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The Use of Heart Rate Measures to Evaluate Stress Levels among Air Traffic Controllers

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ABSTRACT

This paper looks at the possibility of using a heart rate monitor to evaluate stress levels among Air Traffic Controllers (ATCOs). Air Traffic Control (ATC) service requires constant good planning, situation awareness, and always making sound decisions. A study was conducted on two ATCOs for three complete work cycles: the morning shift from 8 a.m. to 4 p.m., the afternoon shift from 4 p.m. to 12 a.m., and the night shift from 12 a.m. to 8 a.m. Both participants have different roles, with Subject A being a planner controller while Subject B is a radar controller. The study used the NASA Task Load Index (NASA-TLX) survey to collect the subjective workload rating and a heart rate monitor armband to measure the heart rate reading of an ATCO and then compare it with the number of aircraft within the controlled area. Two hypotheses were investigated: the first one is the relationship between the number of traffic and heart rate readings, and the second hypothesis is the relationship between the elapsed working time and heart rate reading. The Spearman correlation test has been used to determine these relationships. Based on the results, a *p-value* of less than 0.05 and a positive correlation indicates a significant relationship between the number of aircraft and heart rate readings for both subjects. Elapsed time and heart rate measurement, on the other hand, do not significantly correlate with a *p-value* greater than 0.05 and a negative correlation was produced for both subjects. The unweighted NASA-TLX workload measure confirmed the findings for Subject A but not for Subject B. This might be due to the different roles carried out by both subjects during the experiment. This shows that different work tasks resulted in different workload-induced factors. The results show a promising outcome of using a heart rate monitor to evaluate stress levels among ATCOs. However, more subjects were needed to enable the use of this concept for future purposes of measuring ATCO stress levels to manage workload.

Keywords:
Fatigue; Heart Rate; Air Traffic Controller; Workload

1. Introduction

Demand for air travel worldwide is seen increasing as the global passenger traffic is expected to improve significantly in 2022, reaching 77% of what it was in 2019, post-COVID [1]. Malaysia's aviation industry is also recovering after being impacted by the pandemic. According to the Malaysia

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Aviation Commission (MAVCOM), air passenger traffic has reached 15.6 million in the third quarter of 2022, marking a recovery of 55.9% compared to 2019 [2]. In addition, the KUL-SIN route within the Kuala Lumpur Flight Information Region (KL FIR) has been named the No. 1 Busiest Route in the World, according to a report by Official Airline Guide (OAG) Aviation Worldwide in 2019 (pre-COVID) [3] and the fifth position in a similar report in 2022 (post-COVID) [4]. Therefore, with the demand for air traffic, controllers need to perform more complex perceptual and motor tasks, thus increasing the complexity of high-level mental tasks such as memorisation and decision-making, which can, in the end increase workload [5].

As the amount of air traffic grows over time, the role of an Air Traffic Controller (ATCO) becomes increasingly demanding. ATCOs are responsible for the safe, orderly, and expeditious flow of air traffic and maintaining an optimal separation while handling air traffic and unforeseen occurrences and emergencies [6].

Air Traffic Control (ATC) is a 7-day-a-week, 24-hour-a-day service in Malaysia, and the operation is carried out with five teams rotating shifts. A typical shift for ATCOs in Malaysia is 8 hours, alternating between day, afternoon, and night shifts. Shift work can increase fatigue, which has been demonstrated in numerous studies to impact human cognitive structure and judgment. It is known that errors could arise from mental overload and fatigue, which negatively affect the user's performance [7].

There are various studies regarding stress and fatigue using Heart Rate Variability (HRV) or Heart Rate as a measure in different activities, such as physical training [8,9], driving [10], cycling [11], and swimming [12]. Based on the research, the use of HRV to classify physical fatigue [8] can be promising or with varying performance [10] or does not reflect the onset of physical fatigue [11]. There is also research regarding fatigue based on specific job scope [13,14] and based on the study, it was suggested that the measurement of HRV can be applied in occupational settings to assess burnout [13] or fatigue [14]. In the area of ATC, there was a study conducted at Cheongju Flight Control Tower, South Korea, with heart rates used as a method to measure fatigue due to the nature of shift work for ATCOs [15].

