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Trajectories of body mass index among active-duty U.S. Army soldiers, 2011–2014

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ABSTRACT

Establishing the shape and determinants of trajectories of body mass index (BMI) among Soldiers is critical given the importance of weight management to military service requirements. To establish the shape and determinants of BMI trajectories among Soldiers, we aimed to (1) model the overall BMI trajectory of Soldiers, (2) find the most common trajectory groups among Soldiers, (3) investigate the relationship between BMI trajectories and sociodemographic and military-specific characteristics, and (4) determine if there were Soldiers with large fluctuations in BMI. The study population included all US Army Soldiers on active-duty between 2011 and 2014 who were age 17–62 (n = 827,126). With longitudinal data from the Stanford Military Data Repository, we used group-based trajectory modeling to identify the BMI trajectories of Soldiers and multinomial logistic regression to estimate associations between Soldier characteristics and trajectory membership. Four distinct BMI trajectory groups were found: increasing, decreasing, constant, and inconstant. The constant, increasing, and decreasing trajectories were similar in shape and percentage between men and women. The constant trajectory had the fewest Soldiers who exceeded weight standards or had duty limitations. The increasing trajectory was associated with marriage and fewer service years. The decreasing trajectory was associated with more service years and higher educational attainment. The inconstant trajectory differed in shape between men and women. Over 6% of men and 12% of women had fluctuations in BMI indicative of weight cycling. Understanding the characteristics associated with BMI trends may assist the Army in targeting resources aimed to improve Soldier health and combat readiness.

1. Introduction

US Army Soldiers have similar sociodemographic characteristics to civilians, but military-specific characteristics and demands, including higher levels of physical activity, likely affect trends in body mass index (BMI). In addition to physical fitness tests, twice yearly the Army assesses a Soldier's compliance with weight and body composition standards using BMI-based weight-screening tables and circumference-based relative body fat assessments (Friedl, 2012; United States Army, 2013). These requirements result in the Army representing a population required to self-monitor weight to meet these standards. Despite these requirements, BMI has risen among members of the military, though to a lesser degree than in civilian populations (Smith et al., 2012).

As an anthropometric tool, BMI has been essential for documenting the obesity epidemic and its health consequences (Prentice and Jebb, 2001) and has been used to model the BMI trajectories of populations over time (Heo et al., 2003). Many studies are available on BMI trajectories of adults, children, and some specialized populations (Cole et al., 1995; de Groot et al., 2014; Jackson et al., 2012a; Tu et al., 2015; Walsemann et al., 2012), but few longitudinal studies of BMI trajectories in military populations exist. In civilians, characteristics such as gender (Flegal et al., 2016) are associated with BMI and older age,

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minority status, and low education are predictors of obesity (Zhang and Wang, 2004; Lahmann et al., 2000). Military-specific characteristics such as duty limitations or rank may be associated with BMI, but relatively little research are available on the sociodemographic or military-specific characteristics associated with BMI (Smith et al., 2012). Examining how Soldier characteristics relate to BMI trends could inform future research aimed at increasing compliance with weight standards and corresponds with Army priorities of improving combat readiness (Army Medical Command, 2017).

Using longitudinal data that included the entire population of the Army over a four-year period, we aimed to (1) establish the overall BMI trajectory of the Army by examining BMI changes associated with aging, hypothesizing there would be substantive differences between the BMI trajectory of Soldiers and BMI trajectories of civilians observed elsewhere (Jackson et al., 2012a; National Center for Health Statistics (U.S.), National Health and Nutrition Examination Survey (U.S.), 2016), (2) find the most common trajectory groups among Soldiers, hypothesizing there would be at least three distinct BMI trajectories, a majority group with a constant BMI, those who gained BMI, and those with an inconstant BMI, (3) investigate the relationship between BMI trajectories and select sociodemographic and military-specific characteristics, hypothesizing certain Soldier characteristics would be associated with BMI trajectory, and (4) determine if there were Soldiers with large fluctuations in BMI, hypothesizing fluctuations would be common.

2. Methods

2.1. Data and study population

Data were from the Stanford Military Data Repository (SMDR), a de-identified longitudinal dataset encompassing health, administrative, and sociodemographic data from all active-duty Soldiers between January 2011 and December 2014. Prior to any research activity, the SMDR was created by merging multiple military data systems using a Soldier's social security number that was then replaced with a unique participant ID (Table 1). These data were organized as a person-month panel providing up to 48 months of observation. The sample was restricted to Soldiers 17–62 years old (n = 827,126), which is the typical age range of Soldiers due to minimum entrance and mandatory retirement rules. The study was approved by the institutional review boards of the University of South Carolina, Stanford University, and the Defense Health Agency's Human Research Protection Office.

2.2. Measures

The dependent variable was BMI measured by medical staff at military medical facilities or by trained non-commissioned officers during mandatory body composition checks using the same procedures during the study period. BMI observations were screened for biologically implausible values within the population and within each person's data by subtracting each Soldier's mean BMI from all of their available BMI observations. BMI measures varying ± 5 BMI points from the person's mean were considered implausible values. This permitted any two BMI observations to be up to 10 BMI points apart (~23 kg) before a value was considered biologically implausible within a person's data. To account for the biological influence of pregnancy, we removed BMI observations taken in a month when a woman's medical record had a diagnosis code for pregnancy. We chose not to remove all BMI observations in women who had a pregnancy since Army regulations require women to meet weight standards within six months of childbirth (United States Army, 2013). These cleaning procedures removed 464,729 (2.2%) of the total number of possible BMI observations (Fig. 1).

Table 1
Sources of data from the Stanford Military Data Repository used in the study.

