and 50 untrained aircrew. A number of studies also have demonstrated that aircrew members identify in-flight hypoxia occurrences using their own personal hypoxia symptoms from hypoxia awareness training (Chiang *et al*., 2021). Hypobaric chamber exercises have several purposes, one of which is to recognize the physiological effects or symptoms of individual hypoxia that arise due to changes in atmospheric pressure on the body. Therefore, hypobaric chamber training can be an effective way for flight crew to recognize the symptoms of hypoxia while in flight. If the flight crew cannot recognize the symptoms of hypoxia at the end of the exercise, then it can be said that the training objectives are not achieved, which is usually encountered in prospective training crew students because it is one of the recruitment selection series. It is difficult to determine the exact reason why the flight crew chose not to report the hypoxic incident. There are several reasons why flight crews choose not to report hypoxic events, such as fear due to lack of exercise, unsafe conditions that may develop from perceived disturbances, and the belief that reports are unnecessary because they survived the incident (Holt *et al*., 2019).

Hypoxia Symptoms

Complaints of hypoxic symptoms that occur in flight crew vary. The study showed that hypoxic symptoms that appeared in most flight crew were nonspecific symptoms (54.5% overall; flatulence 14.8%; muscle weakness 16.7%; feeling floating 29.6%; tingling 24%; tear discharge 9.3%; shortness of breath 7.4%; chest pain 1.8%, dizziness/nausea 29.6%; abdominal pain 7.4%, and warmth 1.8%). This was followed by cognitive impairment (18.2% overall; forgetfulness 88.9%; thinking ability weakened 5.6%; numeracy weakened 5.6%; and drowsiness 5.6%); visual impairment (16.2% overall; 100% blurred vision); psychological disorders (3% overall; fear 100%); and psychomotor disorders (4% overall; shaking 100%). This is in line with research by Chiang *et al*. (2021) which stated that one of the most recurrent symptoms of hypoxia during flight and hypoxic training in hypobaric chamber is warmth (43.5%), which is included in nonspecific symptoms. Nonspecific symptoms such as floatiness and dizziness/nausea are subjective symptoms that can occur due to cerebral blood supply insufficiency by adjusting the diameter and resistance of blood vessels, resulting in ischemic hypoxia in the brain (Bao *et al*., 2019). Research conducted by Tu *et al*. (2020) on 341 flight crew got different results, namely that the most common symptoms of hypoxia are poor concentration, which is included in cognitive impairment. Differences in the results of this study can occur due to the subjectivity of research subjects in determining the symptoms of hypoxia felt. Flight crew may already experience hypoxic symptoms such as dizziness or fatigue, but do not realize that it is a symptom of hypoxia (Reinhart, 2008). Some symptoms of physiological events are very similar to those of a hypoxic condition (Chiang *et al*., 2021).

Hypoxia is an important stressor that can induce cell damage, especially to the central nervous system that can result in nerve injury. Prolonged exercise in hypoxic conditions is associated with decreased oxygen supply to the brain, which is partially associated with decreased cognitive functions (De Bels *et al*., 2019). Working memory also appears to be altered under hypobaric and hypoxic conditions. Cognitive performance is affected not only by hypoxia but also by factors such as age, gender, and education (Lefferts *et al*., 2019). The neurological effects of hypoxia include symptoms such as headache and dizziness, as well as certain neurological high-altitude illnesses, which can affect higher cortical function and cause cognitive impairment (Falla *et al*., 2022). The severity of the disorder is related to the length of time exposed to hypoxia, although the individual has a good TUC score. The restoration of brain function after hypoxia might also take longer than arterior reoxygenation and could be made worse by repeated exposure to hypoxia (Shaw, Cabre and Gant, 2021). Hypoxia can also cause some morphological and functional changes of the retina, such as swelling of the optic disc, changes in macular function (color discrimination), changes in retinal and choroid blood flow, and retinal hemorrhage. If hypoxia lasts a long time, changes in O2 levels that occur may lead to cell death directly and thereby to loss of vision (Stefánsson *et al*., 2019). Loss of vision is one of the most devastating consequence of systemic hypoxia, but the cellular mechanisms are unclear (Mesentier-Louro *et al*., 2020). Psychological disorders due to hypoxia can occur due to impaired interactions in the prefrontal and hippocampal networks that cause inattention, hyperactivity, impulsivity, and personality/behavior changes (Zhao, Yang and Cui, 2017). Exposure to hypoxia at high altitudes can cause reductions in white and gray matter in brain regions that can lead to impaired motor function (Davis *et al*., 2015). Additionally, changes in brain associated with hypoxia may play significant role in regulating the perception of psychological fatigue (Stavrou *et al*., 2018).

