Longitudinal Changes in the Body Mass Index of British Army Pilots

William D. Porter; Grant D. Wilde; Nicholas P. Jeffery; P. Lynne Walters; Allison J. Eke; Alaistair J. R. Bushby; Mark S. Adams; Steven J. Gaydos

INTRODUCTION: Aircraft are manufactured according to design parameters that must account for the size and physical characteristics of the pilot. While cockpit dimensions, seats, restraints, and related components do not change substantially over the airframe lifecycle, it is conceivable that the occupant may, even if initially well-suited. This investigation focused on longitudinal body mass index (BMI) changes within a cohort of British Army Air Corps pilots.

METHODS: The study was a retrospective examination of electronic medical record data to assess longitudinal change within a representative cohort of Army pilots. Voluntary subjects were assigned unique subject numbers matched with individual electronic medical record data. Subject's age, service length, height, weight, and BMI were extracted from routine historical aviation medical exams.

RESULTS: Among 106 British Army Air Corps pilots, the mean age was 35.3 yr (SD = 7.4) with average length of service as a pilot of 9.0 yr (SD = 5.2). Within the observed cohort, the mean change in individual weight over time was an increase of 4.6 kg (SD = 7.3). Height remained relatively stable with a mean increase of 0.6 cm (SD = 1.9). Given the increase in weight, BMI was noted to increase longitudinally with a mean of 1.3 $kg \cdot m^{-2}$ (SD = 2.4).

DISCUSSION: British Army pilots experience increases in BMI over time much like the general population. Results of this study serve to inform future policy related to the body composition of aviation applicants, the retention of previously qualified pilots, and the safety concerns of crashworthiness design specifications.

KEYWORDS: aviation, pilot, BMI, longitudinal changes.

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Leonardo da Vinci's *Vitruvian Man* (inspired by the architect Marcus Vitruvius Pollio) remains a well-known exemplar of the human form whereby the ideal proportions of the male body are such that extended arms and legs form a circle with the umbilicus at the center with arm span equalling height.[8] The probity of the "ideal human form" notwithstanding, occupational medicine has indeed come to understand the importance of anthropometrics and ergonomics within the workforce, including aviation. Components of military and civilian aircraft are manufactured according to design parameters that should account for the size and physical characteristics of the occupants, including the wide variations of normal, as well as differences in gender. While the aircraft cockpit, controls, seats, restraint harness, and related components do not change substantially over time for the lifecycle of the airframe, the purpose of this study was to focus on longitudinal changes within the occupant, specifically rotary-wing aviators serving within the British Army Air Corps.

Helicopter stroking seats and restraint harnesses are designed to function and withstand decelerations for a specified range of occupant all-up-mass (AUM) to maintain peak

From Headquarters Army Air Corps, Middle Wallop, United Kingdom; the Medical Centre, Army Aviation Centre, Middle Wallop, United Kingdom; Headquarters, Joint Helicopter Command, Andover, United Kingdom; the Medical Centre, Wattisham Airfield, Suffolk, United Kingdom; the Medical Centre, RNAS Yeovilton, Somerset, United Kingdom; and the RAF Centre of Aviation Medicine, United Kingdom.

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Address correspondence to: Steven J. Gaydos, M.D., M.P.H., U.S. Exchange Officer, Aviation Medicine, HQ Army Air Corps, Middle Wallop, Stockbridge, Hampshire SO208DY, United Kingdom; steven.j.gaydos.mil@health.mil.

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G-forces below injurious levels during a crash sequence. AUM not only includes the individual, but must also allow for any uniform items, personal protective equipment, or survival gear that is worn by or harnessed to the pilot. Although safety ratings typically remain fixed for the airframe following initial design and testing phases, the weight of such aircrew-borne equipment has incrementally increased over time and can be significant, exceeding 20 kg in some cases depending on airframe and operational mission configuration (Army Consultant Adviser Aviation Medicine, personal communication, June 2023). From a safety perspective, this is concerning not only to ensure proper cockpit integration (e.g., freedom of control movement, occupant lookout, functional reach, egress, etc.,) but also because it drives the maximum allowable pilot nude body weight lower.

Body mass index (BMI) is a recognized measure of body composition that accounts for an individual's height and weight as follows: BMI = mass (kg)/height^2 (m). Overweight is defined as 25 to <30 $kg \cdot m^{-2}$, and obese is defined as ≥30 $kg \cdot m^{-2}$ (morbidly obese is ≥40 $kg \cdot m^{-2}$). Although an imperfect metric, it is useful for predicting disease outcomes related to body composition and is widely used within peer-reviewed medical literature. The 2009 Health Survey for England described observed trends in the overall population related to individual weight and BMI within the country (presented in **Fig. 1**).[7] "Overall, men and women had the same mean BMI (27.0 $kg \cdot m^{-2}$), and mean BMI generally increased with age in both sexes up to the age of 74, but dropped back slightly among those aged 75 and over. Almost a quarter of adults (22% of men and 24% of women) were obese. Among both men and women, prevalence of overweight and obesity was lowest in the 16–24 age group, and generally increased in the older groups up to the age of 74."[7] As pilots are recruited from the general population, ongoing changes in weight patterns among potential military recruits as well as qualified aviators remain of interest.