Military health system data repository
Medical diagnosis information
Defense manpower data center
Sociodemographic and military service data
Comprehensive ambulatory/professional encounter record
Height, weight, BMI taken during healthcare encounters
Periodic health assessments
Height, weight, BMI taken during annual health exams
Digital training management system
Height, weight, BMI measured every six months at time of physical fitness tests
eProfile
Duty restrictions determined by medical provider

2.3. Independent variables

The sociodemographic variables included were age, education, marital status, race/ethnicity, service years, branch of service, and rank. For time-variant variables, we used the first observed value in the analysis. Race and ethnicity were separate variables and were combined using federal guidelines (OMB Directive 15, n.d.).

Duty limitations were determined if a Soldier was “Medically Not Ready” (MNR) for deployment by a code of 3 or 4 indicating a substantial duty limitation in one or more categories used to quantify medical readiness in the eProfile system: physical capacity, upper extremities, lower extremities, or psychiatric (United States Army, 2016). Exceeding weight standards was determined by a Soldier exceeding weight and relative body fat standards (United States Army, 2013) during the study interval.

2.4. Statistical analysis

Data were analyzed using Stata, version 14.2 (StataCorp, College Station, TX). All analyses were stratified by gender given expected differences in BMI (Flegal et al., 2016). We determined the overall BMI trajectory of the Army through examining BMI changes associated with aging by graphing the mean BMI of Soldiers at each year of age.

The most common BMI trajectory groups among Soldiers were modeled through group-based trajectory modeling (GBTM) using the Stata *traj* procedure (Jones and Nagin, 2012). GBTM is used to find distinct trajectory groups within a population using multinomial modeling (Tu et al., 2015; Jones and Nagin, 2012). GBTM is a form of finite mixture models used to identify groups of individuals following similar developmental trajectories in an outcome over time, and uses probability distributions based on maximum likelihood estimation to determine group membership (Jones and Nagin, 2012; Jones and Nagin, 2007; Nagin and Odgers, 2010).

Models with 3, 4, and 5 trajectory groups were examined with months as a quadratic, cubic, or quartic polynomial and specified as a censored normal distribution. BMI skewness and kurtosis were 0.43 and 3.35, respectively. Similarly to other research (Walsemann et al., 2012), we used BMI without transformation after preliminary models using the natural log of BMI did not appreciably change model outcomes. The time scale was calendar month to capitalize on the frequent BMI observations.

Preliminary models produced estimates reflecting differences in magnitude between the mean BMI of the trajectory groups instead of BMI changes over time. Graphs of these models displayed horizontal lines showing only differences in mean BMI between the groups, not BMI changes over time. We corrected this by centering mean BMI for each individual at zero, adding back the overall mean of individuals when creating final graphs.

Models were evaluated by increasing the number of trajectories and order of the polynomial. Cubic models required ≥ 3 BMI observations for each individual, ≥ 4 for a quadratic term, and ≥ 5 for a quartic term to include Soldiers with enough BMI observations to contribute to models. The criteria for model selection were percent of Soldiers in each

