Weight and Body Measurement Changes In College Freshmen

by

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Abstract

A limited number of research studies suggest that new college students gain some weight on average during their freshman year. Most studies have had relatively small samples; some have used self-reported rather than measured weight. No known studies have followed body circumference measurements to explore where the effects of weight change may be observed. The purpose of this research was to quantitatively assess links between weight changes and body measurement alterations in entering freshmen through their first year. At the beginning of fall semester 2007, a convenience sample of 240 subjects were weighed, had body fat measured, completed a questionnaire, and had body measurements extracted through 3D body scanning; 205 subjects returned at the end of spring semester 2008. Of these, 187 (67 males and 120 females) had no missing measurements and were used for the analysis.

Of the 187, 100 (43 males and 57 females) gained weight, respectively averaging 6.93 lb and 7.21 lb; 39 (10 males and 29 females) lost weight (respective means of 6.34 lb and 3.72 lb). The remaining subjects remained within ±2 lb of their fall weight and were considered a no change group. Six trunk and two limb (biceps and thigh) measurements were compared. Among males and females who gained weight, seven measurements increased significantly; males' chest and females' thigh measurements increased but not significantly. Significant trunk increases ranged 1.31-1.94 in. in males and 0.89-1.21 in females; males' biceps and thigh increases were 0.61 and 0.79 in., and females' biceps increased 0.46 in. In the weight lost groups, only seat and thigh measurements decreased significantly for males (0.83 and 0.73 in.), and only thigh and biceps (0.59 and 0.38 in.) for females. Weight gain data were clustered into three or four segments for correlation analysis. Just eight significant relationships were found, two in clusters of ±2-6.6 lb and the others in clusters of ±4.2-20.4 lb. The limited results from the correlation analysis may have been influenced by small cluster sizes.

Use of 3D body scanning enabled assessment of the degree of symmetry or asymmetry in circumferential changes. Planar cross-sections of the chest/bust, hip, and waist were derived and overlaid for the two time points. Each overlay was visually categorized as symmetrical or asymmetrical in four possible ways (more in the back and front, most in the back, most in the front, or more on the sides). Males and females who gained and lost weight showed symmetric and asymmetric changes; males had proportionally more cases of symmetry than females.

Findings showed that actual measurement increases that occurred with weight gained or lost varied across trunk locations and were not necessarily symmetric around the body. This has implications for the divergent fields of health care and the apparel industry. Health professionals are interested in where weight may be deposited in relation to obesity. Apparel product developers make assumptions about how bodies change for garment sizing. More longitudinal study is needed to expand understanding of the links between and patterns of weight and body measurement change.

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CHAPTER I. INTRODUCTION

In the United States during the past 30 years, there has been a dramatic increase in overweight and obesity. According to the report, *"F as in Fat: How Obesity Policies Are Failing in America"* (Trust for America's Health Reports, 2008), the obesity rate for adults has been rising in 37 states. The National Health and Nutrition Examination Survey (NHANES) reported that obesity in adult men increased from 31.1% (2003-2004) to 33.3 % (2005-2006); for women, obesity increased from 33.2% (2003-2004) to 35.3% (2005-2006) (Centers for Disease Control and Prevention [CDC], 2007). Overall, 66 % of U.S. adults are categorized as overweight or obese (CDC, 2006). One-third of children are affected by overweight and obesity (Hedley, Ogden, Johnson, Carroll, Curtin, & Flegal, 2004; Ogden, Carroll, Curtin, McDowell, Tabak, & Flegal, 2006). There are regional differences; Mississippi ranks first, West Virginia ranks second and Alabama ranks third in the U.S. for obesity (Trust for America's Health Reports, 2008).

The years between ages 18 and 29 are marked as a critical period for elevated weight gain or obesity (Mokdad, Serdula, Dietz, Bowman, Marks, and Koplan, 1999). The "freshman 15" is a hypothetical phenomenon concerning students coming to college communities that relates to the beginning of that age period. It assumes that freshman students, particularly women, gain weight averaging fifteen pounds by the time they become sophomores (Hodge, Jackson, & Sullivan, 1993). Anderson, Shapiro, and Lundgren (2003) reported that the transition period between high school and college marks a drastic weight change period for young adults. Freshman weight gain has been attributed to junk food consumption, altered sleeping patterns (Graham & Jones, 2002), alcohol consumption (Wilson, Pritchard & Schaffer, 2004), cigarette smoking (Patterson, Lerman, Kaufmann, Neuner, & Audrain-McGovern, 2004), and disordered easting practices (Gutzwllller, Oliver, & Katz, 2003). Some studies have found that there is a significant weight increase in college freshmen (Hoffman, Policastro, Quick & Lee, 2006; Holm-Denoma, Joiner, Vohs, & Heatherton, 2008; Hovell, Mewborn, Randle, & Fowler-Johnson, 1985; Levitsky, Halbmaier, & Mrdjenovic, 2004; Matvienko, Lewis, & Schafer, 2001). One study (Hodge et al, 1993) reported that there was no significant weight gain among freshman subjects.

An approximate increase of 18.3 lb/year occurred in girls during the peak rates of weight gain (around 12.5 years); peak weight gain for boys was 19.8 lb in one year and that occurred at 14 years of age (Barnes, 1975). This weight gain is related to the fat distribution which occurs during the adolescence period. During the adolescence period for girls, growth is more in fat than muscle. Girls' fat accumulates particularly in the region of the trunk and upper thigh. For boys until adolescence, fat shows a greater increase than the growth of bones and muscles. However, the trend gets reversed during adolescence. Fat accumulates in body areas like the buttocks and flanks, abdomen, anterior and lateral surfaces of the upper thigh, breasts, back of neck and upper arm for girls, and for boys, fat accumulates in the trunk, chest, back and abdomen. Between ages 6 and 18 a redistribution of fat from the extremities to the trunk region occurs (Croney, 1971).

Weight gain can have implications for health. Some research in the last 25 years has explored the possible relationship between health risks and body size and where fat is placed, which can affect body shape. The focus has been on the central area of the torso, particularly waist circumference (WC) and waist-to-hip (circumferences) ratio (WHR). Rexrode, Carey, Hennekens, Walters, Colditz, Stampfer, Willett, and Manson (1998) compared the WHR and WC to determine risk of coronary heart disease (CHD) in women and found that WHR and WC were independently associated with coronary heart disease risk in women. Since WHR and WC measurements involve fat, these anthropometric measurements are often used in research related to weight gain.

In relation to apparel, weight has been noted to be the best predictor of female body shape for girth measurements (O'Brien & Shelton, 1941). Thus weight change can affect body measurements. Different changes in girth measurements can affect body shape. An understanding of body measurements and description of body shape guide apparel sizing specifications. The rising incidence of obesity in children, adolescents, and adults has implications for apparel sizing.

Present sizing standards were developed with old anthropometrics and with assumptions about body shapes that may be invalid. Men and women have different body shapes, and it varies from person to person. Schofield and Labat (2005) found that pattern grading was not based on any anthropometric data. Pattern grading is defined as "the process of increasing or decreasing the sample size pattern according to a set of body measurements and proportional relationships to develop a range of sizes for production" (Bye, 1999, p.10). Bye, LaBat, McKinney and Kim (2007) found that the existing grading practices in industry do not provide the necessary apparel fit for consumers. A study by Kurt Salmon Associates reported that 50% of women and 62% of men could not find proper fitting apparel (Kurt Salmon Associates, 1999). Recent increases in the population's weight may make the problem worse.

Exploring where body measurements change in relation to weight change has implications for the two different areas of health and apparel sizing. No research has been reported equating weight changes and changes in body measurements. Established interest in following weight change in college students and the availability of 3D body scanning offers the opportunity to follow body measurement change in adolescents. The proposed research will explore weight and body measurement changes among college students.

Statement of Purpose

The purpose of this study was to investigate possible relationships between changes in weight and body measurements using a sample of freshman males and females. The research sought to build evidence as to whether weight change (increases or decreases) appears to be reflected at particular girth locations on the body.

Research Questions

1. Did the body measurements of freshman males and females who gained or lost weight change from the beginning of fall 2007 to the end of spring 2008?
2. Were weight increases or weight decreases of freshman males and females related to changes in body measurements?
3. Did the body measurements change for the freshman males and females whose weight was stable?

