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State-by-State Comparison of the Body Size of Young Australian Adults

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ABSTRACT

Up to date anthropometric (body size) data on the current Australian Defence Force aircrew population and the potential aircrew population is vital for the design and acquisition of clothing, protective equipment and aircraft. The most recent survey of the current and potential aircrew populations was completed in 2005. The survey team measured civilians at six locations around mainland Australia. They also visited several military bases to measure aircrew. Ideally, this dataset needs to be updated as it has a number of limitations for military applications. Unfortunately, multiple location surveys can be very expensive. The goal of this report is, using the 2005 survey of the civilian population, to determine if a survey of the potential aircrew population could possibly be conducted at fewer locations, hence, saving both time and money.

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State-by-State Comparison of the Body Size of Young Australian Adults

Executive Summary

Anthropometric (body size) data describing the size and shape of the current day male and female military population is vital for the optimised design of clothing, protective equipment and vehicles. Modern military personnel must wear, depending on the situation, a diverse range of clothing, along with protective equipment, such as helmets, respirators and body armour. Australian Defence Force (ADF) personnel may also be required to travel in or operate a range of land, sea and air vehicles, such as submarines, armoured personnel carriers, and aircraft. Complicating the challenge of acquiring new platforms is the fact that many vehicles in the ADF fleet can have long service lives. Given the potentially long service lives of many military vehicles not only is there a requirement to have valid data on the current military population (which is largely male) but also the potential male and female military population who may operate the platform in the decades to come.

The most recent anthropometric survey of a sample of the current and potential aircrew population was conducted in 2004 and 2005 as part of Project MIS 872. Unfortunately, this dataset has a number of issues that limits its use for ADF applications. Ideally, the datasets need to be updated to ensure valid data is available to support the acquisition and upgrading of air platforms, along with the design and sizing of clothing and protective equipment. Unfortunately, large-scale anthropometric surveys conducted at multiple locations can be very costly, time consuming and logistically challenging. A potential cost-saving option to consider is conducting the survey at fewer locations while at the same time capturing an appropriate cross-section of the population. To assess this option for a future survey of the potential aircrew population, this study sought to compare key body dimensions of the civilians measured in each state as part of Project MIS 872 and determine if there are any anthropometrically significant differences between the states. This information can potentially be used to guide the planning of future survey locations.

Ten key body dimensions relevant to aircraft design were selected for comparison: stretch stature, weight, body mass index, stretch sitting height, waist circumference, buttock circumference, acromiale-radiale length, radiale-stylion length, upper-leg length and lower-leg length. A statistical comparison of the males surveyed at the five measurement sites in Victoria, New South Wales, South Australia, Queensland and Western Australia found that there were no statistically significant differences for the ten key body dimensions compared. In contrast to the males, a comparison of the females surveyed in the four states (South Australia, Western Australia, New South Wales and Queensland) found that there were statistically significant differences for four of the ten measurements compared: weight, stretch sitting height, acromiale-radiale length, and upper-leg length.

Statistically significant differences were not found for stretch stature, radiale-stylion length, waist circumference, buttock circumference and lower-leg length.

The results of these comparisons provide support that a future survey of the potential male aircrew population could be conducted at a single location, potentially saving time and money. Given the results of the female comparison, it may be necessary to conduct a survey at multiple locations.

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Glossary

ACT	Australian Capital Territory
ADF	Australian Defence Force
ANOVA	Analysis Of Variance
BMI	Body Mass Index
CAESAR	Civilian American and European Anthropometry Resource
HSD	Honestly Significant Difference
NSW	New South Wales
Qld	Queensland
RAAF	Royal Australian Air Force
RAN	Royal Australian Navy
SA	South Australia
Vic	Victoria
WA	Western Australia

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1. Introduction

Anthropometric (body size) data describing the size and shape of the current day male and female military population is vital for the optimised design of clothing, protective equipment and vehicles. Modern military personnel must wear, depending on the situation, a diverse range of clothing, along with protective equipment, such as helmets, respirators and body armour. Protective equipment, like the body armour shown in Figure 1, must conform closely to the body, while minimising any restriction of movement and at the same time providing protection of the vital organs. Furthermore, a sufficient number of sizes for each item of clothing and protective equipment are required to accommodate both male and female members of the Australian Defence Force (ADF).