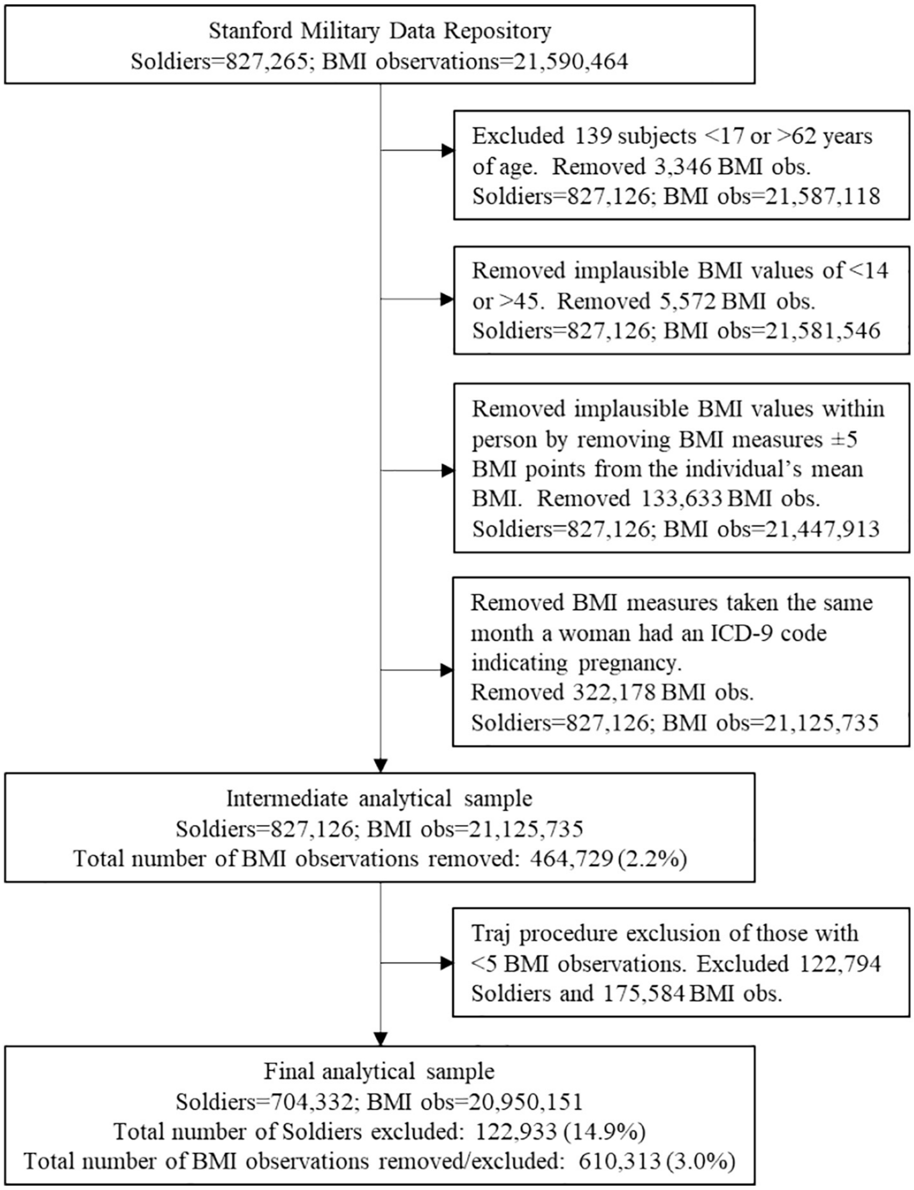

Fig. 1. Flow diagram depicting development of analytical sample of Soldiers and BMI observations, Stanford Military Data Repository, 2011–2014.

trajectory, complexity of the trajectories, stability of the estimates, and size of the Bayesian Information Criterion statistic. Models of 4 trajectories and months as a quartic polynomial were deemed to distinctly describe the main trajectories of Soldiers and had the smallest BIC.

A total of 14.8% of Soldiers were excluded from models due to insufficient BMI data (Fig. 1). More than 70% of Soldiers excluded from the *traj* procedure were junior enlisted with < 4 service years. Of the 122,794 Soldiers excluded from the *traj* procedure, 94,318 (76.8%) exited the Army in 2011 or entered the Army in 2014, leaving too little time to accumulate the ≥5 BMI observations required for final models.

GBTM does not model the intra-individual variability representing the non-trend portions of the trajectories (Frongillo and Rowe, 1999). To identify Soldiers with large intra-individual variability, such as BMI fluctuations caused by weight cycling, we fit person-specific growth curves to a random sample of 10% of men and an equal number of women (7208 men, 7069 women) with ≥8 BMI observations. To determine the degree of BMI fluctuations over time, we obtained the root mean squares error (RMSE) from linear regression models of BMI with time specified as a quartic polynomial. Soldiers with a RMSE of ≥1.0 correspond to those with fluctuations of two or more BMI points, or about 4.5 kg, over the study period. We considered weight cycling to be ≥3 bidirectional changes of ≥2 BMI points (Field et al., 1999) as seen by visual inspection of graphs of BMI over time in Soldiers with an RMSE of ≥1.0.

Bivariate associations described the characteristics of individuals in the trajectory groups. Multinomial logistic regression using BMI trajectory as the dependent variable identified characteristics associated with trajectory membership. Categories of race/ethnicity and marital status were collapsed in regression models for simplicity. Age categories used in the Army's weight allowance tables were used in regression models. Due to Army age requirements, cross-classification of sociodemographics showed categories with few or no Soldiers (e.g. Soldiers ages 17–20 with > 10 service years). These categories were collapsed to create a combined age and service years variable. In final models, rank and branch of service were removed since service years drives rank attainment and women were not in all branches.

3. Results

The overall trajectory showed for men at age 17 a mean BMI of 23.5

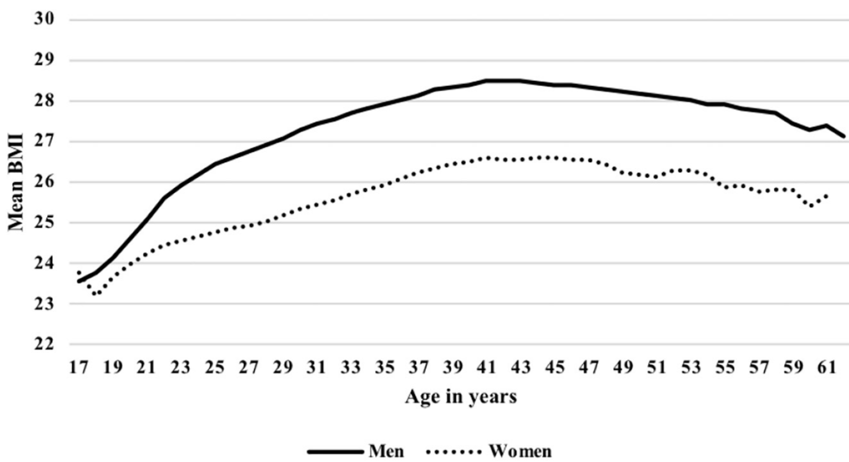

Fig. 2. Mean BMI (kg/m^2) of male and female soldiers ages 17–62, Stanford Military Data Repository, 2011–2014. Men (n) = 708,884, observations = 18,256,225; women (n) = 118,242, observations = 2,869,510.
Note: Standard error at age 17 was 0.422 men, 0.470 women. Standard error at all other ages ranged from 0.003 to 0.076 men, 0.008–0.180 women.

(kg/m^2) (SD 2.9) that gradually rose to 28.5 (kg/m^2) (SD 3.4), with men 43 years of age having the highest BMI. BMI then declined with the mean BMI of men 61 years of age being 27.3 (kg/m^2) (SD 3.0) (Fig. 2). For women 17 years of age, mean BMI was 23.8 (kg/m^2) (SD 2.1) with a small dip noticeable between 18 and 20 years of age, after which BMI began to gradually rise to 26.6 (kg/m^2) (SD 3.7), with women 41 years of age having the highest BMI. BMI did not begin to decline until 48 years of age for women, with the mean BMI of women 61 years of age being 25.7 (kg/m^2) (SD 3.6) (Fig. 2).