4. Do changes in body measurements appear symmetrical or asymmetrical around the front, back, and sides of the body when viewed as planar slices?

CHAPTER II. REVIEW OF LITERATURE

The purpose of this study was to explore whether locational patterns exist that relate changes in weight and body measurements for freshman males and females. The research sought to build objective evidence to increase understanding of whether weight change (increases or decreases) appears more likely to occur at particular points on the body, as assessed by body girth measurements. It is believed that increases or decreases in fat and changes in fat distribution have direct impact on weight changes in the human body and body measurements. This review of literature discusses changes in weight among freshmen, fat distribution and physical growth, body measurements for apparel sizing systems, body shape, three dimensional body scanning, and anthropometric studies using 3D body scanning. These literature reviews explore research studies done in the past and relate them to current studies.

Changes in Weight Among Freshmen

To explore whether the "Freshman 15" is fact or fiction, several research teams have collected data at different institutions since 2000. Research conducted at the State University of New Jersey by Hoffman et al. (2006) assessed weight gain among freshman subjects. An initial sample of 217 volunteer participants in September ended with 67 (32 male and 35 female) participants in the April that followed. Weight and percentage of fat, measured using a digital scale and Bio Electrical Impedance (BIA), were used for statistical analysis. Their results showed that a weight gain of approximately 6.82 lb occurred during the freshman year. Another study (Mihalopoulus, Auinger, & Klein, 2008) surveyed 125 unmarried freshmen living on-campus. They collected data on weight, height, sex, and ethnicity through a self-report survey and analyzed the weight gain and Body Mass Index (BMI) for a period of seven months. Their results showed a significant weight gain for these college freshmen. However, the mean weights gained were less than those found by Hoffman et al. (2006); for men the gain was approximately 3.7 lb and for women 1.7 lb.

Anderson et al. (2003) had previously studied weight gain among freshman subjects. Weight gains over a period of four months (September to December) and nine months (September to May) were assessed using 145 and 46 participants, respectively. From the ANOVA test, they found an overall significant weight gain of approximately 2.9 lb for the period of September to December. Of the 145 participants, 74 % (100) participants gained weight; 20% (27) lost, and the remaining participants showed no change in weight. During the timeline of nine months, a mean gain of 3.7 lb was found. Holm-Denoma et al. (2008) examined weight fluctuation and its predictors among freshmen. They conducted a survey among freshmen (266 male and 341 female) who were asked to self report their weight and height, and completed measures of self-esteem, eating habits, interpersonal relationships, exercise patterns, and disordered eating behaviors. Results showed that there was a significant weight change for both men and women. While men gained a weight of 3.5 lb, women gained 4.0 lb.

In order to measure weight gain among freshmen over a period of 12 weeks, Levitsky et al. (2004) from Cornell University executed a study with 68 freshmen. Weights and heights were measured using a Healthometer scale at two time periods

(September and end of December). They found that the mean weight gain was 4.3 lb and that the increase in BMI was from 20.872.1 to 21.572.3 kg/m^2. Delinsky and Wilson (2008) measured weight gain, relation between dietary restraint and weight gain, disordered eating, and concern about the "freshman 15" among women. They tracked the students from September to April. There were 337 participants in September and 149 in April. They used several scales, including the Dutch Restrained Eating Scale, Eating Disorder Examination Questionnaire, and Rosenberg Self-Esteem Scale, and Body Shape Questionnaire, to collect data. From the self-reported weight, they found a mean weight gain of 3 lb over the studied timeline.

Morrow, Heesch, Dinger, Hull, Kneehans, and Fields (2006) conducted research among freshman women. They tracked 137 students from fall, 2004 to spring, 2005. A balance beam scale and Stadiometer were used to measure weight and height. Additionally, they used the DXA model Lunar DPX-IQ to quantify body fat percent, total fat mass, and total fat free mass. They found that there was a significant weight gain averaging 2.4 lb among these college women during their freshman year. The first published freshman 15 research, conducted by Graham and Jones (2002), collected weight and body fat data from 49 (39 female and 10 male) freshman students at the beginning of fall and end of spring. Of the 49 participants, 59% gained weight averaging 4.6 lb; 26 % of the participants lost weight during the academic year. Graham and Jones found no significant change in body fat among the participants. Though their results show no changes in body fat, several other researchers have studied and presented results pertaining to changes in body fat, fat distribution, body growth and related weight changes, as addressed in the next section.

A pilot study was conducted at Auburn University to examine changes in body weight, fat, shape and size in a group of 35 college freshmen (25 females, 10 males). Weight and height were measured at the beginning and end of the fall semester 2006 and at the end of spring 2007. By the end of fall, female subjects gained an average weight of 1.98 lb and at the end of spring it was around 3.02 lb. Average weight gain by male subjects was 2.2 lb by the end of fall and 5.35 lb by the end of spring (Drawdy, Zizza, & Gropper, 2007). A year later, another study on weight change and body composition was begun at Auburn University. It's 216 freshman students generated the data for the planned research to be reported in chapter IV for September 2007 to April 2008. Analysis of the weight data collected at the beginning and end of fall semester of 2007 showed an average increase of 1.7 lb for female students and 2.8 lb for male students over the period of one semester (Saunders, 2008).

Fat Distribution and Physical Growth

Fat Distribution

The fat distribution pattern in an adult human body is launched during the early adolescence period (Ramirez, 1993). The developing pattern of fat distribution is related to the sexual and skeletal maturity of adolescents (Baumgartner, Roche, Guo, Lohman, Boileau, & Slaughter, 1986). For normal adults of both sexes, subcutaneous fat (fat found just beneath the skin) (Ref. Figure 1) has a preference to accumulate in specific body areas (Ref. Figures 2 and 3) which include the buttocks and flanks, abdomen, anterior and lateral surfaces of the upper thigh, breasts, back of neck and upper arm. Fat in men is mostly stored on the trunk, chest, back and abdomen. Changes in fat distribution are reflected in shape and weight changes (Croney, 1971; Thibodeau, 1990).

During the long period of adulthood, shape and body proportions are not stable (Hooten & Dupertis, 1951). In adulthood, body growth stops except in the central part, including the lower torso. However, fat continually tends to increase in the trunk region with increasing age; fat in the extremities may not change or may even decrease in both males and females (Brozek, 1952). In the trunk region, visceral fat (fat deposited between the internal organs in the torso) increases more when compared to subcutaneous fat during adulthood (Borkan & Norris, 1977) (Ref. Figure 1). Two individuals with similar body weight and sum of skin fold thickness or percent body fat may have different distributions of subcutaneous fat (Mueller, 1982).

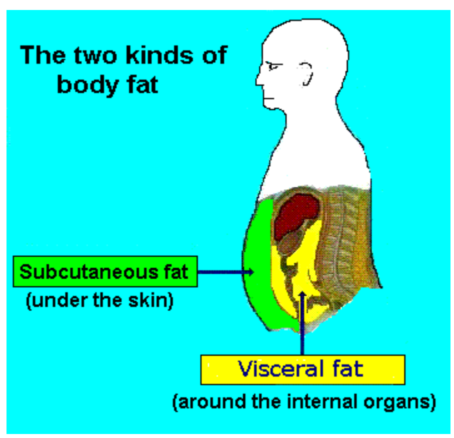


Figure 1. Types of fat (How to get rid of belly fat!, http://www.nutrition-health-supplements.com/belly-fat.html)

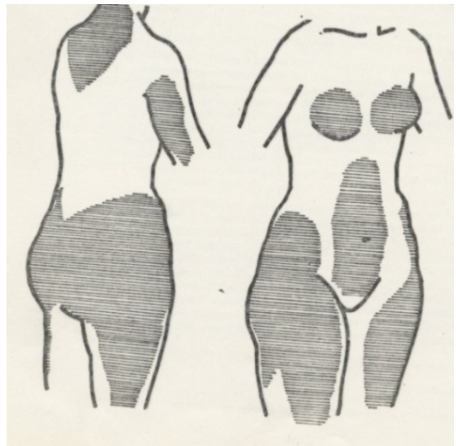


Figure 2. Residual fat areas in women (Croney, 1971).