ADF personnel may also be required to travel in or operate a range of land, sea and air vehicles, such as submarines, armoured personnel carriers, and aircraft. If the ADF can influence the design of a new vehicle that will be acquired, data on the size of the current ADF population is required to ensure the vehicle is designed to maximise the percentage of personnel who can safely operate or travel in the vehicle. If the vehicle is an "off the shelf" acquisition developed using overseas body size information, anthropometric data on the ADF population is required to determine the percentage of personnel that are safely accommodated in the vehicle. Complicating the challenge of acquiring new platforms is the fact that many vehicles in the ADF fleet can have long service lives. For example, the DHC-4 Caribou, shown in Figure 2, was in service with the Royal Australian Air Force (RAAF) for 45 years. Given the potentially long service lives of many military vehicles not only is there a requirement to have valid data on the current military population (which is largely male) but also the potential male and female military population who may operate the platform in the decades to come.

Figure 1 Body armour has to be designed to protect the vital organs. Photo: ADF

Recognising the need to have current anthropometric data available, Project MIS 872 surveyed a sample of the aircrew and potential aircrew populations in 2004 and 2005. In total, this survey measured 250 ADF aircrew, and 1500 civilians 18 to 30 years old who had successfully completed high school. The aircrew were surveyed at RAAF bases Edinburgh, Pearce, Richmond, Williamtown and Amberley, while the civilians were measured at single sites in Adelaide, Canberra, Brisbane, Sydney, Melbourne and Perth. Unfortunately, this dataset has a number of issues which limits its use for ADF applications.

Figure 2 The DHC-4 Caribou was in service with the ADF for 45 years. Photo: SGT Rob Mitchell

Ideally, the current aircrew and potential aircrew datasets need to be updated to ensure valid data is available to support the acquisition and upgrading of air platforms, along with the design and sizing of clothing and protective equipment. Unfortunately, large-scale anthropometric surveys conducted at multiple locations can be very costly, time consuming and logistically challenging. Given the cost of multiple location surveys, a potential cost-saving option to consider is conducting the survey at fewer locations while at the same capturing an appropriate cross-section of the population. To establish if this may be an option for a future survey of the potential aircrew population, the goal of this report is to compare the size of key body dimensions of the civilians measured in each state as part of Project MIS 872 and determine if there are any anthropometrically significant differences between the states. This information can potentially be used to guide the planning of future survey locations.

2. Method

2.1 Project MIS 872 Anthropometric Survey

The MIS 872 Aircrew and Crewstation Anthropometry project surveyed a sample of the current aircrew and potential aircrew recruit population (males and females 18 to 30 years old who have completed secondary school) during 2004 and 2005. To ensure the survey captured an appropriate cross-section of young Australians, the survey team measured volunteers at a single location in the following capital cities: Perth, Adelaide, Melbourne, Canberra, Sydney and Brisbane. In total, they measured 1510 male and female civilians. In addition to this, they also visited several military bases, measuring 255 aircrew that flew a range of aircraft types (only nine aircrew were female). Unlike previous surveys, in which measurements were taken manually using anthropometers, callipers and tape measures, this survey was the first large-scale Australian survey to use a three-dimensional scanner to capture a digital point cloud of the subjects. It took between 45 and 60 minutes to process each subject, and over the course of a standard work day about thirty volunteers could be processed. Initially, each subject completed a brief demographic questionnaire (Olds et al., 2004). Following this, the subject then changed into form-fitting underwear, and number of manual measurements were then taken on the subject, including stretch stature, stretch sitting height, and weight. After this, a number of small triangular landmarkers were placed on 23 body landmarks, including nuchale, cerivcale, radiale right and knee crease right to enable these key body landmarks to be easily located in the scan file. In this case, the landmarks used were the same as the Civilian American and European Surface Anthropometry Resource (CAESAR) survey (Blackwell et al., 2002). The subject then placed a latex swimming cap on their head so the shape of the head could be captured in the scan. Following this, the subject stood in the centre of the scanning station, with their legs slightly spread apart and their arms slightly abducted away from their torso. A stripe of horizontal red laser light passed down the subject from head to toe in about 10 seconds. Cameras positioned in each of the four towers at the corners of the scanner observed the distorted stripe of light as it passed down the body, and using triangulation, a high resolution digital point cloud model of the subject was created. Measurements were then extracted from the scans using specialist software tools, such as girths, cross-sectional areas, volumes, and distances between landmarks (Olds et al., 2004; Schranz, Tomkinson, Olds, & Daniell, 2010).