Final group trajectory models included 606,241 men and 98,091 women (Figs. 3 and 4). Among men and women, we observed a BMI trajectory in which Soldiers gained BMI over time, which was labeled "increasing." The percentage of Soldiers in the increasing trajectory was about equal (11.1% men, 10.6% women). The trajectory with the largest percentage of Soldiers (60.6% men, 60.0% women) involved maintaining a consistent BMI over the time interval and was labeled "constant." A trajectory comprising those who lost BMI over time had the smallest percentage of Soldiers (7.2% men, 7.0% women), and was labeled "decreasing."

One BMI trajectory was substantially different in shape, but not proportion, between men and women, and was labeled "inconstant" (21.1% men, 22.4% women). In men, the inconstant trajectory started at a higher mean BMI than the increasing and constant trajectories, but decreased to a lower point than all other trajectories in 2013. This decrease was followed by a gradual gain leaving the inconstant trajectory with a higher mean BMI in 2014 than in 2011. For women, the inconstant trajectory tended to be relatively flat towards the beginning and end of the time interval with an increase in BMI beginning in 2011 that peaked in 2013 and then declined leaving the mean BMI slightly higher in 2014 than in 2011.

With few exceptions, bivariate associations showed characteristics of male and female Soldiers in all trajectories to be similar, with the increasing trajectory group having primarily enlisted and married Soldiers with fewer service years (Tables 2 and 3). The increasing trajectory also included the largest percentage of MNR Soldiers (13.6% men, 15.4% women), exceeded weight standards (29.4% men, 35.5% women), or had BMI fluctuations (29.4% men, 25.1% women). A larger percentage of women in the increasing trajectory were Black (42.8% women, 18.8% men). The constant trajectory included the smallest percentage of men and women who were MNR (3.0% men, 4.3% women), exceeded weight standards (16.3% men, 25.9% women), or had BMI fluctuations (4.1% men, 7.8% women). Most men and women in the decreasing trajectory were older, officers, married, and had more service years and education.

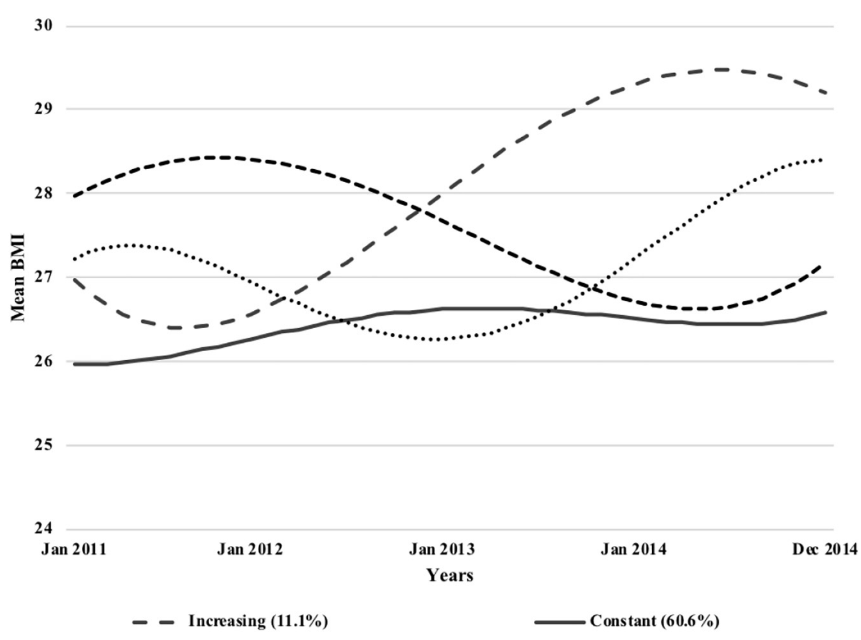

Fig. 3. BMI trajectories of male soldiers, Stanford Military Data Repository, 2011–2014. Soldiers = 606,241, observations = 18,113,713.

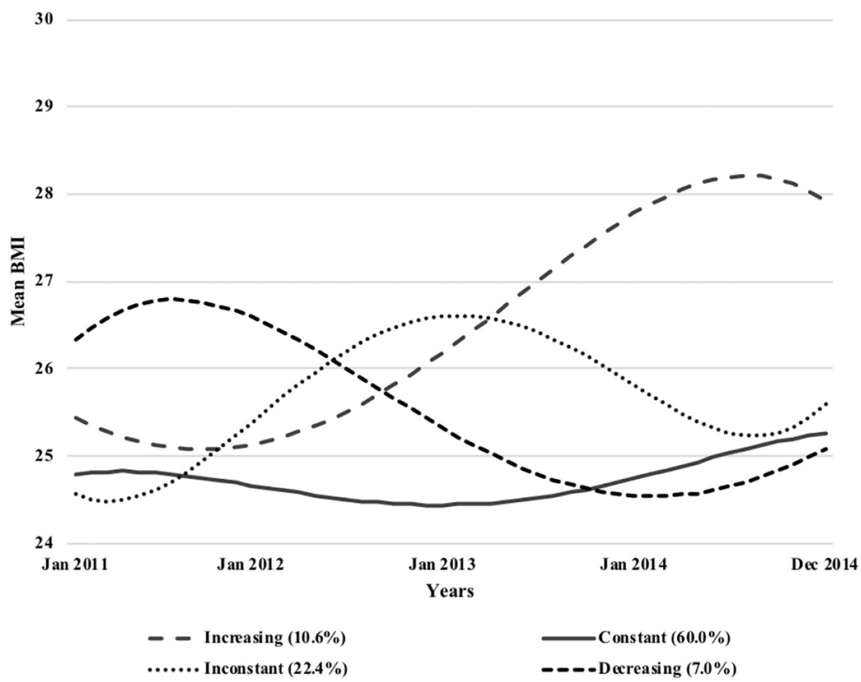

Fig. 4. BMI trajectories of female soldiers, Stanford Military Data Repository, 2011–2014. Soldiers = 98,091, observations = 2,836,438.