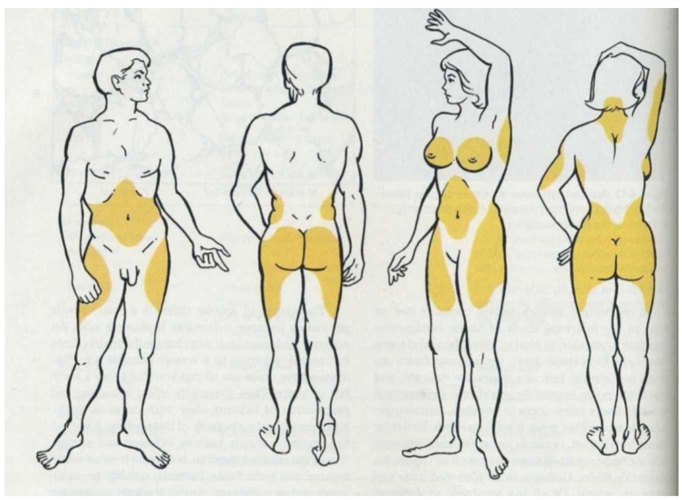


*Figure 3.*Fat storage areas in men and women (Thibodeau, 1990).

Fat Distribution and Sexual Differences

Mueller's (1982) study on the changes of anatomical distribution of fat with age, with 810 participants aged 6-15 and 715 participants aged 25-80, found that there was a general increase in fat among females aged 12-30. Fat continued to increase up to 40 years of age. Girls aged 12-17 had more fat than boys in that age range. During ages 6-18 and into young adulthood, there is a redistribution of fat from the extremities to the trunk for both sexes (Mueller, 1982; Ramirez & Mueller, 1980). Weight gained during late adolescence tends to deposit centrally. Reynolds (1951) found that there was a decrease in extremity fat for both sexes within the age range of 6.5-18.5 years. In adolescence, the redistribution of fat from leg to trunk accelerates, and this acceleration is higher in males than females (Baker, et al., 1951). The distribution of fat in the central region occurs more with obese adolescent girls, with fat being deposited especially in the upper trunk (Deutsch, Mueller, & Malina, 1985; Hattori, Becque, Katch, Rocchini, Boileau, Slaughter, & Lohman, 1987).

A few of the longitudinal studies about skin fold thickness have reported the development of centripetal fat (fat in trunk) distribution after puberty for both sexes (Cronk, Mukherjee, & Roche, 1983; Cronk, Roche, Chumlea, & Kent, 1982). When there is a loss of fat in the anterior leg region (refers to the front left compartment of a normal leg cross section), there is a gain of fat in the mid- trunk area. This pattern continues up to the fourth decade of life, suggesting that an absolute decrease in fat thickness in one part of the body leads to an absolute gain in another part (Garn & Young, 1956).

During the adolescence period for girls, growth is more in fat than muscle. Fat accumulates particularly in the region of the trunk and upper thighs for girls. It is reported that, in general, girls have more subcutaneous fat compared to boys. There is a physiologically disproportionate deposition of subcutaneous fat at central sites in girls during late adolescence. This deposition rate tends to increase as the girls approach their adult size (Hediger, Scholl, Schall & Cronk, 1995). For boys until adolescence, fat shows a greater increase than the growth of bone and muscle. However, that trend gets reversed during adolescence (Croney, 1971).

While it was a known phenomenon that girls accumulate both centripetal (fat in stomach) and peripheral fat (fat in arms, legs and subscapular), Ramirez (1993) found that many boys in his study also accumulated centripetal and peripheral fat. His subjects were adolescents aged between 12 and 20 whose arms and legs were measured to determine fat accumulation. In boys, the trunk skinfolds were found to increase until they reached 13 years of age, and then found to decline for a brief period through 14 years of age. Following that, the trunk skinfold was found to increase through late adolescence. (Malina, Bouchard and Bar-or, 2005). For adult men, subcutaneous fat tends to redistribute from peripheral to central regions (Schwartz, Shuman, Bradbury, Cain, Fellingham, Beard, Kahn, Stratton, Cerqueria, & Abrass, 1990) and to internal organs (Borkan, Hults, Gerzof, Robbins, & Silbert, 1983).

Sinha, Kapoor and Kapoor (2008) conducted a study to track the subcutaneous fat accumulation for two generations of males. Data on body weight, height and skin fold thickness at the biceps, triceps, subscapular, suprailiac and medial calf of 414 adolescent boys and their fathers were collected. The boys belonged to the age group 11 to 17. Results showed a continuous increase in body weights for age groups of 11 to 17 and 35 to 55. Patterns of subcutaneous fat distribution in adolescent boys and their fathers were assessed by their skin fold thickness. Fatness consistently increased with age, and fat distribution patterns were found to be established during ages 16 to 17. Another study reported that among a sample of boys aged 13 to 18, early-maturing boys had more subcutaneous fat on the trunk compared to late-maturing boys (Beunen, Malina, Lefevre, Claessens, Renson, Simons, Maes, Vanreusel, & Lysens, 1994). Poehlman, Toth, Bunyard, Gardner, Donaldson, Colman, Fonong, and Ades (1995) conducted a study to estimate changes in waist circumference due to subcutaneous fat for a group of men and women aged between 18 and 88 years. He reported an average increase in waist circumference of 0.28 cm per year for women and 0.18 cm per year for men.

Fat Distribution and Weight Changes

Fat distribution and deposition results in weight change with increasing age. After puberty, fat accounts for 16 % of the total weight for boys and 27 % of total weight for girls (National Center for Health Statistics, 2001). Peak weight gain for boys was 19.8 lb in one year and that occurred at 14 years of age (Barnes, 1975). Studies have reported that an approximate increase of 18.3 lb/year occurred in girls during the peak rates of weight gain (around 12.5 years). Weight gain slows during the period of menarche, but extends into late adolescence. From about one year after menarche to age 18 years, girls on average gained a total weight of 6.5 kg (14.3 lb) (Hediger, Scholl, Schall, & Cronk, 1995). Average weight gain among females during puberty (older than ages 13.4) was found to be within 15-55 lb of weight and for males it was 15-65 lb. Normally, during the latter half of adolescence, females gained 14 lb of weight (Barnes, 1975; Wong, Wilson & Whaley, 1995).

Siervogel,Wisemandle, S. Guo, Roche, Chumlea, and Towne (1998) calculated the rate of increase in total body fat as .57 kg/years males between ages 18 and 45, and .37 kg/year for men between ages 45 and 65 years. The most rapid increase in visceral fat, resulting in an increase in waist size, occurred in late adolescence (Ref. Figure 3). Kemper (1985) found a linear weight increase in boys from 38 to 63 kg as their age moved from 12 to 17 years, and found that the skinfold thickness of the trunk increased with a simultaneous decrease in the upper arm. On the contrary, there was an increase in both trunk and upper arm thickness for girls of same age group.

Body Measurements for Sizing Systems

Women's Sizing

Women's apparel sizing systems follow an arithmetic progression of size numbers that do not denote body measurements. In 1939, the U.S. Department of Agriculture sponsored a sizing study among U.S. women. O'Brien and Shelton (1941) manually collected 59 body measurements from 14,698 women. They found that women with the same bust measurements differed in their hip measurements by 5 to 6 inches. Additionally, they had calculated the correlation between weight and 19 girth measurements of 10,000 women. The correlation between weight and chest, bust, waist, abdominal extension, hip, and maximum thigh were found to be 0.8950, 0.8981, 0.8771, 0.8990, 0.9190, and 0.8725, respectively. These statistics suggested a strong relationship between weight and girth measurements. The measurements were used as the foundation for today's women's sizing.

Since all the participants were white, this study was biased from the point of data collection. Thus, the collected data were not sufficiently appropriate to standardize the sizing chart (O'Brien & Shelton, 1941). Nonetheless, these data were used to develop a "voluntary standard" published in 1958 by the National Bureau of Standards (NBS) as CS215-58, titled *Body Measurements for the Sizing of Women's Patterns and Apparel.* This standard was based on the 1939 study. It classified women into "Misses", "Women's", "Half-Sizes" and "Juniors" categories. Furthermore, it had classifications of height (Tall, Regular, and Short), and bust and hip measurement (Slender, Average, and Full) (U.S. Department of Commerce, 1958).