2.2 Subject Selection

To ensure the anthropometric dataset appropriately represented the potential aircrew population only subjects with a body mass index (BMI) less than 30 kg m^{-2} were included in the dataset used for this analysis. Furthermore, as many of the survey subjects measured at the Australian Captial Territory (ACT) site were high-level athletes (elite basketballers and gymnasts, for example) and were not representative of the potential aircrew population the ACT data was not included in this analysis. As only 71 females

were measured at the Melbourne location this data was excluded from the analysis due to the small number of subjects measured.

2.3 Measurements Selected for Comparison

A subset of the 36 measurements provided to the Commonwealth by the University of South Australia were chosen for this statistical comparison. The measurements were chosen because they represent the overall body size, shape and proportions of the subjects, are relevant to aircraft design and were measured manually or could be reliably and accurately extracted from the three dimensional scan files. The ten measurements are listed in Table 1.

Table 1 The ten anthropometric dimensions chosen for comparison.

Measurement	Measurement Type
Stretch stature	Manual
Weight	Manual
Stretch sitting height	Manual
Acromiale-radiale length	Digital
Radiale-stylion length	Digital
Waist circumference	Digital
Hip circumference	Digital
Upper-leg length	Digital
Lower-leg length	Digital
Body mass index	Manual

2.4 Data Cleaning

To determine if any anomalous values were present in the dataset two approaches were taken. Firstly, for the values identified as outliers in box plots of each dimension the corresponding scan file for that subject was inspected to determine if the measurement was correct. If the data was identified as erroneous the data was corrected if possible (limb lengths could be measured from the scans, however it was not possible to measure circumferences, as specialised software was not available and some of the measurements [stretch stature, stretch sitting height and weight] were taken manually), otherwise the value was removed from the dataset. In addition, scatterplots of stretch stature versus weight, stretch stature versus stretch sitting height, waist circumference versus hip circumference, acromiale-radiale length versus radiale-stylion length, and upper-leg length versus lower-leg length were visually inspected for anomalous data. Again, for any identified anomalous data the scan of the subject was examined and if possible the

relevant dimension was corrected, otherwise the erroneous value was removed from the dataset.

2.5 Statistical Analysis

The statistical analyses were performed using version 12 of Statistica (Statsoft Inc., Tulsa, Oklahoma, USA). A one way analysis of variance (ANOVA) was used to determine if there were statistically significant differences between the states for each anthropometric dimension. To control the family wise error rates statistical significance was set at $p < 0.01$. If the F test was statistically significant comparisons were made between each of the states using Tukey's Honestly Significant Difference (HSD) method with the Spjøtvoll/Stoline correction for unequal group sizes.

3. Results

3.1 Males

Table 2 lists the results of the one way ANOVA for the state-by-state comparison of the ten anthropometric dimensions for civilian males 18 to 30 years old who have successfully completed secondary school. For all ten anthropometric dimensions the differences between the means of the five groups were not statistically significantly different.

Table 2 Results of the one way ANOVA for the ten anthropometric dimensions for males 18-30 years old.