This research proposes a similar study in Malaysia's work setting to see if the same concept can be replicated here. It aims to investigate using heart rate measures to evaluate the stress level of ATCOs performing shift work based on various factors, such as elapsed working hours and the number of aircraft under control. This is based on the assumption that the heart rate measurement gathered was an indicator of fatigue resulting from stress due to task load. The result is then compared to a subjective rating given by the controllers using the NASA Task Load Index (NASA-TLX) questionnaire.

2. Methodology

Based on the results in [15], it was determined that the degree of fatigue could be quantitatively measured through the change in heart rate of ATCOs on shift. It was hypothesised that the increase in the number of aircraft within the control area and the elapsed working hours contribute to the increase of ATCO's fatigue and stress, which can be monitored by an increase in heart rate. These experiment sessions were intended as a preliminary session to verify the use of heart rate as a fatigue indicator in the Malaysian air traffic environment.

2.1 Experiment

The experiment was conducted at the Kuala Lumpur Air Traffic Control Center (KLATCC), Sepang, for three complete working cycles on Sunday, December 8, 2022, from 0800 to 1600, on Monday, December 19, 2022, from 1600 to 0000 and on Tuesday, December 20, 2022, from 0000 to 0800. Each work cycle lasted 8 hours with scheduled breaks every 1 or 2 hours. At the beginning of each experiment session, the participant was briefed on the experiment procedure and was fitted with the heart measurement device. The device was fitted to the participant for the entire duration of the work cycle. At the end of each session, a NASA Task Load Index (TLX) questionnaire was given to the ATCO to gather information on the perceived workload rating of the subjects during control duty. The questions must be answered as soon as the subjects have been relieved of their radar duty on every session in the format of a pen-and-paper survey. The NASA-TLX method assesses workload using a 7-Likert scale from 1 (very low) to 7 (very high) on six subjective subscales that are: Mental Demand (MD), Physical Demand (PD), Temporal Demand (TD), Frustration (F), Effort (E) and Performance (P) [16]. The average value of the six-dimensional workloads represented the overall workload. The unweighted NASA-TLX will be used to estimate the workload and compared to the heart rate measurement.

2.2 Sectorization

Malaysia’s airspace is separated into two different Flight Information Regions (FIR): Kuala Lumpur FIR (KL FIR) and Kota Kinabalu FIR (KK FIR). The KL FIR covered the peninsular area bordering Malaysia with its neighbouring foreign border with Singapore, Thailand, Indonesia, and India. The sector areas in KL FIR are divided into 14 major sectors by segmenting the airspace into a geometric constraint. However, during the experiment period, the sectors were combined into five sectors, as shown in Figure 1. Different sector configurations were used depending on the expected traffic flow. During low traffic, sectors are usually combined or merged to ensure optimum controller task load.