In 1971, the U.S. Department of Commerce released a new voluntary standard, known as PS 42-70. This standard was a revision of CS 215-58 with modifications based on the health surveys made in 1960-62 by the U.S. Public Health Service. In this standard, the bust girth was increased by one grade interval per size code; “Slender” and “Full” hip options were eliminated from the “Women’s” category and “Tall from the “Junior” category. (U.S. Department of Commerce, 1970).

The current standard sizing chart was developed by the American Society of Testing and Materials (ASTM). In 1995, the “Misses” standard ASTM D5585-95 was released with sizes ranging from 2 to 20. A sizing standard for women aged above 55, ASTM D5586-95, was also released by ASTM in 1995. Both the standards were based on the PS 42-70 chart with updated information (ASTM, 1995). Later, in 2002, the “Juniors” standard ASTM D6829-02 was released with sizes ranging from 0 to 19 (ASTM, 2002). In the “Misses” standard D5585-01(see Table 1), the sizes include 2, 4, 6, 8, 10, 12, 14, 16, 18, and 20. The bust, waist and hip measurements from the chart keep increasing for every size from 2 to 10 with a difference of 1 in., from 10 to 16 with an increase of 1.5 in. and from 16 to 20 with a difference of 2 in. Similarly, the upper arm size increases by 0.25 in. for sizes between 2 and 10, by 0.375 in. between 10 and 16, and by 0.675 in. between 16 and 20. The thigh max measurement follows an increase of 0.75 in. for sizes between 2 and 10, 1 in. between 10 and 16, and 1.25 in. between 16 and 20. (Table 2) Likewise, all the other measurements follow an arithmetic progression at different sections of intervals.

Table 1

ASTM Misses Standard Table – D5585-01 (ASTM, 2001)

Girth Measurements in in.

Size	2	4	6	8	10	12	14	16	18	20
Bust	32	33	34	35	36	37½	39	40½	42½	44½
Waist	24	25	26	27	28	29½	31	32½	34½	36½
High hip	31½	32½	33½	34½	35½	37	38½	40	42	44
Hip	34½	35½	36½	37½	38½	40	41½	43	45	47
Mid-neck	13	13¼	13½	13¾	14	14⅜	14¾	15⅛	15⅝	16⅛
Neck base	13½	13¾	14	14¼	14½	14⅞	15¼	15⅝	16⅛	16⅝
Armscye	14¼	14⅝	15	15⅜	15¾	16⅜	17	17⅝	18⅜	19⅛
Upper arm	10	10¼	10½	10¾	11	11⅜	11¾	12⅛	12¾	13⅜
Elbow	9⅜	9½	9⅝	9¾	9⅞	10⅛	10⅜	10⅝	11	11⅜
Wrist	5⅝	5¾	5⅞	6	6⅛	6¼	6⅜	6½	6⅝	6¾
Thigh, max	19½	20¼	21	21¾	22½	23½	24½	25½	26¾	28
Thigh, mid	18¼	18¾	19¼	19¾	20¼	21	21¾	22½	23½	24½
Knee	13	13⅜	13¾	14⅛	14½	15	15½	16	16½	17
Calf	12½	12⅞	13¼	13⅝	14	14½	15	15½	16	16½
Ankle	8⅜	8⅝	8⅞	9⅛	9⅜	9⅝	9⅞	10⅛	10⅜	10⅝
Vertical trunk	56	57½	59	60½	62	63½	65	66½	68	69½
Total crotch	25	25¾	26½	27¼	28	28¾	29½	30¼	31	31¾

Table 2 *Measurement Increase on Women's Sizing Chart*

Size	2-10	10-16	16-20
Bust	1"	1 ½"	2"
Waist	1"	1 ½"	2"
Hip	1"	1 ½"	2"
Thigh max	¾"	1"	1 ¼"
Upper arm	¼"	3/8"	5/8"

Men's Sizing

In general, men's apparel sizes are denoted by direct measurements. American producers were the first to apply standard sizing techniques to make quality garments. During the American Civil War, more than a million military men were measured for their chest sizes and height. In 1890, a sizing chart for juveniles and youth was developed covering chest sizes from 21 in. to 36 in. In 1921, the first report of an American anthropometric survey including clothing sizing was published (Ashdown & Na, 2007). In 1988, an anthropometric study called ANSUR was conducted among 1774 army men and 2208 women to develop a sizing chart for military clothing (Fan & Yu, 2004). In 1998, ASTM published its first sizing chart, "Standard Tables of Body Measurements for Men Sizes Thirty-Four to Sixty (34 to 60) Regular" (see Table 3), which has since undergone revisions (ASTM, 2004). Measurements of chest and hip monotonically increase by 1 in with each size increase (ref. Table 4). For the waist measurement, sizes 34-38 have a 1 in. increment; sizes 38-52 have a 1½ in. increment and sizes 54-60 have a 2 in. increment (ref. Table 5). An increasing trend followed by a decreasing trend is seen in the upper arm measurement. Table 6 tabulates the measurement pattern for upper arm. Thigh measurements exhibit a repeating pattern of fractions, which is shown in Table 7.

Table 3

ASTM Standard Tables of Body Measurements for Men Sizes Thirty-Four to Sixty (34 to 60) Regular- D6240-98 (ASTM, 2004)