Dimension	Sum of squares (between groups)	df (between groups)	Mean squares (between groups)	Sum of squares (within groups)	df (within groups)	Mean squares (within groups)	F	p
Stretch stature	545.26	4	136.31	32149.98	650	49.46	2.76	0.027
Weight	619.84	4	154.96	58980.91	650	90.74	1.71	0.147
Body mass index	16.92	4	4.23	3723.03	650	5.73	0.74	0.566
Stretch sitting height	122.91	4	30.73	8890.11	650	13.68	2.25	0.063
Waist circumference	32223.56	4	8055.89	2479460.83	649	3820.43	2.11	0.078
Buttock circumference	38057.49	4	9514.37	1931739.10	650	2971.91	3.20	0.013
Acromiale-radiale length	1881.77	4	470.44	253016.35	650	389.26	1.21	0.306
Radiale-stylion length	1936.84	4	484.21	127580.27	650	196.28	2.47	0.044
Upper-leg length	3005.50	4	751.37	498665.87	650	767.18	0.98	0.418
Lower-leg length	1731.24	4	432.81	415576.01	650	639.35	0.68	0.608

3.2 Females

Table 3 lists the results of the one way ANOVA for the state-by-state comparison of the ten anthropometric dimensions for civilian females 18 to 30 years old who had successfully completed secondary school. Statistically significant differences at $p < 0.01$ were found for four of the ten anthropometric dimensions: weight, stretch sitting height, acromiale-radiale length and upper-leg length. The differences for stretch stature, body mass index, waist circumference, buttock circumference, radiale-stylion length and lower-leg length were found not to be statistically significant.

Table 3 Results of the one way ANOVA analysis for the ten anthropometric dimensions for females 18-30 years old.

Dimension	Sum of squares (between groups)	df (between groups)	Mean squares (between groups)	Sum of squares (within groups)	df (within groups)	Mean squares (within groups)	F	p
Stretch stature	432.74	3	144.25	22535.26	545	41.35	3.49	0.016
Weight	1181.39	3	393.80	36143.67	545	66.32	5.94	0.001
Body mass index	48.71	3	16.24	3243.87	545	5.95	2.73	0.043
Stretch sitting height	298.38	3	99.46	6656.68	545	12.21	8.14	0.000
Waist circumference	40493.75	3	13497.92	2147428.94	545	3940.24	3.43	0.017
Buttock circumference	30560.25	3	10186.75	2018001.84	542	3723.25	2.74	0.043
Acromiale-radiale length	5103.75	3	1701.25	178681.21	545	327.86	5.19	0.002
Radiale-stylion length	747.98	3	249.33	110272.82	545	202.34	1.23	0.297
Upper-leg length	11761.38	3	3920.46	475450.37	545	872.39	4.49	0.004
Lower-leg length	972.75	3	324.25	327203.38	545	600.37	0.54	0.655

3.2.1 Weight

Table 4 shows the mean weight of females measured in each of the four states and the associated Tukey's HSD analysis. The states are arranged by effect size from the heaviest to the lightest. The heaviest subjects were from South Australia (μ = 62.8 kg), followed by Western Australia (μ = 60.4 kg), Queensland (μ = 59.3 kg) and New South Wales (μ = 59.1 kg). Statistically significant differences at $p < 0.01$ were found for the heaviest group (South Australia) and the lightest group (New South Wales). No other groups were found to be statistically significantly different.

Table 4 Tukey's HSD results for weight.

State	SA	WA	Qld	NSW
Mean (kg)	62.8	60.4	59.3	59.1
SA		0.065	0.027	0.001
WA			0.825	0.475
Qld				0.998
NSW				

3.2.2 Stretch Sitting Height

Table 5 shows the mean stretch sitting height of females measured in each of the four states and the associated Tukey's HSD analysis. The states are arranged by effect size, from the state with the largest stretch sitting height to the state with the smallest stretch sitting height. The subjects with the largest mean stretch sitting height were from South Australia (μ = 882 mm), followed by New South Wales (μ = 881 mm), Western Australia (μ = 876 mm), and Queensland (μ = 860 mm). The differences between the three states with the largest stretch sitting heights were not statistically significantly different. However, South Australia and New South Wales had a statistically significantly larger mean stretch sitting height than the smallest state Queensland at $p < 0.01$.