Over the last 50 yr, several authors have published cross-sectional anthropometric datasets related to cohorts of aviation crews. These studies involved the collection of individual measurements from large populations within a relatively short time span. While useful to describe the distribution of a population, these cohort measurements represent temporal "snapshots" rather than longitudinal changes (summary data reflected in **Table I**). As many of these published assessments predate the widespread inclusion of women within military occupations (or contain very small numbers of women), data for male populations are presented to elucidate the ongoing trends in body composition. Collectively, these sample studies suggest that the average weight of aviation crews has increased over the past 50 yr, mirroring the patterns observed in the general nonmilitary population.

In contrast to weight, average individual adult stature can be assumed to at least remain stable or, given enough time, decrease slowly as part of the natural aging process. Sorkin and colleagues studied the longitudinal change in height of 1068 individuals between the ages of 17–94 as part of the Baltimore Longitudinal Study on Aging and concluded that the "cumulative height loss from age 30 to 70 years averaged about 3 cm for men and 5 cm for women."[10] Additionally, the authors conclude "Because BMI is inversely proportional to the square of height, even a small change in height might have a large effect on BMI. The change in height with age has a substantial and increasing effect on BMI beyond middle age. In the 60-year period from age 20 to 80 years, BMI on average will increase by 1.5 $kg \cdot m^{-2}$ for men and 2.5 $kg \cdot m^{-2}$ for women, independent of any change in weight."

METHODS

Rather than a cross-sectional distribution anthropometric survey, this study was a retrospective examination of electronic medical record (EMR) data to assess individual longitudinal changes in BMI of British Army pilots. The null hypotheses for this study were as follows:

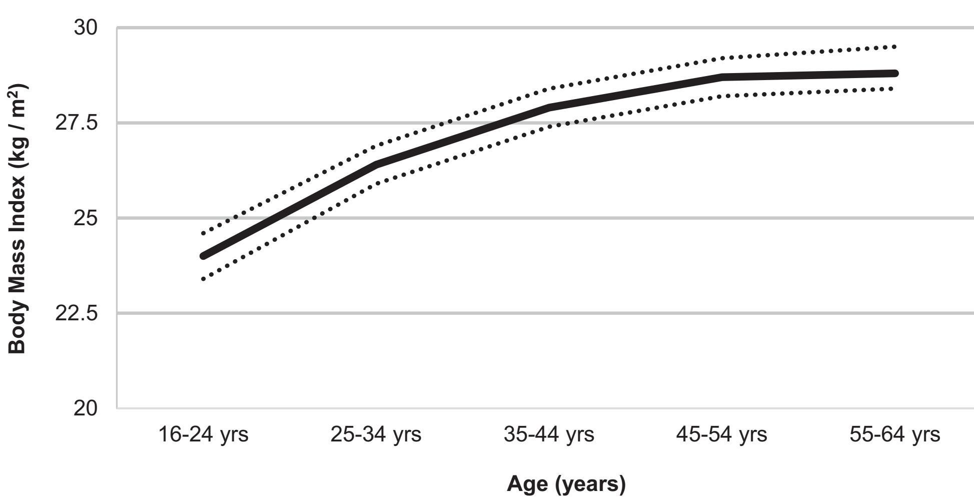


Fig. 1. Male body mass index ($kg \cdot m^{-2}$) and 95% confidence intervals as a function of age, general population. Created from data extracted from Health Survey for England.[7]

Table I. Cross-Sectional Anthropometric Datasets Related to Male Aviation Cohorts.

YEAR	AUTHOR	*N*	MEAN WEIGHT (kg)	SD	MEAN HEIGHT (cm)	SD
1964	Gifford[5]	1549	77.7	8.7	177.6	5.9
1970	Churchill[3]	1482	77.6	10.8	174.6	6.3
1970	Bolton[1]	1998	75.0	8.8	177.5	6.2
1988	Schrimsher[9]	29,000	79.2	9.1	179.0	6.3
1988	Donelson[4]	487	80.0	9.6	177.0	6.5
2008	Choi[2]	246	84.6	13.3	178.7	6.9
2012	Gordon[6]	977	88.2	12.6	177.5	6.5

SD = standard deviation.

- $H0_1$: There is no change in mean pilot height over time.
- $H0_2$: There is no change in mean pilot weight over time.
- $H0_3$: There is no change in mean pilot BMI over time.

