A Cross-Cultural Anthropometric Analysis in Military Aviation

Yousuf Al Wardi; Sasirajan Jeevarathinam; Saleh Al Sabei

BACKGROUND: Aircrew-aircraft compatibility is important in military aviation for flight safety. Anthropometric aircrew selection standards in RAFO were embedded from the selection standards of western defense forces as the aircrafts were imported from there. Henceforth efforts were made to fit local native aviators into aircrafts not initially designed for them. In view of this, this study was carried out to obtain the anthropometric data of Oman aircrew recruits and compare these with published western and eastern data with a hope to understand and highlight the aircrew-aircraft mismatch issues, if any.

METHODS: The anthropometric data of 2296 Omani recruits from 2003 to 2012 were collected and their statistical distribution of data was collated. Published data from the UK and Singapore were used to carry out the comparative distribution of five anthropometric dimensions.

RESULTS: Minimal differences were noted between Oman and Singaporean recruits whereas differences were most pronounced between Oman and Western populations (UK). Aircrew cadets from Oman, Singapore, and UK differed significantly in standing height. The UK cadets (M = 177.4 cm) showed the highest standing height followed by Oman cadets (M = 171.9cm), and then Singapore cadets (M = 168.5 cm).

DISCUSSION: This study has provided opportunities to recognize the discrepancies involved in selection of Middle Eastern aircrew for western cockpits. This adds impetus to the scope for application of military recruitment standards suitable to the native population in aiding the ideal man-machine interface. This approach shall consider national policy, the significant anthropometric trends of the general population, and the procured aircraft profile of the country.

KEYWORDS: anthropometric, culture, military, recruitment.

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Most aircraft currently utilized in the civil and military aviation industries have been manufactured by the United States, Russia, United Kingdom, or countries from the European Union.[3,9] These countries, being the main aircraft suppliers, tend to have significant influence on the aviation industry worldwide. Most defense forces use five critical anthropometric dimensions for aircrew: sitting height, arm length (functional reach), leg length (buttock-heel) and thigh length (buttock-knee). It is also stated that aircraft manufacturers utilize the 5th and 95th percentile data of the native population or the data supplied by customer defense forces for cockpit designing and also that engineers try to limit the population anthropometric rejection rate for aircraft operability to 12–15%.[7,12] The populations of different countries have differing anthropometric dimensions and studies have concluded that the Western population has a larger build compared to the Eastern population.[15] The majority of countries purchase and use the aircrafts provided by the western suppliers without any changes made to the aircraft framework and fittings. In this case, the human is fit to the needs of the machine instead of the machine being fit for the human operators.

It is well-known that aircrew-aircraft compatibility is of prime importance in the military aviation for task accomplishment and flight safety.[14] Anthropometric aircrew selection standards, taking the Royal Air Force of Oman (RAFO) as an example, were taken from the selection standards of western defense forces as the aircraft were imported from those

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developed countries. This has led to tailoring the recruitment standards, which has resulted in many of the applicants being unfit to operate the military aircraft. Consequently, a significant percentage of the population was out of the selection range, which meant that the selection available was considerably limited due to efforts made to fit the local native aviators into aircraft which were not initially designed for them. Therefore, significant candidates who might have had appropriate skills and enthusiasm were lost. This was evidenced in our earlier ad hoc study,[1] where we found an Omani recruits anthropometric rejection rate of 37.4%, which was far higher than the aircraft manufacturer proposed anthropometric rejection rate of 12–15%.

Anthropometric data on Eastern military aviators are scarce. This is due to the lack of previous studies conducted on the subject, which is mainly attributed to the military aircrafts' differing nature compared to ones used in the civilian sector. These differences are mainly manifested in the need for ejection seats, specialized electronic systems, speed and maneuvers.[5,10] Conducting such studies could play an important role in altering the way aircrafts are currently being manufactured to make the fittings more flexible and accommodating for a wider range of cultures. It also has the potential for presenting the aviation industry useful anthropometric information which could influence the mechanism of carrying out specific military related operations. These studies are particularly beneficial to aviation in developing countries in addition to provoking thoughts about manufacturing the military aircrafts in the developing countries themselves.

Safety is an imperative aspect in the aviation industry and is a vital requirement in military. Anthropometry is an essential part in the design and operation of the military aircraft to ensure flight safety.[16] Anthropometric mismatches are detrimental to flight safety; they may result in an increase in human error induced by poor design and pilots not meeting anthropometric requirements. Operational effectiveness is compromised when the design of the displays and controls relies on certain ergonomic standards and pilots who do not meet these standards have trouble adequately reading the displays and accessing the controls which puts them at risk. Timely egress is crucial in military operations, the ejection seats are also designed to meet certain standards. Pilots may sustain injuries or lose their lives if these standards are not adequately met.