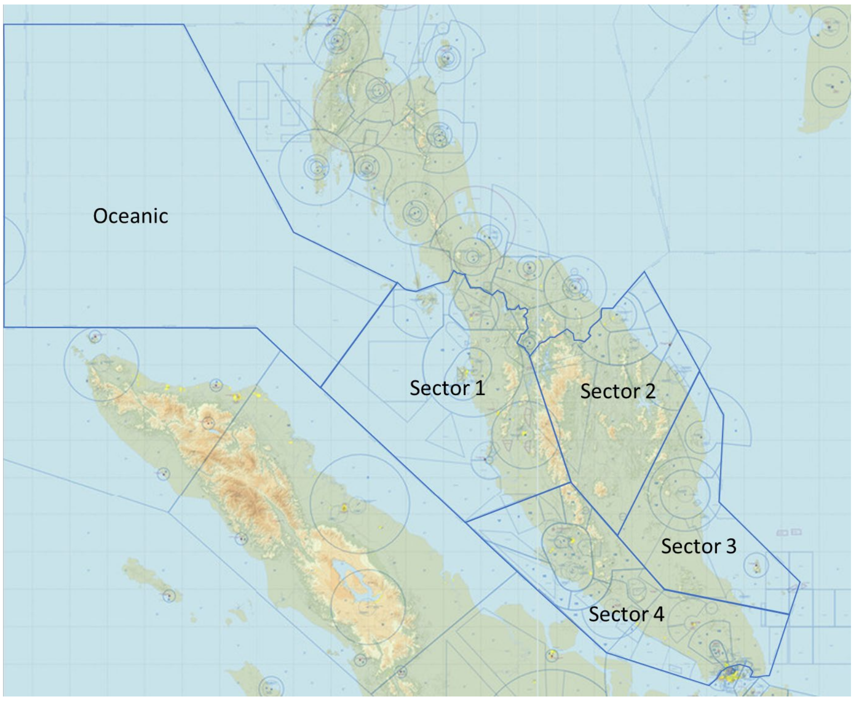

Fig. 1. Sector classification for the experiment sessions

2.3 Participant

Two males active ATCOs aged 35 and 46 with more than five years of working experience participated in the experiment sessions. Subject A was assigned as a planner and worked with sectors 2, 3, and Oceanic, while Subject B was assigned as a radar controller and worked with sectors 1, 2, 3 and 4 for the three experiment days. The assigned sector configurations depend on the forecasted traffic demand, where during low traffic demand, several sectors are combined or merged and assigned to a single controller.

Even when both radar and planner controllers are assigned to the same sector, both have different tasks allocated to them. The radar controller oversees identifying aircraft and giving flight clearances, for example, heading, flight level or route instructions to the aircraft, as well as detecting, identifying, and solving possible traffic conflicts within the sector. The planner is responsible for strategically solving potential future traffic conflicts with neighbouring sectors before the aircraft enters the sector [17].

2.4 Research Instrument

There are several heart rate monitoring devices with different fitting styles, namely wristbands, armbands, and chest strap types of fittings. This experiment was conducted using an armband heart rate monitor to ensure the wearer is comfortable over an extended period. An armband heart rate monitor was determined to be a reliable tool for measuring heart rate according to research by Crawley that compares the reliability of SenseWear heart rate armband to an electrocardiogram (ECG), the Actiheart Mini Mitter and the Polar Heart Rate Monitor [18]. Yu *et al.,* also concluded that the arm-worn heart rate monitor (Polar OH1) provides usable heart rate measurements in daily living conditions with routine physical activity [19]. In this research, the Kalenji heart rate monitor armband has been used to measure the heart rate. It measured the heartbeat per minute (BPM), and all data was gathered through Bluetooth 4.0 protocol to a web-based application, namely the Decathlon Coach.

The heart rate measure was then compared to the subjective rating gathered from the NASA-TLX survey. The NASA-TLX workload is widely used to assess mental workloads in the field of Aviation [20], and there is a high correlation between the weighted NASA-TLX and unweighted NASA-TLX [21]. This study used categorisation from research by Eiterheim and Fernandes [22] to interpret the unweighted NASA-TLX mental load value. This can be seen in Table 1, with values less than 50 considered an acceptable workload level, values between 50 and 70 considered within limits of workload level, and values higher than 70 considered to be sometimes acceptable in certain situations. Similar findings were gathered by Triyanti *et al.,* [23].

Table 1
Categorisation of NASA-TLX value of ATCO [22]

Justification	Categories	Interpretation
< 50	Medium	Acceptable
50-70	High	Within limits
> 70	Very High	Sometimes accepted in certain situations

The research findings would suggest the suitability of heart rate measures as a stress indicator for ATCOs. Consequently, suitable stress management techniques, such as gamification [24] and exercise [25], can later be proposed as mitigation actions.

3. Results

It is hypothesised that the heart rate will increase because of feeling fatigued as the number of aircraft within the control area increases and as the elapsed working time increases. Spearman correlation analysis has been used to determine these relationships. The Spearman correlation test was used to explore whether the heart rate increased with an increasing number of aircraft. Spearman's correlation coefficient measures the strength and direction of association between two ranked variables.