A two-sided alternative for each null hypothesis was chosen as height, weight, or BMI may potentially increase or decrease over time. Holding power constant at 80%, a sample size of $N = 100$ was estimated to allow for the detection of a mean change in BMI of $2\,kg \cdot m^{-2}$ (SD = 7) (≥5% of the upper limit of normal BMI). In contrast to other aviation anthropometric cohort studies, we gathered retrospective health record data on individual participants and then examined trends in BMI across time. All British Army Air Corps pilots are required to complete an annual medical examination for the continuation of flying duties, and records from these examinations include entries for height and weight.

The study protocol was executed under the oversight of the Ministry of Defense Research Ethics Committee, and data were managed in accordance with the Data Protection Act and General Data Protection Regulation. Study investigators first obtained written approval to recruit study participants from the Commanding Officers of British Army Air Corps units and formations. Informational briefings to potential volunteer participants were then provided as to the nature and aims of the study. These briefings were conducted in small group settings in the absence of unit leadership or members of the chain of command (to preclude potential for undue influence). Volunteers expressing interest completed individual consent forms. No investigators were in the chain of command for any of the potential participants. Unit commanders did not receive any feedback on the number of participants recruited, nor was any individual participant data shared with them.

Participants were assigned a uniquely coded subject number matched with individual data from the Defense Medical Information Capability Program EMR. Data were first used to determine the demographic and summary characteristics of the study population. Paired *t*-tests were used to compare initial and final data points related to each individual participant's weight, height, and BMI. Age and length of service as a pilot were assumed to be colinear based on known and enduring recruiting and training practices associated with military service. Finally, a scatterplot with trendline was constructed to examine the relationship between change in service years and BMI for each participant. Data management and statistical analysis were completed with Microsoft Excel®.

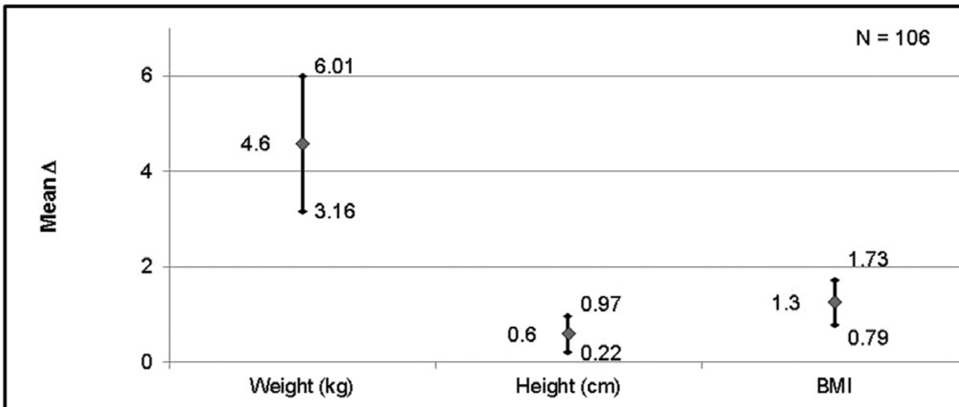
RESULTS

The study cohort consisted of 106 British Army Air Corps pilots. The mean age was 35.3 yr (SD = 7.4) and the average length of service as a pilot was 9.0 yr (SD = 5.2). **Fig. 2** depicts the mean change in individual weight with an increase of 4.6 kg (SD = 7.3), while mean height remained relatively stable across the dataset with a mean increase of 0.6 cm (SD = 1.9). BMI increased with a mean of $1.3\,kg \cdot m^{-2}$ (SD = 2.4). **Fig. 3** depicts a scatterplot ($R^2 = 0.2413$) of change in BMI vs. time as a pilot (yr).

DISCUSSION

This study assessed longitudinal change in BMI of British Army pilots and demonstrated that this population experienced an increase in BMI over time, much like the general population. A potential strength of this report relates to the longitudinal nature of the study. Numerous authors and groups have published cross-sectional anthropometric datasets related to cohorts of aviation crews. While important, these studies involved collection of individual measurements from large populations within a relatively short time span. Such cohort measurements represent "snapshots" in time of anthropometric distributions. The current study used a different approach by focusing on the longitudinal change of an individual's BMI.