Table 2
Characteristics of male soldiers by BMI trajectory, Stanford Military Data Repository, 2011–2014.

Sociodemographic variables, mean (SD) or %	Increasing 11.1% *n* = 66,317 obs = 2,545,037	Constant 60.6% *n* = 380,085 obs = 10,084,005	Inconstant 21.1% *n* = 118,135 obs = 3,791,959	Decreasing 7.2% *n* = 41,704 obs = 1,692,712	Excluded 14.5%[a] *n* = 102,643 obs = 144,975
Mean BMI	28.0(3.5)	26.4(3.5)	27.1(3.4)	27.5(3.3)	25.9(3.9)
Age at first observation, years	26.9(7.0)	27.5(7.7)	27.2(7.5)	30.5(7.6)	24.5(6.7)
Rank categories[b]					
E1–E4	62.5	58.9	60.5	36.6	80.1
E5–E9	28.2	25.6	26.9	39.4	13.8
W1-O10	9.3	15.4	12.5	24.0	6.1
Years in service					
< 4	56.7	57.1	57.1	34.8	74.1
4–10	22.4	19.9	20.2	26.3	16.4
11–18	14.3	13.4	14.3	26.3	3.9
18 or more	6.7	9.6	8.4	12.6	5.6
Marital status					
Married	74.2	62.7	68.0	82.4	32.4
Single	24.3	35.4	30.3	15.9	65.5
Divorced/widowed	1.6	1.9	1.7	1.7	2.1
Education level					
High school/GED	82.1	75.4	78.9	66.1	85.0
Some college	8.1	8.4	8.1	10.6	5.4
Bachelors	7.2	11.3	9.2	14.7	7.6
Graduate	2.6	4.9	3.8	8.5	2.0
Race/ethnicity					
NH White	62.9	64.0	62.7	62.7	66.1
NH Black	18.8	17.7	18.3	17.7	15.7
NH Asian/Pacific Islander	2.8	3.7	3.2	3.3	3.7
Multi-racial	1.9	2.4	2.5	3.7	1.9
American Indian/Alaskan Native	0.8	0.6	0.6	0.5	0.8
Hispanic	11.8	12.4	11.5	12.1	11.8
Branch of army					
Combat arms	44.9	47.3	46.0	42.0	51.4
Combat support	40.2	36.7	38.3	38.9	35.2
Combat service support	14.9	16.0	15.7	19.1	13.4
Medically not ready	13.6	3.0	5.9	6.0	0.1
Exceed weight standards	29.4	16.3	23.8	19.3	23.7
BMI fluctuations (RMSE ≥ 1.0)	12.2	4.1	7.9	10.3	–
BMI observations	38.4(8.9)	26.5(14.1)	32.1(11.4)	40.6(7.6)	1.4(1.5)

[a] Percent of total sample of men (*n* = 708,884).
[b] Enlisted ranks: E1–E9; officer ranks: W1-O10; NH = non-Hispanic.

Table 3
Characteristics of female Soldiers by BMI trajectory, Stanford Military Data Repository, 2011–2014.

Sociodemographic variables, mean (SD) or %	Increasing 10.6% n = 10,215 obs = 407,894	Constant 60.0% n = 61,647 obs = 1,550,747	Inconstant 22.4% n = 19,674 obs = 603,980	Decreasing 7.0% n = 6555 obs = 273,817	Excluded 17.0%[a] n = 20,151 obs = 30,609
Mean BMI	26.5(3.1)	24.7(3.2)	25.7(3.4)	25.5(3.2)	24.5(3.4)
Age at first observation, years	28.3(7.6)	26.8(7.6)	27.4(7.6)	29.4(7.6)	23.8(6.0)
Rank categories[b]					
E1–E4	54.1	61.8	60.2	43.2	81.0
E5–E9	30.4	19.9	22.9	31.5	10.4
W1-O10	15.6	18.3	16.9	25.3	8.6
Years in service					
< 4	52.2	63.8	59.7	44.6	78.8
4–10	22.3	18.9	20.3	25.1	14.8
11–18	18.1	10.4	12.7	22.1	3.6
18 or more	7.4	6.9	7.3	8.2	2.8
Marital status					
Married	66.1	56.4	60.5	67.6	38.5
Single	25.6	37.1	32.1	24.3	56.9
Divorced/widowed	8.3	6.5	7.4	8.1	4.6
Education level					
High school/GED	69.5	69.0	70.2	61.4	80.0
Some college	10.8	9.0	9.7	10.8	6.8
Bachelors	13.8	14.9	13.9	18.1	9.8
Graduate	5.9	7.1	6.2	9.8	3.3
Race/ethnicity					
NH White	36.9	43.4	41.9	41.5	48.3
NH Black	42.8	34.0	35.9	34.9	31.0
NH Asian/Pacific Islander	3.6	4.9	4.3	4.5	3.8
Multi-Racial	4.1	3.6	3.9	4.3	2.9
American Indian/Alaskan Native	0.9	1.0	0.8	0.9	1.1
Hispanic	11.8	13.1	13.2	13.9	12.8
Branch of army					
Combat arms	0.0	0.0	0.0	0.0	0.0
Combat support	28.6	33.3	45.5	50.0	0.0
Combat service support	71.4	66.7	54.6	50.0	100.0
Medically not ready	15.4	4.3	5.5	8.5	0.09
Exceed weight standards	35.5	25.9	29.3	28.5	33.1
Weight fluctuations (RMSE ≥ 1.0)	25.1	7.8	18.8	17.7	–
BMI observations	40.0(8.5)	25.2(14.9)	30.7(12.2)	41.8(7.3)	1.5(1.4)

[a] Percent of total sample of women (n = 118,242).
[b] Enlisted ranks: E1–E9; Officer ranks: W1-O10; NH = non-Hispanic.