3.1 Subject A

Table 2 displays the analysis findings from the correlation test between the two variables: the number of aircraft under his jurisdiction and the heart rate reading for Subject A. Based on the analysis, it was gathered that a positive correlation coefficient value of 0.687 with a high statistical significance (p = 0.001) between the heart rate of Subject A and the number of aircraft within the control area. This also suggests a moderate correlation between the two variables. This can also be seen through the scatter plot in Figure 2, with a higher heart rate measured during higher traffic loads. Although there are instances where the heart rate was higher than average during low traffic demand and vice versa, it should be noted that the ATCO workload is not only affected by the amount of traffic in the assigned sector. Other sector characteristics, such as sector size and number of crossings, can also influence controller workload level.

Table 2
Result of the Spearman's rho correlation test on the number of aircraft for Subject A

			Heart rate	No. of aircraft within the control area
Spearman's rho	Heart rate	Correlation coefficient	1.000	0.687
		Sig. (1-tailed) / p		0.001
		N	59	59
	No. of aircraft within the control area	Correlation coefficient	0.687	1.000
		Sig. (1-tailed) / p	0.001	
		N	59	59

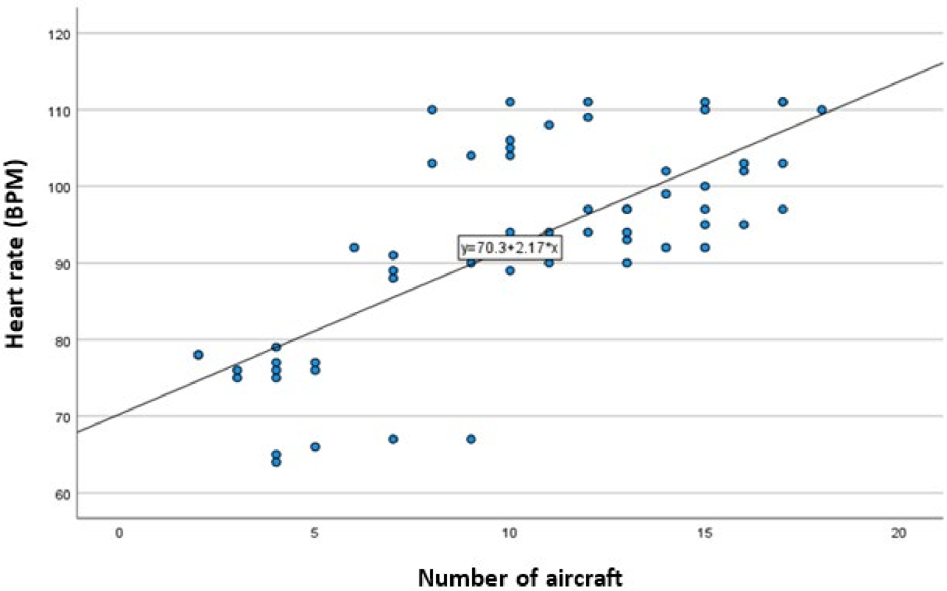

Fig. 2. Scatter plot graph based on heart rate vs number of aircraft of Subject A

Table 3 presents the analysis findings from the correlation test between the two variables: Subject A's time elapsed and the heart rate reading. Time elapsed was divided into two groups: the first and last hour of work for three work cycles. Based on the results, no correlation was found between the two variables (r_s = -0.098, p = 0.427). It was gathered that the effect of hours working on the subject's heart rate was not significant for the corresponding three work cycles.

Table 3
Result of the Spearman's rho correlation on the elapsed time for Subject A

			Heart rate	Elapse time
Spearman's rho	Heart rate	Correlation coefficient	1.000	-0.098
		Sig. (1-tailed) / p		0.427
		N	6	6
	No. of aircraft within the control area	Correlation coefficient	-0.098	1.000
		Sig. (1-tailed) / p	0.427	
		N	6	6

The overall result for the unweighted NASA-TLX workload perceived by Subject A is presented in Figure 3, with a bar graph representing the overall subjective workload and a line chart illustrating the number of aircraft. The graph combination showed the workload fluctuation throughout the day was partially influenced by the number of aircraft that flew in the sector areas. Subject A overall workload showed a clear relationship between the two variables except during the 1000-1100 work period. This corresponds with the results gathered from the correlation analysis.