Helicopter crashworthiness is predicated upon life-saving energy absorption systems that include stroking seats and restraint harnesses designed to optimally function within a specified range of occupant AUM. If an occupant exceeds the maximum seat weight, excess morbidity or mortality may result from the crash sequence. As mentioned, aircrew-borne equipment which may include aviation life support equipment, body armor, personal weapon and ammunition, and austere environment survival equipment contribute to occupant AUM and can be substantial depending on airframe and operational mission sets. Excessive weight may also inhibit safe egress during emergency procedures (especially with cockpit intrusion from an accident), and a large body habitus could potentially interfere with safe operation of the aircraft's controls, weapon or reconnaissance systems, or other vital cockpit equipment suites. Any such occurrence would be unacceptable from a risk mitigation and safety perspective. Lastly, although an imperfect metric, BMI can be useful for



	Weight (kg)	Height (cm)	BMI
Mean Δ	4.6	0.6	1.3
Std Dev	7.3	1.9	2.4
95% CI for Δ	3.16 – 6.01	0.22 – 0.97	0.79 – 1.73
P-value	0.0000	0.0022	0.0000

Paired t-test, (2) tails, 105 deg freedom

Fig. 2. Mean change in weight, height, and BMI among British Army Air Corps pilots.

health promotion and disease prevention. Healthy, fit aircrew are important not only for fitness to fly, but also service career longevity and long-term health as many diseases are associated with elevated BMI.

This study is subject to several limitations. Reliance on retrospective data previously entered into an EMR precluded control for any variation in measurement, and there was no direct evidence that height and weight were measured throughout the study period using a standard protocol or measurement device. However, technical standards do exist for the proper conduct of the annual aviation medicine exam, as well as medical equipment calibration requirements for medical centers. Given the vague nature of this potential for variation, it is difficult to assess if it would bias conclusions away from or toward rejection of the null hypotheses. Other potential sources of bias may include selection (volunteer) bias, healthy worker effect, and undercoverage bias.

The number of female pilots across the British Army Air Corps is known to be small (approximately 5–10% of the overall Army Air Corps pilot population). Although investigators did not intentionally exclude female participants from the study, no female pilots chose to participate. This may have been driven by concerns for the maintenance of anonymity with expected small numbers of women within the dataset, or other unknown reasons. As the focus of this study was related to concerns for individuals at risk to exceed the seat weight limits, future research should also consider the operational impacts of situations whereby pilots may weigh less than the minimum seat limit. In the case of stroking seats for example, there is also a minimum weight within the design specifications.

In summary, British Army pilots experience increases in BMI over time much like the general population. Results of this study should be used to inform future policy formulation related to the body composition of aviation applicants, the

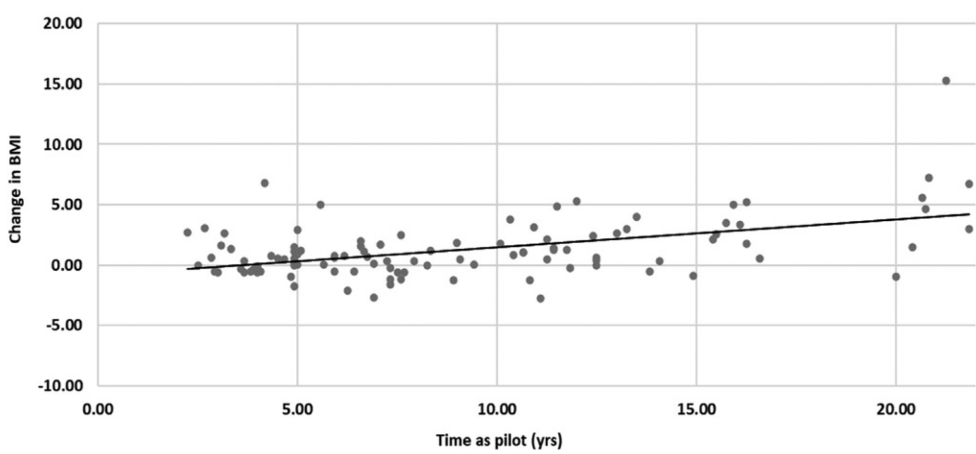


Fig. 3. Scatterplot of change in BMI vs. time as pilot (yr).

retention of previously qualified personnel, and the safety concerns of AUM that does not reside within safety system design specifications. Furthermore, acquisition programs and safety ratings should consider not only anthropometric data of the intended cohort, but also the potential for longitudinal changes over time.

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Authors and Affiliations: William D. Porter, M.D., M.P.H., Grant D. Wilde, M.B.Ch.B., MFOM, and Mark S. Adams, M.B.B.S., MFOM, Medical Centre, Army Aviation Centre, Middle Wallop, United Kingdom; Nicholas P. Jeffery, M.B.B.S., MFOM, Headquarters, Joint Helicopter Command, Andover, United Kingdom; P. Lynne Walters, M.B.Ch.B., MFOM, Medical Centre, Wattisham Airfield, Suffolk, United Kingdom; Allison J. Eke, M.B.B.S., MFOM, Medical Centre, RNAS Yeovilton, Somerset, United Kingdom; and Alaistair J. R. Bushby, MRCGP, MFOM, RAF Centre of Aviation Medicine, Bedfordshire, United Kingdom; Steven J. Gaydos, M.D., M.P.H., Headquarters Army Air Corps, Middle Wallop, United Kingdom.

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