This study was carried out to compare the anthropometric data of Omani aircrew recruits with published western and eastern aircrew recruit data with the hope of understanding and highlighting the aircrew-aircraft mismatch issues of recruiting native populations to the acquired aircraft profile of the country. This could provide a future platform for further research in this field.

METHODS

Subjects

Data were collected retrospectively from the Royal Air Force of Oman (RAFO) recruitment center. The data were for candidates who underwent full anthropometric measurements during the period from 2003 to 2012. The measurements of 2296 recruits were included for calculation and analysis.[1] An informed consent was obtained from the candidates during the recruitment process, in case their data was anonymously used. The study was ethically approved by the IRB equivalent at the organization and official permission granted by higher authorities to proceed with the study.

Equipment

An anthropometric rig was operated by qualified technicians to measure the different dimensions. The data were stored electronically in the recruitment center.

Procedure

For a cross-cultural comparison, published data from the UK and Singapore were obtained from literature. The Singapore data were extracted from an anthropometric study of Singapore candidate aviators.[15] The data of the Royal Air Force, UK (RAF) were obtained from an anthropometric survey of 2000 Royal Air Force Aircrew 1970/71.[2]

Statistical Analysis

Data analysis was utilized to study the association between the essential anthropometric measurements and the countries in question. The data were collated and analyzed using the Statistical Package for Social Sciences (SPSS) software version 20. It was encoded initially prior to entering it into the SPSS sheet, then screened for any incomplete or missing data. There were no erroneous responses, therefore data analysis was carried out on all the cases. The analysis aimed to define descriptive and inferential statistics, and to explore the relationship between variables. During analysis for descriptive statistics there were no outliers and the dependent variables were continuous and measured at interval levels. Therefore, the one-way Analysis of Variance (ANOVA) was conducted for data analysis in this research study. The ANOVA tests only show that there is an overall difference between the groups but does not specify exactly which ones differ. Post hoc tests are therefore used to confirm where the differences occurred between groups. In this case, due to the assumption of homogeneity of variances, Tukey's post hoc statistical test was applied to analyze anthropometric differences between different country recruit populations studied.

RESULTS

Using the aforementioned methodology, the following results were obtained. The data analysis looked for any significant difference between the five measurements and the three different countries. In addition, it checked the correlation between all four measurements revealing which measurement is affected by standing height. Furthermore, a comparison of 5^{th} and 95^{th} percentiles of the five measurements for the three countries was obtained. **Table I** displays the mean values, standard deviations

Table I. Anthropometric Data of Omani Candidates (N = 2296).

		STANDING HEIGHT (cm)	SITTING HEIGHT (cm)	ARM REACH (cm)	THIGH LENGTH (cm)	LEG LENGTH (cm)
Mean		171.9	90.3	77.1	58.6	104.9
SD		4.9	2.7	3.3	2.9	4.1
Minimum		162.3	76.5	51.5	50.0	94.5
Maximum		188.5	99.0	90.0	88.0	120.0
Percentiles	3	163.6	86.4	72.0	54.9	98.5
	5	164.2	86.5	72.6	55.5	100.0
	25	168.2	88.1	75.0	56.7	102.0
	50	171.6	90.0	77.0	58.0	104.5
	75	175.0	92.0	79.0	60.0	107.5
	95	181.0	95.0	83.0	63.0	112.5
	98	183.0	96.5	84.8	65.0	114.0

and the percentiles for the five recorded measurements of data analysis.

Tables II and **III** show the detailed results of the anthropometric measurements in relation to the countries. Aircrew cadets from Oman, Singapore, and UK differed significantly in standing height [$F(2, 5125) = 942.2$, $P < 0.001$]. The UK cadets (M = 177.4) showed the highest standing height followed by Oman cadets (M = 171.9) and then Singapore cadets (M = 168.5). The post hoc test shows that the differences were significant between Oman and Singapore ($P < 0.001$), Oman and UK ($P < 0.001$), and Singapore and UK ($P < 0.001$).

There was a significant difference between cadets from Oman, Singapore, and UK in sitting height [$F(2, 5125) = 909.55$, $P < 0.001$]. The UK cadets (M = 93.6) showed the highest sitting height followed by Oman cadets (M = 90.3), and then Singapore cadets (M = 89.4). The post hoc test shows that the differences were significant between Oman and Singapore ($P < 0.001$), Oman and UK ($P < 0.001$), and Singapore and UK ($P < 0.001$).