Table 4
Relative risk ratios and 95% confidence intervals from multinomial logistic regression of characteristics of male soldiers by BMI trajectory, Stanford Military Data Repository, 2011–2014.

Sociodemographic variables	Relative Risk Ratios [95% CI]		
	Increasing	Inconstant	Decreasing
Age (y) service (y)			
17–20 all service	Ref.	Ref.	Ref.
21–27 < 4 years	0.931 [0.908, 0.955]	0.897 [0.879, 0.914]	1.403 [1.343, 1.463]
21–27 > 4 years	0.932 [0.902, 0.962]	0.860 [0.838, 0.883]	2.094 [1.994, 2.199]
28–39 < 4 years	0.811 [0.779, 0.845]	0.845 [0.818, 0.873]	1.568 [1.480, 1.662]
28–39 > 4 years	0.809 [0.786, 0.833]	0.865 [0.846, 0.885]	2.806 [2.686, 2.930]
≥40 all service	0.642 [0.617, 0.669]	0.784 [0.760, 0.808]	2.119 [2.013, 2.230]
Education level			
High school/GED	Ref.	Ref.	Ref.
Some college	0.873 [0.846, 0.901]	0.921 [0.899, 0.944]	1.082 [1.045, 1.121]
Bachelors	0.613 [0.594, 0.633]	0.797 [0.778, 0.815]	1.208 [1.171, 1.246]
Graduate	0.520 [0.493, 0.548]	0.754 [0.727, 0.782]	1.329 [1.275, 1.397]
Race/ethnicity			
NH White	Ref.	Ref.	Ref.
NH Black	1.074 [1.051, 1.098]	1.045 [1.027, 1.063]	0.997 [0.970, 1.025]
NH other	0.958 [0.924, 0.994]	0.990 [0.963, 1.018]	1.027 [0.985, 1.070]
Hispanic	1.037 [1.011, 1.065]	1.091 [1.069, 1.113]	1.089 [1.054, 1.125]
Marital status			
Unmarried	Ref.	Ref.	Ref.
Married	1.966 [1.926, 2.008]	1.374 [1.352, 1.395]	1.904 [1.850, 1.960]

Note: reference: constant trajectory.

Table 5
Relative risk ratios and 95% confidence intervals from multinomial logistic regression of characteristics of female Soldiers by BMI trajectory, Stanford Military Data Repository, 2011–2014.

Sociodemographic variables	Relative risk ratios [95% CI]		
	Increasing	Inconstant	Decreasing
Age (y) service (y)			
17–20 all service	Ref.	Ref.	Ref.
21–27 < 4 years	1.077 [1.007, 1.152]	1.110 [1.058, 1.164]	1.439 [1.311, 1.580]
21–27 > 4 years	1.380 [1.269, 1.501]	1.205 [1.131, 1.283]	2.160 [1.936, 2.409]
28–39 < 4 years	1.504 [1.370, 1.652]	1.241 [1.156, 1.332]	1.661 [1.465, 1.885]
28–39 > 4 years	2.002 [1.864, 2.151]	1.377 [1.303, 1.456]	3.223 [2.929, 3.547]
≥ 40 all service	1.766 [1.610, 1.937]	1.376 [1.281, 1.479]	2.482 [2.205, 2.794]
Education level			
High school/GED	Ref.	Ref.	Ref.
Some college	0.939 [0.874, 1.010]	0.944 [0.891, 1.001]	0.989 [0.905, 1.080]
Bachelors	0.789 [0.739, 0.842]	0.852 [0.811, 0.895]	1.078 [1.002, 1.160]
Graduate	0.606 [0.550, 0.668]	0.733 [0.682, 0.789]	1.036 [0.938, 1.145]
Race/ethnicity			
NH White	Ref.	Ref.	Ref.
NH Black	1.388 [1.323, 1.457]	1.062 [1.023, 1.102]	1.016 [0.957, 1.079]
NH Other	1.005 [0.927, 1.091]	0.961 [0.904, 1.021]	1.009 [0.920, 1.107]
Hispanic	1.004 [0.935, 1.079]	1.018 [0.967, 1.072]	1.113 [1.026, 1.208]
Marital status			
Unmarried	Ref.	Ref.	Ref.
Married	1.449 [1.385, 1.516]	1.154 [1.116, 1.193]	1.420 [1.343, 1.501]

Note: reference: constant trajectory.