	Small (34-37)				Medium (38-41)				Large (42-45)				X-Large (46-49)		
Weight (Approximate pounds)	128	131	138	145	153	165	180	185	195	200	210	215	230	235	245
	Girth Measurements (in.)														
Sizes	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
Chest	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
Waist	28	29	30	31	32	33	34	35	36	37	38	39 ¼	40 ½	41 ¾	43
Seat (hip)	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
Head circumference	21 ⅝	21 13/16	22	22 3/16	22 ⅜	22 9/16	22 ¾	22 15/16	23 ⅛	23 5/16	23 ½	23 11/16	23 ⅞	24 1/16	24 ¼
Neck base	14	14 ¼	14 ½	14 ¾	15	15 ¼	15 ½	15 ¾	16	16 ¼	16 ½	16 ¾	17	17 ¼	17 ½
Shoulder circumference	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
Armscye	16 ⅜	16 ¾	17	17 ⅜	17 ¾	18 ⅛	18 ½	18 ⅞	19 ¼	19 ⅝	20	20 ⅜	20 ¾	21 ⅛	21 ½
Upper arm	11 ½	11 ¾	12	12 ¼	12 ¾	13	13 ¼	13 ¾	13 ½	13 ¾	14	14 ¼	14 ½	14 ¾	15
Elbow	10 ⅞	11 1/16	11 ¼	11 7/16	11 ⅝	11 13/16	12	12 3/16	12 ⅜	12 9/16	12 ¾	12 15/16	13 ⅛	13 5/16	13 ½
Wrist	6 ¾	6 ⅞	7	7 ⅛	7 ¼	7 ⅜	7 ½	7 ⅝	7 ¾	7 ⅞	8	8 ⅛	8 ¼	8 ⅜	8 ½
Thigh	20 ¾	21 ⅜	22	22 ⅝	23 ¼	23 ⅞	24 ½	25 ⅛	25 ¾	26 ⅜	27	27 ⅝	28 ¼	28 ⅞	29 ½
Knee	14 ½	14 ¾	15	15 ¼	15 ½	15 ¾	16	16 ¼	16 ½	16 ¾	17	17 ¼	17 ½	17 ¾	18
Calf	13 ½	13 ¾	14	14 ¼	14 ½	14 ¾	15	15 ¼	15 ½	15 ¾	16	16 ¼	16 ½	16 ¾	17
Ankle	8 ½	8 ¾	9	9 ¼	9 ½	9 ¾	10	10 ¼	10 ½	10 ¾	11	11 ¼	11 ½	11 ¾	12
Trunk (total trunk, torso)	59 ¼	60 ⅜	61 ½	62 ½	63 ½	64 ½	65 ½	66 3/16	66 ⅞	67 9/16	68 ¼	68 ⅞	69 9/16	70 ¼	70 ⅞
Total crotch	24 ½	25 ⅛	25 ¾	26 ⅜	27	27 ½	28	28 ½	29	29 ½	30	30 ½	31	31 ½	32
	Vertical Measurements (in.)														
Sizes	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
Stature	67 ¾	68 ⅛	68 ½	69 1/16	69 ⅜	69 13/16	70 ¼	70 7/16	70 11/16	70 ⅞	71 ⅛	71 ¼	71 ⅜	71 ½	71 9/16
Cervicale height	58 ⅜	58 11/16	59	59 ½	59 ¾	60 ⅛	60 ½	60 11/16	60 ⅞	61 1/16	61 ¼	61 ⅜	61 ½	61 9/16	61 ⅝
Head height, including neck	9 ⅜	9 7/16	9 ½	9 9/16	9 ⅝	9 11/16	9 ¾	9 ¾	9 13/16	9 13/16	9 ⅞	9 ⅞	9 ⅞	9 15/16	9 15/16
Waist height	41 ¾	41 ⅞	42	42 ⅜	42 ½	42 ¾	43	43 ⅛	43 ¼	43 ⅜	43 ½	43 ⅝	43 11/16	43 11/16	43 ¾
Armscye depth	4 15/16	5	5 1/16	5 ⅛	5 5/16	5 7/16	5 ½	5 ⅝	5 11/16	5 13/16	5 ⅞	16	6 1/16	6 ⅛	6 ¼
Arm inseam	19	19	19	18 ⅞	18 ⅞	18 ¾	18 ¾	18 ⅝	18 ⅝	18 ½	18 ½	18 ⅜	18 ⅜	18 ¼	18 ¼
Crotch height (inseam)	32 ¼	32 ¼	32 ¼	32 ⅜	32 ⅜	32 ⅜	32 ½	32 ½	32 ½	32 ½	32 ½	32 ½	32 7/16	32 3/16	32 ⅛
Knee height	17 ½	17 ½	17 ¾	17 ¾	18	18	18 ¼	18 ¼	18 ¼	18 ¼	18 ⅜	18 ⅜	18 ½	18 ½	18 ½
Ankle height	2 ⅛	2 ⅛	2 ¼	2 ¼	2 ⅜	2 ⅜	2 ½	2 ½	2 ½	2 ½	2 ⅝	2 ⅝	2 ⅝	2 11/16	2 11/16
Waist length (cervicale to waist)	16 ⅝	16 13/16	17	17 ⅛	17 ¼	17 ⅜	17 ½	17 9/16	17 ⅝	17 11/16	17 ¾	17 ¾	17 13/16	17 ⅞	17 ⅞
True rise	9 ½	9 ⅝	9 ¾	10	10 ⅛	10 ⅜	10 ½	10 ⅝	10 ¾	10 ⅞	11	11 ⅛	11 ¼	11 ½	11 ⅝
	Width and Length (in.)														
Sizes	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
Across shoulder (point to point)	16 ½	16 ⅝	16 ¾	16 ⅞	17	17 ¼	17 ½	17 ¾	18	18 ¼	18 ½	18 ¾	19	19 ¼	19 ½
Across chest 4 in. down	15	15 ¼	15 ½	15 ¾	16	16 ¼	16 ½	16 ¾	17	17 ¼	17 ½	17 ¾	18	18 ¼	18 ½
Across back 5 in. down	15 ½	15 ¾	16	16 ¼	16 ½	16 ¾	17	17 ¼	17 ½	17 ¾	18	18 ¼	18 ½	18 ¾	19
Shoulder slope degrees	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
Cervicale to wrist	32	32 ⅛	32 ¼	32 9/16	32 ⅞	33 3/16	33 ½	33 ⅝	33 13/16	34	34 ⅛	34 5/16	34 ½	34 ⅝	34 ⅞
Hand and foot width	3 ¼	3 ⅜	3 ½	3 ⅝	3 ¾	3 ⅞	4	4 ⅛	4 ⅛	4 ⅛	4 ⅛	4 ¼	4 ¼	4 ¼	4 ¼
Hand length	7 ⅛	7 ⅛	7 ¼	7 ¼	7 ¼	7 ¼	7 ½	7 ½	7 ½	7 ½	7 ¾	7 ¾	7 ¾	7 ¾	8
Foot length	8 ½	9	9	9 ½	10	10	10 ½	10 ½	10 ½	10 ½	11	11	11	11	11 ½

Table 3 (Continued)

			XXL - 2XL (50-53)				XXXL - 3XL (54-57)				XXXXL - 4XL (58-60)	
Weight (Approximate pounds)	250	260	270	280	300	315	320	330	345	350	360	370
						Girth Measurements (in.)						
Sizes	49	50	51	52	53	54	55	56	57	58	59	60
Chest	49	50	51	52	53	54	55	56	57	58	59	60
Waist	44 ¼	45 ½	46 ¾	48	49 ½	51	52 ½	54	56	58	60	62
Seat (hip)	49	50	51	52	53	54	55	56	57	58	59	60
Head circumference	24 7/16	24 ⅝	24 13/16	25	25 3/16	25 ⅜	25 9/16	25 ¾	25 15/16	26 ⅛	26 5/16	26 ½
Neck base	17 ¾	18	18 ¼	18 ½	18 ¾	19	19 ¼	19 ½	19 ¾	20	20 ¼	20 ½
Shoulder circumference	55	56	57	58	58 ½	59	60	61	62	63	64	65
Armscye	20 13/16	21 ⅛	21 7/16	21 ¾	22 1/16	22 ⅜	22 ⅝	23	23 5/16	23 ⅝	23 15/16	24 ¼
Upper arm	15 ¼	15 ½	15 ¾	16	16 ¼	16 ½	16 ¾	17	17 ¼	17 ½	17 ¾	18
Elbow	13 11/16	13 ⅞	14 1/16	14 ¼	14 7/16	14 ⅝	14 13/16	15	15 3/16	15 ⅜	15 9/16	15 ¾
Wrist	8 ⅝	8 ¾	8 ⅞	9	9 ⅛	9 ¼	9 ⅜	9 ½	9 ⅝	9 ¾	9 ⅞	10
Thigh	30 ½	30 ¾	31 ⅜	32	32 ⅝	33 ¼	33 ⅞	34 ½	35 ⅛	35 ¾	36 ⅜	37
Knee	18 ¼	18 ½	18 ¾	19	19 ¼	19 ½	19 ¾	20	20 ¼	20 ½	20 ¾	21
Calf	17 ¼	17 ½	17 ¾	18	18 ¼	18 ½	18 ¾	19	19 ¼	19 ½	19 ¾	20
Ankle	12 ¼	12 ½	12 ¾	13	13 ¼	13 ½	13 ¾	14	14 ¼	14 ½	14 ¾	15
Trunk (total trunk, torso)	71 7/16	71 11/16	72 15/16	73 ½	74 5/16	75 ⅛	75 15/16	76 ¾	77 1/16	78 ⅜	79 9/16	80 ½
Total crotch	32 ½	33	33 ½	34	34 ½	35	35 ½	36	36 ⅝	37 ¼	37 ⅞	38 ½
						Vertical Measurements (in.)						
Sizes	49	50	51	52	53	54	55	56	57	58	59	60
Stature	71 ⅝	71 ¾	71 ⅞	72	72 ¼	72 7/16	72 ⅝	72 13/16	73	73 3/16	73 ⅜	73 ½
Cervicale height	61 11/16	61 ¾	61 ⅞	62	62 3/16	62 ⅜	62 ½	62 11/16	62 13/16	63	63 ⅛	63 ¼
Head height including neck	9 15/16	10	10	10	10 1/16	10 1/16	10 ⅛	10 ⅛	10 3/16	10 3/16	10 ¼	10 ¼
Waist height	43 ¾	43 13/16	43 ⅞	44	44 ⅛	44 ¼	44 ⅜	44 ½	44 ⅝	44 ¾	44 ⅞	44 15/16
Armscye depth	6 5/16	6 7/16	6 ½	6 ⅝	6 ¾	6 13/16	6 15/16	7	7 ⅛	7 ¼	7 5/16	7 ⅜
Arm inseam	18 ⅛	18 ⅛	18 ⅛	18 ⅛	18	18	18	17 ⅞	17 ⅞	17 ⅞	17 ¾	17 ¾
Crotch height (inseam)	31 ⅞	31 13/16	31 ¾	31 ¾	31 ¾	31 ⅝	31 ⅝	31 ½	31 ⅜	31 ⅜	31 ¼	31 ⅛
Knee height	18 ¾	18 ¾	18 ¾	18 ¾	19	19	19	19	19 ¼	19 ¼	19 ¼	19 ¼
Ankle height	2 ¾	2 ¾	2 ¾	2 ¾	2 ⅞	2 ⅞	2 ⅞	2 ⅞	3	3	3	3
Waist length (cervicale to waist)	17 15/16	17 15/16	18	18	18 1/16	18 ⅛	18 ⅛	18 3/16	18 3/16	18 ¼	18 ¼	18 5/16
True rise	11 ⅞	12	12 ⅛	12 ¼	12 ⅜	12 ⅝	12 ¾	13	13 ¼	13 ⅜	13 ⅝	13 ¾
						Width and Length (in.)						
Sizes	49	50	51	52	53	54	55	56	57	58	59	60
Across shoulder (point to point)	19 ¾	20	20 ¼	20 ½	20 11/16	20 ⅞	21 1/16	21 ¼	21 7/16	21 ⅝	21 13/16	22
Across chest 4 in. down	18 ¾	19	19 ¼	19 ½	19 ¾	20	20 ¼	20 ½	20 ¾	21	21 ¼	21 ½
Across back 5 in. down	19 ¼	19 ½	19 ¾	20	20 ¼	20 ½	20 ¾	21	21 ¼	22	22 ¾	22 ½
Shoulder slope degrees	25	25	25	25	25	25	25	25	25	25	25	25
Cervicale to wrist	35 ⅛	35 ¼	35 7/16	35 ⅝	35 13/16	36	36 3/16	36 ⅜	36 9/16	36 ¾	36 15/16	37 ⅛
Hand and foot width	4 ⅜	4 ⅜	4 ⅜	4 ⅜	4 ½	4 ½	4 ¾	4 ¾	5	5	5	5
Hand length	8	8	8	8 ¼	8 ¼	8 ¼	8 ¼	8 ½	8 ½	8 ½	8 ½	8 ½
Foot length	11 ½	11 ½	11 ½	12	12	12	12	12 ½	12 ½	12 ½	13	13