The cadets from Oman, Singapore, and UK showed significantly different thigh lengths [$F(2, 5125) = 540.50$, $P < 0.001$]. The UK cadets (M = 60.7) showed the highest level of thigh length followed by Oman aircrew (M = 58.6) and then Singapore aircrew (M = 57.3). The post hoc test shows that the differences were significant between Oman and Singapore ($P < 0.001$), Oman and UK ($P < 0.001$), and Singapore and UK ($P < 0.001$).

There was a significant difference between cadets from Oman, Singapore, and UK in leg length [$F(2, 5125) = 472.05$, $P < 0.001$]. The UK cadets (M = 108.9) showed the longest leg length, followed by Oman cadets (M = 104.9), and then Singapore cadets (M = 104.7). The post hoc test shows that the differences were significant between Oman and UK ($P < 0.001$), and Singapore and UK ($P < 0.001$), and not significant between Oman and Singapore ($P = 0.532$).

Cadets from Oman, Singapore, and UK differed significantly in arm reach [$F(2, 5125) = 421.68$, $P < 0.001$]. The UK cadets (M = 80.2) showed the highest arm reach followed by Singapore cadets (M = 79.1) and then Oman cadets (M = 77.1). The post hoc test shows that the differences were significant between Oman and Singapore ($P < 0.001$), Oman and UK ($P < 0.001$), and Singapore and UK ($P < 0.001$).

The 5th and 95th percentiles of the five anthropometric measurements were compared between the three countries as illustrated in **Fig. 1**.

Table II. Differences Between Countries in Anthropometric Measurements.

		N	MEAN	SD	*F*	SIG.	DIFF.
Stature					**942.20**	**0.001**	**(2, 5125)**
	Oman	2296	171.9	4.9			
	Singapore	832	168.5	5.3			
	U.K.	2000	177.4	6.2			
Sitting height					**909.55**	**0.001**	**(2, 5125)**
	Oman	2296	90.3	2.7			
	Singapore	832	89.4	3.2			
	U.K.	2000	93.6	3.1			
Thigh length					**540.50**	**0.001**	**(2, 5125)**
	Oman	2296	58.6	2.9			
	Singapore	832	57.3	2.6			
	U.K.	2000	60.7	2.7			
Leg length					**472.05**	**0.001**	**(2, 5125)**
	Oman	2296	104.9	4.1			
	Singapore	832	104.7	4.7			
	U.K.	2000	108.9	5.1			
Arm Reach					**421.68**	**0.001**	**(2, 5125)**
	Oman	2296	77.1	3.3			
	Singapore	832	79.1	3.7			
	U.K.	2000	80.2	3.7			

The UK RAF holds the highest 5th percentile for all the five measurements followed by Oman and then Singapore. Similarly, for the 95th percentile except for arm reach Singapore Air Force have higher 95th percentile than RAFO.

The only significant correlation was between standing height and thigh length. It was a perfect (r = 1.00) and significant ($P < 0.001$) correlation; i.e., as thigh length increases the standing height will increase.

Table IV examines the correlations between the measurements and emphasizes the fact that the only significant correlation was between standing height and thigh length. Thus,

Table III. Tukey HSD Post Hoc Test of Anthropometric Differences Between Countries.

		DIFF	95% C.I LOWER	95% C.I UPPER	SIG.
Stature					
	Oman vs. Singapore	-3.40	-3.92	-2.88	0.001
	Oman vs. U.K.	5.50	5.11	5.89	0.001
	Singapore vs. U.K.	8.90	8.37	9.43	0.001
Sitting height					
	Oman vs. Singapore	-0.90	-1.18	-0.62	0.001
	Oman vs. U.K	3.30	3.09	3.51	0.001
	Singapore vs. U.K.	4.20	3.92	4.48	0.001
Thigh length					
	Oman vs. Singapore	-1.30	-1.56	-1.04	0.001
	Oman vs. U.K.	2.10	1.90	2.30	0.001
	Singapore vs. U.K.	3.40	3.13	3.67	0.001
Leg length					
	Oman vs. Singapore	0.20	-0.64	0.24	0.532
	Oman vs. U.K.	4.00	3.67	4.33	0.001
	Singapore vs. U.K.	4.20	3.75	4.65	0.001
Arm Reach					
	Oman vs. Singapore	2.00	1.67	2.33	0.001
	Oman vs. U.K.	3.10	2.85	3.35	0.001
	Singapore vs. U.K.	1.10	0.76	1.44	0.001

the most affected measurement by standing height was the thigh length.

DISCUSSION

The anthropometric measurements of the human body have significantly changed over time, while aircraft were designed and built to stay in service for a long duration of time.[8,11] This might lead to a human-machine incompatibility which is especially evident in flight suits and the use of safety protective equipment.