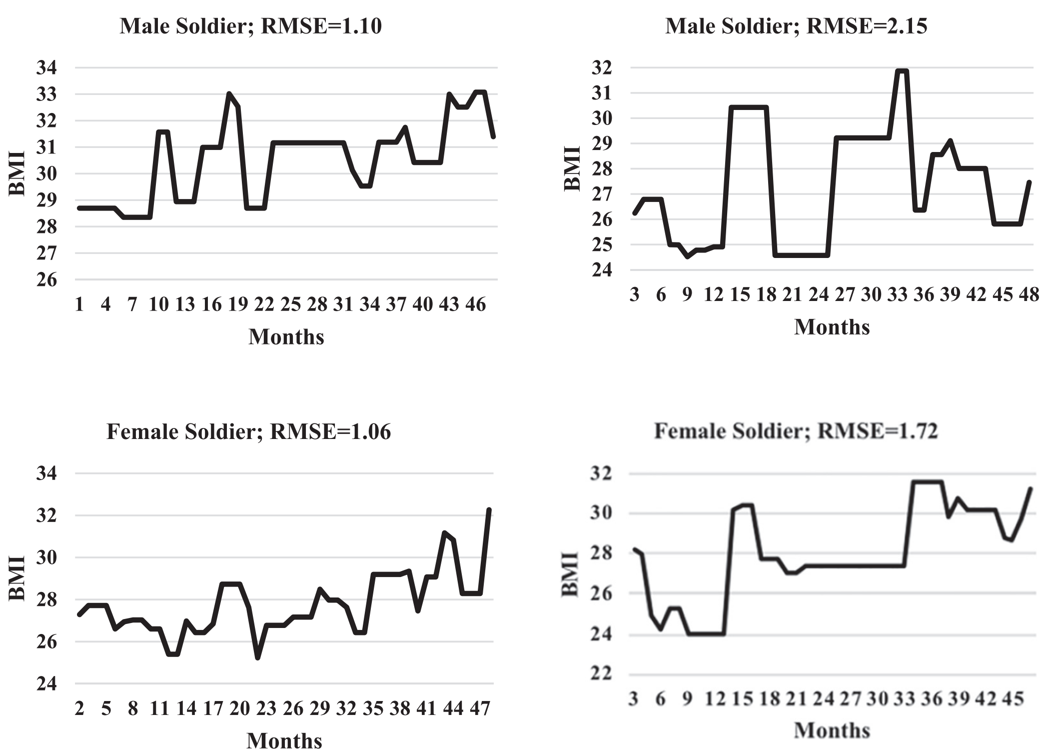

Fig. 5. Examples of weight cycling in Soldiers with an RMSE of ≥1.0, Stanford Military Data Repository, 2011–2014.

In multinomial logistic regression models, the reference group was the constant trajectory and Soldiers 17–20 years of age with any amount of service for the age-related variables (Tables 4 and 5). For men, increasing age and service years were related to a decreased risk of increasing-trajectory membership. Men 21–27 years of age with < 4 service years, compared to the reference group, had 0.931 (95% CI 0.908–0.955) time the risk of increasing-trajectory membership relative to the constant trajectory. Men ≥40 years of age with any service, compared to the reference group, had 0.642 (95% CI 0.617–0.669) times the risk of increasing-trajectory membership. Men ≥40 years of age with any amount of service had 2.119 (95% CI 2.013–2.230) times the risk of membership in the decreasing trajectory relative to the constant trajectory. Higher education, compared to the high school/GED reference group, was associated with a decreased risk of increasing-trajectory membership relative to the constant trajectory. Married men, compared to unmarried, were 1.966 (95% CI 1.926–2.008) times more likely to be in the increasing trajectory relative to the constant trajectory.

For women, increasing age and service years were related to a higher risk of increasing-trajectory membership. Women 21–27 years of age with < 4 service years compared to the age and service reference group, had 1.077 (95% CI 1.007–1.152) times the risk of increasing-trajectory membership relative to the constant trajectory. Women at ≥40 years of age with any service, compared to the reference group, had 1.766 (95% CI 1.610–1.937) times the risk of increasing-trajectory membership. The risk gradient associated with age and service years was consistent in the increasing and inconstant, but not the decreasing trajectory. Women ≥40 years of age with any amount of service had 2.482 (95% CI 2.205–2.794) times the risk of decreasing-trajectory membership relative to the constant trajectory. Higher education increased decreasing-trajectory membership risk. Black and married women, compared to White and unmarried, were more likely to be in the increasing trajectory relative to the constant trajectory. Higher education increased decreasing-trajectory membership risk.

The analysis of intra-individual variability among 14,277 randomly selected Soldiers revealed that 6.4% and 12.8% of men and women respectively, had BMI fluctuations (RMSE of ≥1.0). Visual inspection of 40 randomly selected graphs of BMI over time in individuals with fluctuations showed evidence of weight cycling in 13 out of 20 graphs of men (65%) and 15 out of 20 graphs of women (75%) (Fig. 5). If one were to extrapolate this analysis to the entire population of Soldiers and 45,366 (6.4%) of men in the Army were found to have BMI fluctuations, 29,488 would likely be weight cyclers, which equates to 4.2% of all male Soldiers. If 15,135 (12.8%) of female Soldiers were found to have BMI fluctuations, 11,351 would likely be weight cyclers, which equates to 9.6% of all female Soldiers.

4. Discussion

We established the overall BMI trajectory of U.S. Army Soldiers and found that BMI increased with age, similarly to but to a lesser degree than civilians. For male Soldiers, highest BMI was 28.5 (kg/m^2) in their forties, whereas the average civilian men's highest BMI is in their sixties, at 29.4 (kg/m^2) (Jackson et al., 2012a; National Center for Health Statistics (U.S.), National Health and Nutrition Examination Survey (U.S.), 2016). For female Soldiers, highest BMI was 26.6 (kg/m^2) in their forties, whereas an average civilian woman's highest BMI is in their fifties at 30.2 (kg/m^2) (National Center for Health Statistics (U.S.), National Health and Nutrition Examination Survey (U.S.), 2016). Differences between Soldiers' and civilian's highest BMI and the age at which BMI begins to decline are likely a result of factors related to military service.

Army weight regulations allow Soldiers' BMI and relative body fat to increase with age to a limited degree (Friedl, 2012; United States Army, 2013), but Soldiers must continually self-monitor weight to avoid administrative actions for exceeding weight standards. Weight self-monitoring has been found to be a successful strategy for preventing weight gain among civilians (Burke et al., 2011). Soldiers who stay in the Army beyond initial obligations represent those who successfully self-manage weight, thus large increases in BMI are not as likely among career Soldiers, such as those in their forties.