Table 4

Chest and Hip Measurement Increase in Men's Sizing Chart

Size	34-60
Chest	1"
Hip	1"

Table 5

Waist Measurement Increase in Men's Sizing Chart

Size	34-38	38-52	52-54	54-60
Waist	1"	1 1/4"	1 1/2"	2"

Table 6

Upper Arm Measurement Increase in Men's Sizing Chart

Size	34-37	37-38	38-60
Upper arm	1/4	1/2	1/4

Table 7

Thigh Measurement Increase in Men's Sizing Chart

Size	34-36	36-37	37-38	38-44	44-45	45-46	46-52	52-53	53-54	54-60
Thigh	5/8	2/3	4/7	5/8	2/3	4/7	5/8	2/3	4/7	5/8

Body Shape

One of the most important features used to classify biological specimens is shape. In 1638, Galileo did a shape analysis and found that bones in small animals were not scaled down from bigger animals (Dryden & Mardia, 1998). Initially shape analysis was performed from a biological point of view. Later, several research studies were done to identify different types of human body shapes. In the 19th century, researchers used a grid system to study biological size and shape variation. In this system, body shapes were placed on a grid and compared for size variations (Thompson, 1917). In 1930, a mechanism to classify body types was initiated by William Sheldon. He used nude photographs of 4,000 undergraduate male students aged 16-20 to arrive at a classification of body types (Sheldon, Stevens, & Tucker, 1940). Basically size is not related to shape. Mossiman (1988) elucidated that there is no relationship between size and shape. Saying that shape should be used for classification and could be used to classify organisms within species as small or large, he concluded that shape does not depend on size. Recently, 3D body scanned images have been used in body shape analysis, including in the apparel industry. The purpose of studying human shape in relation to the apparel industry has been to improve sizing.

Female Figure Identification Technique (FFIT) for Apparel

Research on body shape analysis using 3D body scanning by Simmons (2002) identified different types of body shapes in females. A convenience sample of 222 females aged 18 and older was selected. Subjects were scanned using the Textile and Clothing Technology corporation $[TC]^2$ NX-12 scanner. Their body measurements, including bust, waist, hip, stomach and abdomen circumferences were extracted and used to identify the body shapes of the participants. Software was developed to identify shapes; the nine shapes identified were hourglass, bottom hourglass, top hourglass, triangle, inverted triangle, spoon, oval, diamond and rectangle. These are shown in Figure 4 and descriptions are as follows:

- *Hourglass.* Hourglass acted as a basis for many shape categorizations. Bust, waist and hip were the measurements used to define this shape. If the ratio of bust-to-waist and hip-to-waist are equal, then it is defined as hourglass.
- *Bottom hourglass***.** It is a subset of hourglass shape. In this shape, hip measurement is larger than bust measurement and the ratio of bust-to-waist and hip-to- waist are significantly large enough to produce a definite waistline.
- *Top hourglass*. It is also a subset of hourglass shape, but is exactly the opposite of the bottom hourglass shape. In this shape, bust measurement is larger than hip measurement and the ratio of bust-to-waist and hips-to waist are significant enough to produce a definite waistline.
- *Spoon*. Bust, waist, hip and high hip were used to determine this shape. If a person has large difference between her hip and bust measurement and has a low ratio of bust-to-waist and high ratio of hip-to-waist when compared to the hourglass shape, it is defined as spoon shaped.
- *Rectangle*. This shape is determined by waist, bust and hip circumference. The conditions for this shape are the bust and hip measurement should be equal and bust-to-waist and hip-to-waist ratio should be low.

- *Diamond*. The measurements used to define this shape are bust, waist, hip, stomach and abdomen. The person will fall into this category when the averages of the subject's abdomen, stomach and waist are larger than the bust measurement.
- *Oval*. Measurements used to determine this shape are the same for the diamond shape. The person will fall into this category when the averages of the subject's abdomen, stomach and waist are smaller than bust measurement.
- *Triangle*. This shape is determined by bust, waist and hips measurements. If a person has a larger hip measurement than bust measurement and low hip-to-waist ratio, the person has the triangular shape.
- *Inverted triangle***.** The measurements used to determine the inverted triangle shape are the same as the triangle shape. In this shape, the bust measurement is larger than the hip measurement and there is a smaller bust-to- hip ratio.

Of the 222 subjects, 40 % were bottom hourglass, 21.6% were hourglass, 17.1% were spoon, 15.8% were rectangle, 3.6% were oval, and 1.8% subjects were triangle. Simmons (2002) didn't find any subject reflecting the shape of inverted triangle, diamond and top hourglass. This study demonstrated that female body shapes differ from person to person. However, the existing systems of sizing charts do not seem to take into consideration these variants in shape, resulting in inappropriate or compromised fit of the resultant garment.

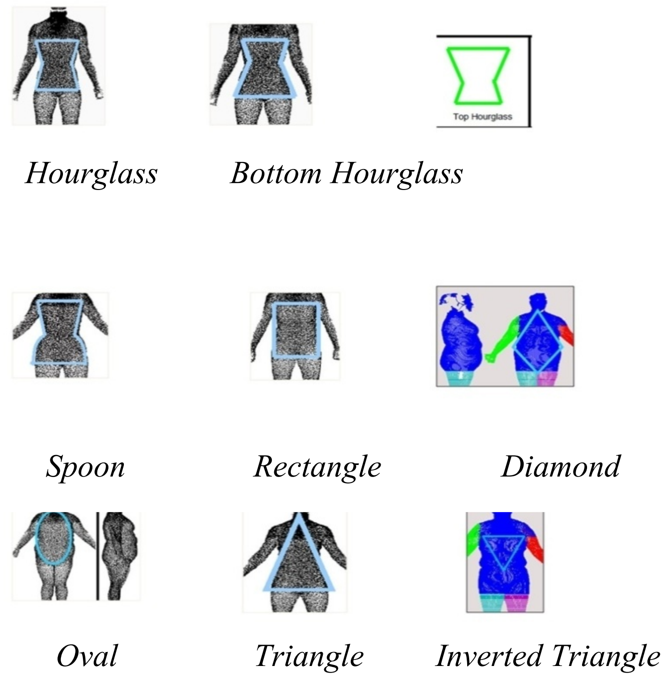


Figure 4. FFIT Body shape (Simmons, 2002).