The overall workload was observed to be related to the total number of aircraft managed. Most of the time, the overall workload was between the low and medium levels of workload. However, during the work period of 2100-2200, the overall workload peaked at 61.33, with the highest number of aircraft managed in the assigned sector, which was within the Kuala Lumpur Terminal Area (KL TMA), contributing to the heavy traffic of aircraft. Regardless, the following work period of 2300-2330 recorded the lowest overall workload of 26 for a combined assigned sector. With a combined sector, the control area becomes more extensive. There could be two possible outcomes for the combined sector: one, the workload would be higher due to a larger controlled area, and two, the workload would be lower due to a more separated aircraft. In this case, the workload was reported to be lower, possibly due to a larger control area with fewer aircraft.

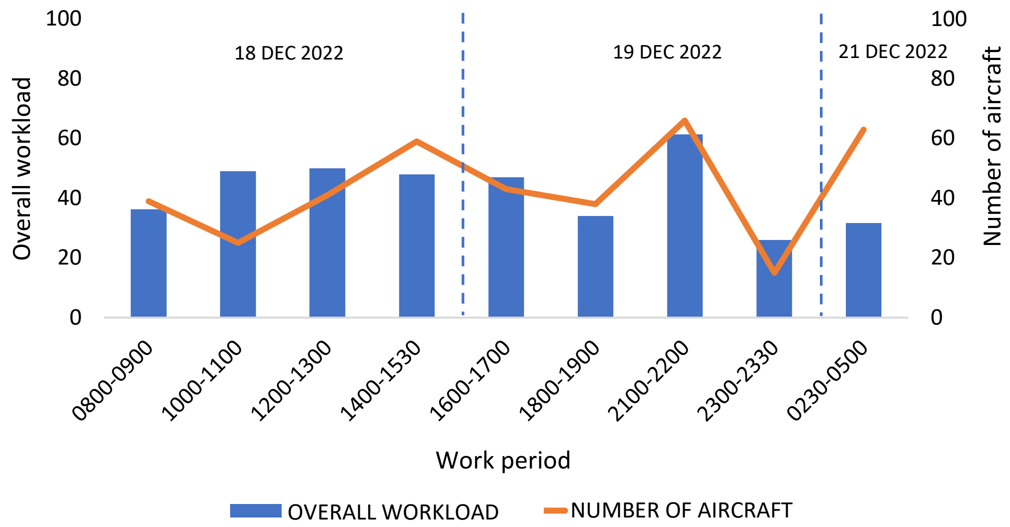

Fig. 3. Weighted Overall Workload Subject A

3.2 Subject B

The correlation test results between the number of aircraft under his control and Subject B's heart rate reading are shown in Table 4. Based on the analysis, it was gathered that a positive correlation coefficient value of 0.318 with a moderate statistical significance (p = 0.016) between the heart rate of Subject B and the number of aircraft within the control area. This suggests a weak correlation strength between both variables, as in Figure 4, with a generally higher heart rate measured during higher traffic load. The heart rate measures are more scattered than the data for Subject A, corresponding to a lower correlation value gathered for the subject.

Table 4
Result of the Spearman's rho correlation test on the number of aircraft for Subject B

			Heart rate	No. of aircraft within the control area
Spearman's rho	Heart rate	Correlation coefficient	1.000	0.318
		Sig. (1-tailed) / p		0.016
		N	46	46
	No. of aircraft within the control area	Correlation coefficient	0.318	1.000
		Sig. (1-tailed) / p	0.016	
		N	46	46