Among civilians, declines in muscle mass contribute to downward trends in BMI with age (Jackson et al., 2012b). Soldiers may be more physically active than civilians (Smith et al., 2012), but lean tissue decline associated with aging may also explain BMI decreases among Soldiers. Downward shifts in Army physical fitness standards with age support this theory. As Soldiers age, the number of repetitions of strength exercises required to pass physical fitness tests decreases, while the length of time allowed to pass cardiovascular fitness events increases (United States Army, 2012). Military-specific factors such as long-term weight self-monitoring, limits in weight gain, and greater physical activity are explanations for why Soldiers reach a lower peak BMI and at an earlier age. Although it is possible that older Soldiers have been less affected by the US's obesogenic environment, we believe it more likely that military-specific factors, combined with normal lean tissue declines with age, may explain why the average Soldier's BMI declines sooner than the average civilian.

We identified four distinct BMI trajectory groups among Soldiers which supports our hypothesis of at least three distinct trajectories: constant, inconstant, and increasing. Our analysis also revealed a decreasing trajectory comprising the smallest percent of Soldiers. Military-specific and sociodemographic characteristics such as MNR, service years, age, and marriage were associated with BMI trajectory membership. We also found evidence of BMI fluctuations among Soldiers supporting our hypothesis that Soldier characteristics are associated with BMI trajectory, and that a small, but non-trivial number of Soldiers had BMI fluctuations indicative of weight cycling.

Most Soldiers had a constant trajectory, reflecting adherence to weight control regulations. These Soldiers had the lowest mean BMI and fewer were MNR, exceeded weight standards, or had BMI fluctuations. Soldiers in the constant trajectory appear to be those most able to self-manage weight. Intervention studies using self-monitoring techniques typically consist of small samples with larger studies enrolling a few thousand individuals (Burke et al., 2011). The military represents the largest known population consistently self-monitoring weight, thus adding to the evidence of self-monitoring as an effective weight management strategy.

Soldiers in the increasing trajectory had BMI gains, we postulate, that were primarily of adipose tissue. The Army's physical training program relies on resistance training and running (United States Army, 2012). Studies on muscle changes in response to resistance training show gains in muscle and BMI after a 12-week program which is similar to the length of time Soldiers spend in basic combat training (BCT) where they begin physical training routines (Abe et al., 2000; Basic Combat Training, n.d.). Research on body composition changes in women after BCT show rapid gains in BMI due to fat-free mass increases (Friedl et al., 2001). In the increasing trajectory, BMI gains did not occur until > 1 year into the study interval making BMI gains from increased muscularity unlikely.

In both men and women, the greatest percentage of Soldiers who exceeded weight standards, were MNR, or had BMI fluctuations were in the increasing trajectory. BMI fluctuations could be caused by weight gain only, but most graphs showed clear evidence of weight cycling. The increasing trajectory had the highest mean BMI and the largest percentage of MNR Soldiers. Studies have found a higher BMI associated with musculoskeletal injuries (Anandacoomarasamy et al., 2008; Knapik et al., 2007), which is a common cause of MNR among Soldiers (Nelson and Kurina, 2013). Studies have also shown weight cycling to be predictive of future weight gain (Kroke et al., 2002; Saarni et al., 2006; Blake et al., 2013).

Married Soldiers had the highest risk of increasing-trajectory membership which supports existing research associating marriage with weight gain (Sobal et al., 2003). For both men and women, degree attainment reduced the risk of increasing and inconstant-trajectory membership, which concurs with research on the positive effects of education on BMI (Cohen et al., 2013; McLaren, 2007). With the exception of more Black women in the increasing trajectory, we did not find race/ethnicity associated with group membership, contrasting other research that found an association between higher BMI among Black or Hispanic Soldiers (Smith et al., 2012).

To our knowledge, this is the first study to identify distinct BMI trajectories in a military population. We know of one study that used the same method to model BMI trajectories of veterans, but they did not center BMI resulting in a description of magnitude differences in BMI, not actual trajectories (Rosenberger et al., 2011). Strengths include the longitudinal design, size, and breadth of the dataset, which allowed for robust analysis with high statistical power. Adding to the credibility of trajectory models is the number of BMI observations and BMI measures taken during medical visits or in standardized Army events. A weakness was the limited years of observation time, but consistency since 2014 in body composition regulations allows conclusions to be applicable beyond the years studied. Nearly 15% of the sample was excluded from GBTM primarily because these Soldiers had fewer service years in which to accumulate BMI observations. Although the bivariate analysis did not indicate substantive differences in the characteristics studied, these Soldiers may have unique characteristics not captured here.

5. Conclusion

This study found unique patterns in BMI among career Soldiers, adding to evidence of weight self-monitoring as an effective weight management technique. In civilian populations, workplace health programs incentivizing weight management may consider a formal self-monitoring component to increase action towards weight goals. In the Army, increasing the frequency of annual mandatory weight assessments may motivate Soldiers to maintain a weight that complies with regulations and minimizes weight fluctuations, which could improve combat readiness. We found four distinct BMI trajectories among Soldiers as well as differences in characteristics associated with trajectory membership, such as service years and education. While some characteristics are less modifiable than others, a strategy for improving combat readiness could be interventions targeting modifiable characteristics associated with BMI trajectories of concern. Further investigation into military-specific characteristics, gender-specific processes, and potential mediators such as eating behaviors that may influence BMI could help the Army better implement interventions aimed at improving Soldier health.

Disclaimer

The views expressed in this article are those of the authors and do not reflect the official policy of the Department of Army, Department of Defense, or the U.S. Government.

Conflicts of interest

None.

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