Body Shape Assessment Scale (BSAS)©

Connell, Ulrich, Brannon, Alexander, and Presley (2006) developed another scale to assess the body shape of female figures. They used 42 body scan printouts of women aged 20 to 55 and 14 female shape scales from the literature to classify the scans according to their shapes. Based on the usefulness of the 14 scales in classifying figures, a new scale called the Body Shape Assessment Scale (BSAS)© was developed with nine components. They are body build, body shape, posture, hip shape, shoulder shape, front torso shape, bust shape, buttocks shape, back shape, and posture as its element scales. This scale was validated using experts.

Of the nine components, body build (see Figure 5), body shape (see Figure 6), hip shape (see Figure 7), bust prominence (see Figure 8), buttocks shape (see Figure 9) and front torso (see Figure 10) scales may be related to fat accumulation and weight increase. Fat accumulation is a factor that influences body build ranging from slender to heavy, and weight increase could be reflected in body shape changes such as front torso shape. Definitions of these BSAS© shapes are offered in the following pages.

Body build. The frontal view of the overall appearance of body was used to assess the body build. Figures range from slender to heavy.

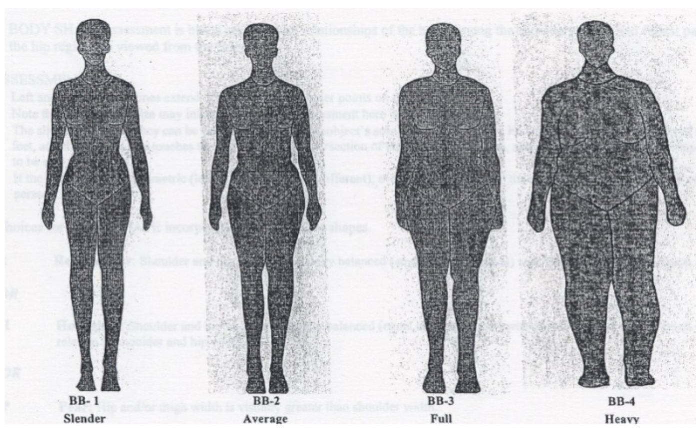


Figure 5. BSAS© Body Build (Connell et al., 2006).

Body shape. This component was used to classify the body shape into hourglass, pear, rectangle or inverted triangle. The relationship between waist, shoulder and hip according to their width from a frontal view was used.

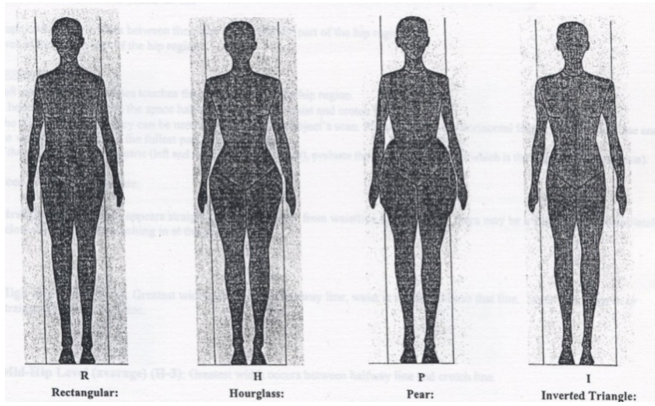


Figure 6. BSAS© Body Shape (Alexander, 2004).

igh-hip, middle-hip, or low-hip when viewed from the front. High, middle, and low describe the placement of the widest location.

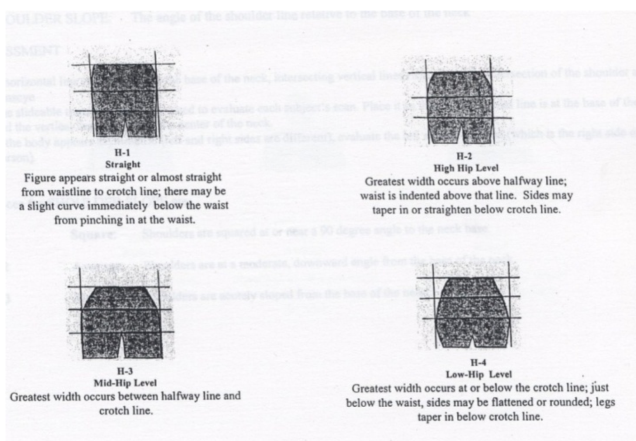


Figure 7. BSAS© Hip shape (Alexander, 2004).

Bust shape. The extension of the bust from flat to prominent as viewed in a side profile was used to classify the bust shape. Flat, average, and prominent are the three stages.

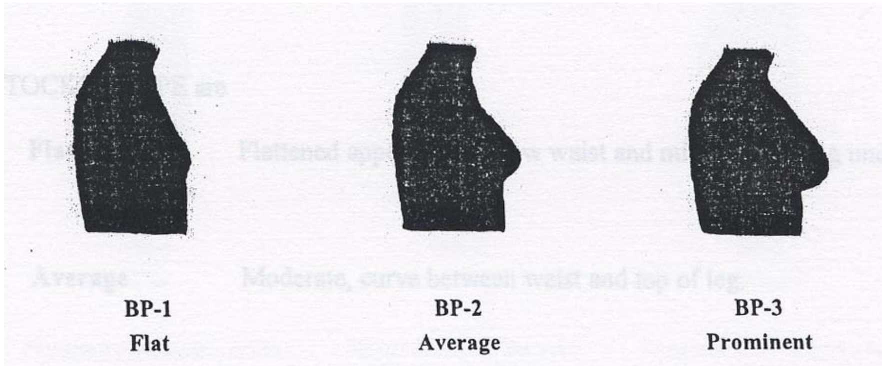


Figure 8. BSAS© Bust shape (Alexander, 2004).

Buttocks shape. Similar to bust, degree of prominence through side view was used to assess buttocks shape as flat, average and prominent.

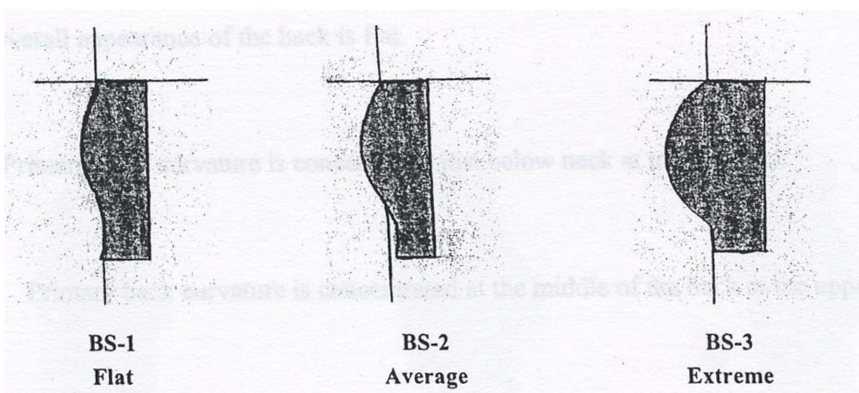


Figure 9. BSAS© Buttocks shape (Alexander, 2004).

*Front torso shape***.** A side profile of the body scans was used for the assessment of front torso shape. The shape of the torso from bust to top of leg was used to categorize the shape into b, B and D categories.