Aircrew-aircraft compatibility is of prime importance in military aviation to ensure task accomplishment and flight safety.[4,18] Anthropometric aircrew selection standards in the

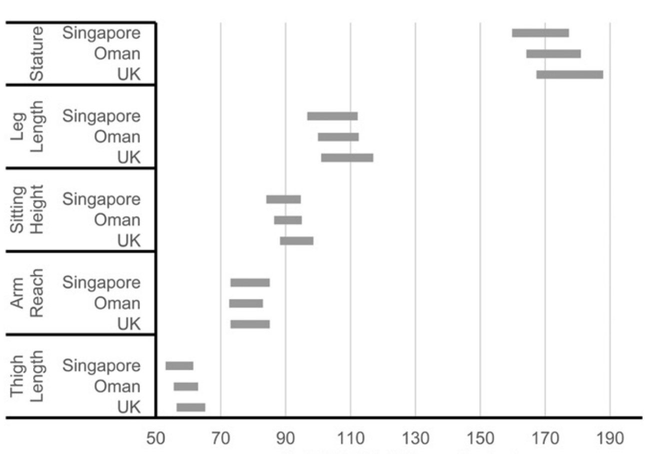

Fig. 1. The comparison of the anthropometric measurements for the three countries.

Table IV. CORRELATION BETWEEN THE FIVE MEASUREMENTS.

	STANDING HEIGHT	SITTING HEIGHT	THIGH LENGTH	LEG LENGTH	ARM REACH
Standing Height	1				
Sitting Height	0.983	1			
Thigh Length	1.000**	0.983	1		
Leg Length	0.941	0.987	0.941	1	
Arm Reach	0.473	0.626	0.473	0.744	1

** Correlation is significant at the 0.01 level.

Royal Air Force of Oman (RAFO), were taken from the selection standards of western defense forces as the aircraft were imported from those developed countries. The RAFO anthropometric standard limits practiced since establishment (which were actually adopted from the UK Royal Air Force) are a standing height of 162 to 188 cm, sitting height of 86.5 to 101 cm, arm reach of 74 to 90 cm, thigh length of 56 to 66 cm, and leg length of 100 to 120 cm. Henceforth, efforts were made to fit the local native aviators into an aircraft not initially designed for them. In view of this, this study was carried out to obtain the anthropometric data of Oman aircrew recruits and compare these with published Western and Eastern aircrew data with hopes of understanding and highlighting the aircrew-aircraft mismatch issues.

This study has emphasized a significant difference being present in the body dimensions of different ethnic groups which has given rise to some issues when it comes to selecting aviators. In a small Asian country, taking Singapore as a specific example with only a population of 2.7 million, there is a higher rate of rejection compared to the European countries.

A comparative distribution of anthropometric dimensions among different aircrew was conducted in this study. Minimal difference was noted between Oman and Singaporean recruits in stature, sitting height, and leg length, whereas the most pronounced differences were found to be between Oman and the Western population (UK). The Omani distribution of Thigh Length was midway between the Singaporean and Western population. The 95th percentile distribution of Arm Reach for the Omani recruits was comparatively lower to all the other populations studied. This might cause serious ergonomic implications when aircrafts are imported to suit the native population.

As mentioned earlier an aircraft cockpit is designed to nominally accommodate the 5th to 95th percentile of the population across aviation significant anthropometric parameters and that military aircraft engineers design the cockpit so that only 12–15% of the population should be too small or too large to operate the aircraft.[6,7,12,17] The majority of the anthropometric rejection in aircrew recruits in our study was mainly due to the failure to satisfy the minimum limit of anthropometric recruitment standards.

Although there are significant issues associated with the differences in anthropometric data and the ergonomic considerations, these have not been discussed extensively in the aviation industry. There are considerable differences in the body dimensions and proportions between different ethnic groups which can ultimately result in some serious ergonomic complications, consequently increasing the chances of human error and therefore of accidents occurring.[13] Variances in the body dimensions and proportions might lead to issues with the 'design eye position' in addition to difficulties in reaching some of the equipment and pedals present within the cockpit. Occasional pain, discomfort, and the possibility of injury are also some of the adverse effects which could be experienced. Caution should therefore be exercised when fitting Eastern bodies into Western cockpits.

This study has provided an opportunity to recognize the discrepancies involved in selection of Middle Eastern aircrew for Western cockpits. This also adds impetus to the scope for application of military recruitment standards suitable to the native population in aiding the ideal man-machine interface. This approach shall consider national policy, the significant anthropometric trends of the general population and the procured aircraft profile of the country. The organization should take care and be aware of the problems which might arise in fitting sub-anthropometric standards in a military aircraft.

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