Relationship between Age and Hypoxia Symptoms

The results of this study showed that most of the 62 people who experienced symptoms of hypoxia were aged 26-35 years, which was as many as 30 people (57.7%). Most of the 37 people who did not experience symptoms of hypoxia were also aged 26-35 years, namely 22 people (42.3%). This is in line with previous studies, namely flight crews who experienced hypoxia were on average 30-39 years old (Tu *et al*., 2020; Chiang *et al*., 2021). Based on the results, p value = 0.267 (>0.05) shows that there is no significant difference in the incidence of hypoxia in each age group seen in Table 4. This is not in accordance with what has been stated by Lopez *et al*. that the age group of 30-39 years has a better tolerance to hypoxia than the younger age group (20-29 years) and older (>40 years) (Gunarsih, 2014). Study subjects in the early adult age group (26-35 years) tended to have longer experience hypoxic demonstration exercises compared to the late adolescent age group (17-25 years) so that they were more familiar and able to name their individual hypoxic symptoms after exercise. Sucipta, Adi and Kaunang (2018) as an explanation that the vital capacity of the lungs peaks at the age of 20 years and begins to decline with age. This is supported by Dzhalilova *et al*. (2021) study, that age plays an important role in organism hypoxia tolerance. Elderly flight crew already have decreased physiological and cognitive functions. Decreased tolerance to hypoxia can result in shorter TUC (Gunarsih, 2014). The absence of differences in each age group with hypoxic events can be caused by several factors, such as physical activity, smoking history, comorbidities that can increase metabolic workload that can increase susceptibility to hypoxia, environmental temperature, and intensity of exposure to hypoxia (Rainford and Gradwell, 2016). The onset and intensity of hypoxic symptoms and compensatory response also depend on several factors, such as altitude reached and rate of ascent, PO2 from breathing gas if wearing an O2 mask, and duration of exposure (Shaw, Cabre and Gant, 2021).

Time of Useful Consciousness

This study showed that most of the flight crew who were sampled had sufficient TUC values (3-4 minutes), which was 68 people (68.7%). This was also found in (Gunarsih, 2014) research, namely the average TUC in 158 samples was for 3.9 minutes. TUC is calculated from the moment the O2 mask is removed and the TUC endpoint is determined when the flight crew incorrectly answers two consecutive numbers or does not do the given summation problem for 15 seconds or does not carry out the supervisor's commands. Sufficient values on the flight crew were found to match TUC estimates at an altitude of 25,000 feet, which is 3-5 minutes (Davis *et al*., 2021). Research by Khan, Adil, Mangi (2013) showed different results, where as many as 71 flight crew from 104 participants had a 5-minute TUC score that was included in the good category. The study did not examine the health status of flight crew at the time of hypoxic training.

Relationship between Age and TUC

The results of this study showed that most of the 68 people who had sufficient TUC scores were aged 26-35 years, which was 31 people (59.7%). Flight crews aged 26-35 years are most commonly found with the rank of captain who has had a long tenure. Based on the results, p value = 0.084 (>0.05) shows that there is no significant difference in TUC values in each age group seen in Table 7. This is not in line with Yoneda *et al*.'s research which found that older military aircrews respond more quickly during TUC when exposed to acute hypoxia, which is associated with prior hypoxic exposure (Kumar, 2022). Veronica Gunarsih's research in 2014 states that increasing age will tend to shorten TUC. This is based on the theory of a decrease in the maximum speed of oxygen use or VO2 max due to reduced cardiac output and a decrease in the ratio of expiratory volume in the first second (VEP1) which leads to a decrease in lung function. This decrease in physiological function will reduce tolerance to hypoxia so that TUC is shorter (Gunarsih, 2014).

The absence of differences in TUC values in each age group can be caused by several factors that can arise at various ages, such as low hemoglobin (Hb) and excess body mass index (BMI). Hb acts as a carrier of O2 to all body tissues. The lower an individual's Hb, the less O2 the blood can carry throughout the body's tissues, which can shorten TUC. In addition, in individuals with excess BMI there is visceral fat that can block diaphragm movement so that it can reduce respiratory tract compliance and lung vital capacity which will shorten TUC (Gunarsih, 2014). In this study, researchers did not examine Hb and BMI in flight crew. Reduced body fat mass and increased cardiorespiratory fitness may have major effect on the TUC (Kim *et al*., 2023).

There are several factors, such as fitness, BMI, flight hours, Hb, and smoking history that can affect the onset of hypoxia symptoms and the duration of WSE that were not examined in this study. This study also does not see a causal relationship between the two variables.

CONCLUSION

Based on the results of the study, it was concluded that the average research subjects had sufficient TUC values (3-4 minutes) and felt symptoms of hypoxia with the most complaints feeling nonspecific disorders, such as flatulence, muscle weakening, feeling floating, tingling, tears, shortness of breath, chest pain, dizziness / nausea, abdominal pain, and warmth. There was no significant difference between age with hypoxic symptoms and TUC scores. Active flight crews are expected to know the purpose of hypoxia demonstration exercises in the hypobaric chamber so that they can recognize their individual hypoxia symptoms and report any hypoxia symptoms felt at the end of the exercise because it can be very useful for aircrews when flying at high altitude. Active flight crews are also advised to pay attention to factors that can affect TUC in order to have a good TUC value so that they can take corrective actions properly when experiencing hypoxia at high altitude.

CONFLICT OF INTEREST

There is no conflicts of interest to disclose.

AUTHOR CONTRIBUTION

N.T.A.P., P.M.S., and M.K. conceived the study. N.T.A.P. developed the theoretical framework and analysed the data. A.I.I. supervised the project. N.T.A.P. and M.K. wrote the manuscript with input from all authors. All authors provided critical feedback and helped shape the research, analysis, and manuscript.

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