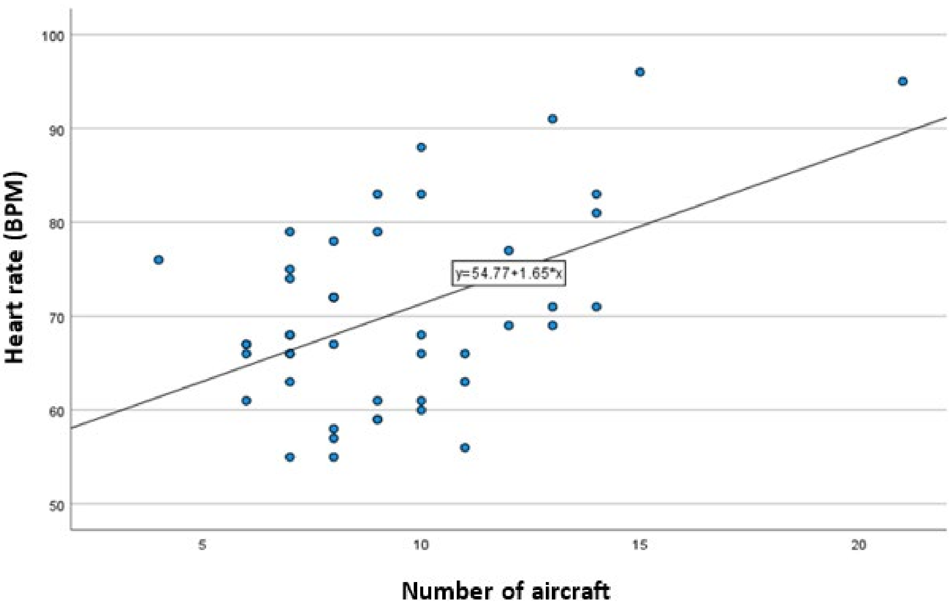

Fig. 4. Scatter plot graph based on heart rate vs the number of aircraft for Subject B

The correlation test results between the elapsed time and Subject B's heart rate reading are shown in Table 5. A negative moderate correlation value of 0.594 was found with a poor significance of p = 0.107. The negative correlation value for Subject B relates to a decreasing heart rate with a longer elapsed time.

Table 5
Result of the Spearman's rho correlation on the elapsed time for Subject B

			Heart rate	Elapse time
Spearman's rho	Heart rate	Correlation coefficient	1.000	-0.594
		Sig. (1-tailed) / p		0.107
		N	6	6
	No. of aircraft within the control area	Correlation coefficient	-0.594	1.000
		Sig. (1-tailed) / p	0.107	
		N	6	6

The subjective workload for Subject B showed an overall higher workload value than that of Subject A. Subject B was assigned to a planner position, which differs from the radar position held by Subject A. Even though both radar and planner are responsible for the provision of Air Traffic Services (ATS) in the same volume of airspace, they perform different but interconnected tasks while working as a team [17].

The overall workload rating for Subject B was recorded as very high for each session. The range of overall workload was between 63.33 to 90.67, as shown in Figure 5. The relationship between the overall period and the total aircraft number was not directly proportional compared to Subject A's results. This corresponds with the findings gathered from the correlation analysis. The overall workload for Subject B has a poor correlation with the number of aircraft, as the task was to strategically plan incoming traffic as opposed to managing the current traffic load.