Table 5 Tukey's HSD results for stretch sitting height

State	SA	NSW	WA	Qld
Mean (mm)	882	881	876	860
SA		0.996	0.556	0.000
NSW			0.626	0.001
WA				0.014
Qld				

3.2.3 Acromiale-Radiale Length

Table 6 shows the mean acromiale-radiale length of females measured in each of the four states and the associated Tukey's HSD analysis. The states are arranged by effect size from the state with the largest mean acromiale-radiale length to the state with the smallest mean acromiale-radiale length. The subjects with the largest mean acromiale-radiale length were from South Australia (μ = 301 mm), followed by Western Australia and Queensland (both μ = 297 mm), and New South Wales (μ = 293 mm). The acromiale-radiale length of the female South Australians was statistically significantly larger than the females from New South Wales. No statistically significant differences were found between the other states for this dimension.

Table 6 Tukey's HSD results for acromiale-radiale length

State	SA	WA	Qld	NSW
Mean (mm)	301	297	297	293
SA		0.379	0.419	0.001
WA			0.992	0.090
Qld				0.513
NSW				

3.2.4 Upper-Leg Length

Table 7 shows the mean upper-leg length of females measured in each of the four states and the associated Tukey's HSD analysis. The states are arranged by effect size from the state with the largest mean upper-leg length to the state with the smallest mean upper-leg length. The subjects with the largest mean upper-leg length were from New South Wales (μ = 398 mm), followed by South Australia (μ = 395 mm), Queensland (μ = 393 mm) and Western Australia (μ = 387 mm). Statistically significant differences were found between the top state (New South Wales) and the state with the smallest mean upper-leg length (Western Australia). No statistically significant differences were found between the other states for this dimension.

Table 7 Tukey's HSD results for upper-leg length

State	NSW	SA	Qld	WA
Mean (mm)	398	395	393	387
NSW		0.847	0.709	0.002
SA			0.973	0.076
Qld				0.468
WA				

4. Discussion

As part of Project MIS 872, an anthropometric survey of the current and potential ADF aircrew populations was conducted in 2004 and 2005 in Victoria, South Australia, New South Wales, Queensland, Australian Capital Territory and Western Australia. This dataset needs to be updated for a number of reasons which limit its use for military applications. Given the significant cost of recent military anthropometric surveys conducted at multiple locations around Australia, the goal of this analysis was to examine if there were any significant differences in key body dimensions of the civilian subjects surveyed at each of the five mainland metropolitan locations. Potentially, providing support for a future survey of the potential aircrew population being conducted at fewer locations and, hence, at a reduced cost.

A statistical comparison of the 655 males surveyed at the five measurement sites in Victoria, New South Wales, South Australia, Queensland and Western Australia found that there were no statistically significant differences for the ten key body dimensions compared (which described the overall size, shape and proportions of the subjects): stretch stature, weight, body mass index, stretch sitting height, waist circumference, buttock circumference, acromiale-radiale length, radiale-stylion length, upper-leg length and lower-leg length.

In contrast to the males, a comparison of the 549 females surveyed at the four measurements sites (New South Wales, South Australia, Queensland and Western Australia) found that there were statistically significant differences for four of the ten measurements compared: weight, stretch sitting height, acromiale-radiale length, and upper-leg length. Statistically significant differences were not found for stretch stature, waist circumference, buttock circumference, body mass index, radiale-stylion length and lower-leg length. For the dimensions found to be statistically significantly different pairwise comparisons were made between each of the states using Tukey's HSD method. A state-by-state comparison of weight found that there was a statistically significant difference for the heaviest state South Australia (μ = 62.8 kg), and the state with the lowest mean weight Queensland (μ = 59.1 kg). The post hoc pairwise comparisons of stretch sitting height found that the two states with the largest stretch sitting height South Australia (μ = 882 mm) and New South Wales (μ = 881 mm) had a statistically significantly larger stretch sitting height than the state with the smallest mean sitting height Queensland (μ = 860 mm). For acromiale-radiale length, the state with the largest mean measurement for this dimension South Australia (μ = 301 mm) was statistically significantly greater than the state with the smallest mean measurement for this dimension New South Wales (μ = 293 mm). For upper-leg length, the state with the largest mean upper-leg length New South Wales (μ = 398 mm) was statistically significantly greater than the state with the smallest mean upper-leg length Western Australia (μ = 387 mm). Overall, South Australia appears to be the largest on average of the four states, being the largest/heaviest for three of the four dimensions (weight, stretch sitting height and acromiale-radiale length). Queensland was overall the smallest, being the smallest for one of the dimensions (stretch sitting height) and second smallest for the other three