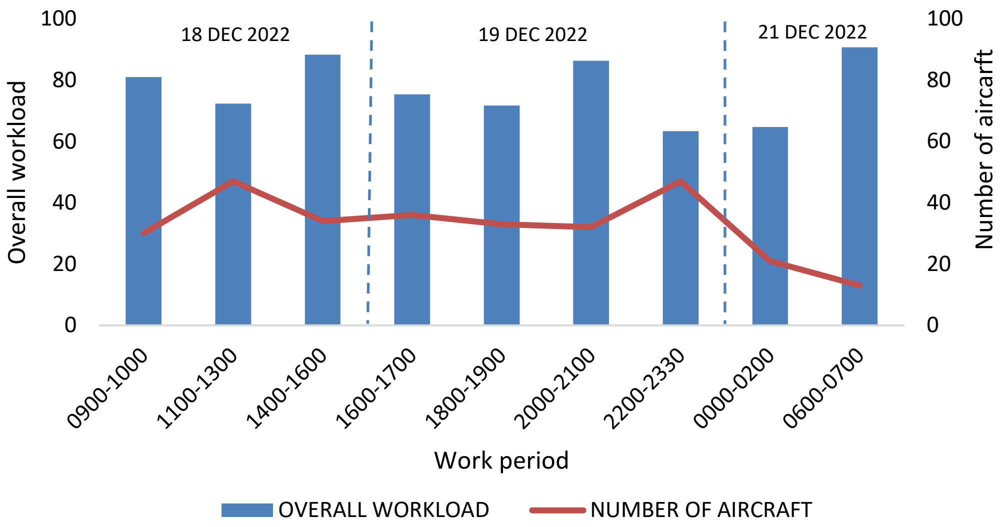

Fig. 5. Weighted Overall Workload Period Subject B

4. Conclusions

An ATCO is responsible for monitoring and navigating the movement of all aircraft in their area of responsibility. To ensure the safe and efficient movement of aircraft, an ATCO must issue instructions and clearances to pilots and ensure safe separation between aircraft. Therefore, an ATCO's workload increases as the number of aircraft within its control area increases or when the ATCO work for a more extended period. It is hypothesised that the controller would feel more fatigued due to a higher workload, resulting in a higher heart rate value. This was investigated in this research.

Based on the experiment, the data shows that both subjects' heart rates elevated when the number of aircraft within the control area was higher. This is consistent with earlier studies that found that one of the factors contributing to ATCO fatigue is the quantity of aircraft or aircraft volume [15]. Based on the correlation test, it can be observed that there is a weak (r_s = 0.318, p = 0.016) to moderate (r_s = 0.687, p = 0.001) positive correlation between the number of aircraft within the control area and the heart rate reading for subjects B and A, respectively.

ATCO's workload can be affected by other factors relating to the features of the air traffic and air traffic control (ATC) sector [26]. For example, the study shows that Subject A's heart rate peaked at 110 BPM (Figure 2) during one of the work sessions with a combined sector and a relatively large number of aircraft. However, the workload gathered from the unweighted NASA-TLX for the corresponding work session was considered to be within the acceptable limit (Figure 4), referring to the categorisation of NASA-TLX value suggested in [21] (Table 1). Therefore, using a single heart rate measurement value to pinpoint a moment when ATCO could be feeling stressed or fatigued might not be feasible. Nevertheless, the measure could be used as an indicator that the controller might be feeling slightly overwhelmed by the control activities.

The analysis showed no correlation (r_s = -0.098, p = 0.427) or non-significant negative correlation (r_s = -0.594, p = 0.107) between heart rate measure and elapsed working hours for subjects A and B, respectively. The elapsed working hours were not the factor that caused an ATCO to fatigue. Malaysia's directives on the maximum working hours, working scheduling and allocation of breaks were designed in line with the ICAO Doc 9966 on the Oversight of Fatigue Management Approaches [27]. Based on this preliminary study, it can be hypothesised that the allocation of breaks practised by the control centre has effectively managed controller fatigue.

The unweighted NASA-TLX workload measure confirmed the findings for Subject A but not for Subject B. The unweighted NASA-TLX workload value corresponds with the number of aircraft for Subject A, where an increased number of aircraft handled by Subject A followed by a higher NASA-TLX perceived workload value. However, this is not the case for Subject B, with no pattern can be observed between both measures. This might be due to a different role carried out by both subjects during the experiment. Subject A acted as a radar controller, whereas Subject B served as a planner controller during the experiment. This shows that different work tasks resulted in different workload-induced factors.

The findings gathered in this preliminary research show a promising outcome of using a heart rate monitor to evaluate stress levels among ATCOs. However, more subjects were needed to enable the use of this concept for future purposes of measuring ATCO fatigue to manage workload. Investigation can also be conducted into using heart rate measures on other factors affecting workload, such as sector complexity, weather, work environments, and health issues. Also, information on ATCO stress levels can be used within organisational management using a similar concept to the use of the Internet of Things (IoT) that has already been explored extensively in the case of monitoring water quality, such as proposed by Zulkifli *et al.,* [28].

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