dimensions (upper-leg length, weight and acromiale-radiale length). The results for the WA and NSW samples were mixed. The WA sample were on average the second largest for two of the dimensions (weight and acromiale-radiale length), third largest for stretch sitting height, and smallest for upper-leg length. The NSW subjects were on average the smallest for two dimensions (weight and acromiale-radiale length), while they were largest for one dimension (upper-leg length) and second largest on average for stretch sitting height.

4.1 Implications for Future Anthropometric Surveys

This study has statistically compared key anthropometric dimensions for young adult males and females measured in single metropolitan locations in the five mainland states for males and four mainland states for females. A comparison of the size of young civilian males found no statistically significant differences for the ten key body dimensions compared. Given these dimensions describe the overall body size and proportions of the male subjects this result provides evidence that a future survey of the male potential aircrew population could be conducted in one of these states. This would greatly reduce the logistical challenges and cost of the survey. The results for the female analysis are not as clear cut as the male results, as four of the ten dimensions were found to be statistically significantly different. It is unclear why differences were observed in the body dimensions of the female subjects but not the males.

4.2 Limitations of Study

As part of project MIS 872, a sample of the potential male and female aircrew population was surveyed at one location in each mainland capital city (excluding the Northern Territory). It may be the case that the size of subjects in regional areas may be different to those in metropolitan locations selected for this survey, although given all but one of the survey locations were tertiary education institutes (the Victorian location was an industrial park in the eastern suburbs of Melbourne) it would be reasonable to assume that many subjects who had grown up in regional areas were included in the survey. It also must be considered that the subjects were volunteers and this may impact how representative the sample is. A comparison of the BMI of MIS 872 subjects (not filtered by BMI) found that when compared to the Australian national nutrition survey conducted in the mid 1990s (Australian Bureau of Statistics, 1998) that took health related dimensions (in light clothing rather than underwear) the proportion of overweight subjects were underrepresented in the MIS 872 survey. The health-based survey reported that 27% of males and 18% of females 18 to 24 years old were overweight based on their body mass index, while only 10% of female and 19% of male MIS 872 subjects (not filtered by BMI) were overweight. Given the Defence focus of the survey and the requirement for measurements to be taken while only wearing underwear, potential volunteers who were overweight or obese may have been less inclined to participate.

5. Concluding Remarks

It is vital that up to date anthropometric data is available for the potential aircrew population to support the acquisition of future air platforms. A comparison of the size of the potential male and female aircrew population surveyed in several mainland capital cities found that there were no statistically significant differences in the size of males for ten key body dimensions. This result provides support for a future survey of the male potential aircrew population being conducted at one location. This represents a significant cost reduction for any future survey of the potential aircrew population. The result for the female potential aircrew population is less clear cut, and based on this analysis, it may be necessary to conduct a female survey at multiple locations around Australia

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19. ABSTRACT

Up to date anthropometric (body size) data on the current Australian Defence Force aircrew population and the potential aircrew population is vital for the design and acquisition of clothing, protective equipment and aircraft. The most recent survey of the current and potential aircrew populations was completed in 2005. The survey team measured civilians at six locations around mainland Australian. They also visited several military bases to measure aircrew. Ideally, this dataset needs to be updated as it has a number of limitations for military applications. Unfortunately, multiple location surveys can be very expensive. The goal of this report is, using the 2005 survey of the civilian population, to determine if a survey of the potential aircrew population could be conducted at fewer locations, hence, saving both time and money.