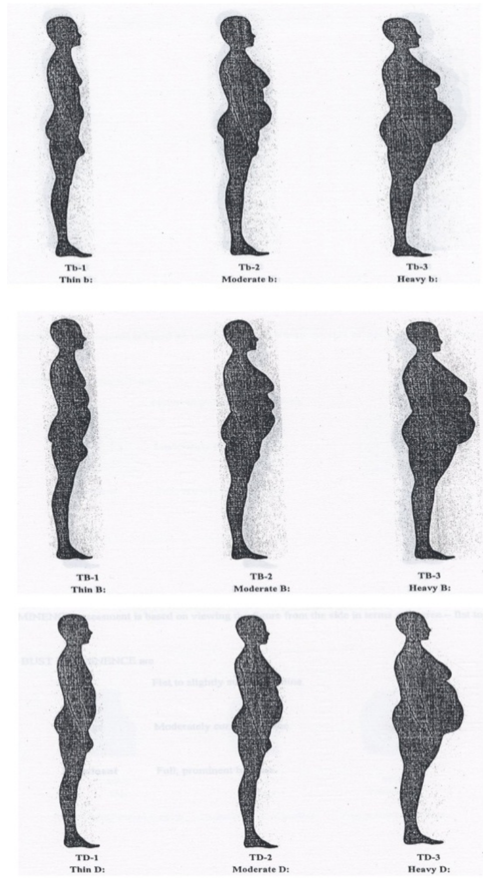


Figure 10. BSAS© Front Torso Shape (Connell et al., 2006).

Alexander (2004) conducted research using the BSAS© to identify female body shape and exploring the relationship between body shape characteristics, fit problems, body cathexis, and clothing benefits sought. A convenience sample of 529 women between ages 19-35 were studied. Some relationships between body shape and age, fit problems, body cathexis, clothing benefits were identified. Body shape, body build, and some of the body component parts were also linked.

Male Body Shape Analysis

As a part of the SizeUSA project, [TC]^2 conducted a male shape analysis study. A set of 3691 men grouped under the age headings of 18-25, 26-35, 36-45, 46-55, 56-65 and 66 plus were scanned for their body shapes. Of the 3691 men, 47% were Non-Hispanic White, 19% were Non-Hispanic Black, 9% were Hispanic, and 8% were other ethnicities. In the total population, approximately 27% were within the age range of 18-25. Shapes of this subset were analyzed and are represented in Table 8. From the above study, it has become evident that different types of body shapes are prevalent even among men (SizeUSA, 2004).

Table 8

Men's Shape Designations for SizeUSA ([TC]^2, 2004)

	Black	Hispanic	White	Others
Number of subjects	146	190	484	175
Square Shoulders %	24.66	46.32	38.84	40
Slope Shoulders %	50	26.32	36.36	28.57
Right Low Shoulder %	28.08	26.32	36.57	37.71
Left Low Shoulder %	20.27	6.84	5.37	7.43
Erect Posture %	34.93	34.74	26.24	34.86
Stooped Posture %	19.18	15.26	22.73	15.43
Head Forward Posture%	30.82	30	42.15	27.43
Lower Front Waist %	12.33	13.68	4.55	4
High Left Hip%	2.05	7.89	4.13	4
High Right Hip %	8.22	13.68	9.5	9.14
Shifted Hips %	0	0.53	0.62	0
Forward Shoulders %	41.1	41.58	45.87	41.71
Raise Back Waist %	15.75	5.79	6.4	4.57
Flat Seat -%	1.37	3.16	1.24	4
Prominent Seat %	36.3	16.84	18.8	10.86
Chest Dart %	19.18	8.95	11.36	10.29
Prominent Blades %	1.37	1.05	0.83	0
Prominent Biceps %	18.49	8.42	9,09	9.14
Prominent Calves %	4.79	13.16	21.07	14.86
Bow Legs %	11.64	7.89	8.06	6.86
Portly%	5.48	9.47	9.3	8.57
Sway Back. %	0	1.58	0.62	1.14

Body Shape and Symmetries

In 1986, Robinette derived an anthropometric sizing system based on height and weight measurement. Three dimensional blocks in Figure 11 were used to demonstrate this system. Size X would fit block A and block C, Size Y would fit Block E and Block F, and Size Z would fit block B and D (Barker & Coletta, 1986). This system elucidated that even with same block volume, shapes of blocks differed from each other. Similarly, there is a chance for difference in the symmetry of body measurements.

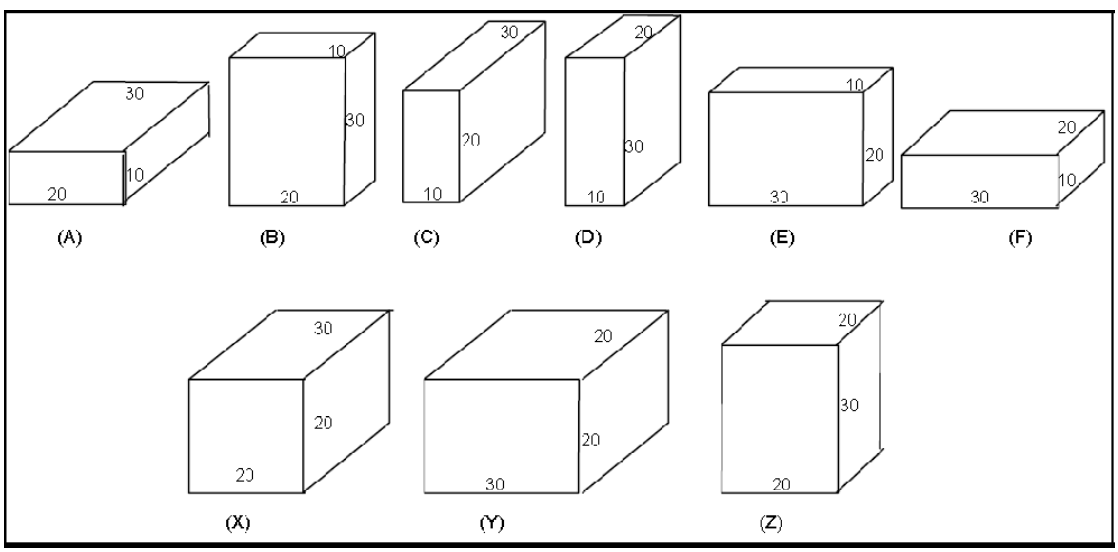


Figure 11. Illustration of Robinette's anthropometric sizing system (Barker et al., 1986).

Three Dimensional Body Scanning

Traditionally, anthropometric measurements were taken using a tape measure, weight scale, anthropometer, caliper, sliding compass, and head spanner (Simmons & Istook, 2003). "The precision and accuracy of measurements taken with a tape measure are often not sufficient to detect small, but important differences in body dimensions" (Heisey, 1984, p. 9). For an anthropometric survey of U.S. Army personnel in 1988, four hours were invested to locate the physical landmarks and measure the body of a single subject (Paquette, 1986). The development of 3D body scanning reduces hours to seconds. Now, body scanning technology used for measuring body measurement is cheaper, faster and provides more detail than traditional anthropometry (Petrova & Ashdown, 2008).

Simmons and Istook (2003) compared 3D body scanning measurement methods and evaluated them against anthropometric methods for apparel sizing. They chose 21 body measurements which were used for designing a well-fitted garment. The measurements were mid neck/neck base, chest/bust, waist by natural indentation/waist by navel, hip/seat, sleeve length, arm length, inseam, outseam, shoulder length, thigh, bicep, and wrist. Three different types of scanners produced by [TC]^2, SYMCAD, and CYBERWARE were used for the study. They concluded that the [TC]^2 scanner identified the greatest number of body sites needed for the study and also had the capacity of producing many more measurements with specific application for apparel.

Textile and Clothing Technology Corporation 3D Body Scanner

[TC]^2 developed its 3D body scanner particularly for the apparel industry. [TC]^2 uses the technique called Phase Measuring Profilometry (PMP) based on moiré technique (Paquette, 1996). "This method involves shifting the rating preset distances in the direction of the varying phase and capturing images at each position" (Fan et al., 2004). The white light used in this scanner projects a sinusoidal fringe on the object. Due to the irregularities in the object, the projected grating are distorted, and from the resulting fringe pattern, the contour of the object can be determined (Demers, Hurley, Wulpern, & Grindon, 1997). The latest version of this scanner, the NX16, has 16 cameras and 16 sensors ([TC]^2, 2008). Each sensor takes four images, each with same degree of phase shift of the projected sinusoidal patterns. The four captured images are used to determine the phase of each pixel. Finally, the phase is used to calculate the three dimensional data points. The data clouds for each of the six views, as shown in Figure 12, are the output of the PMP process. By knowing the exact orientation of each view with respect to one other, the individual views are combined (Demers et al., 1997). The point accuracy of this scanner is < 1mm and circumferential accuracy is < 3mm. ([TC]^2, 2008).

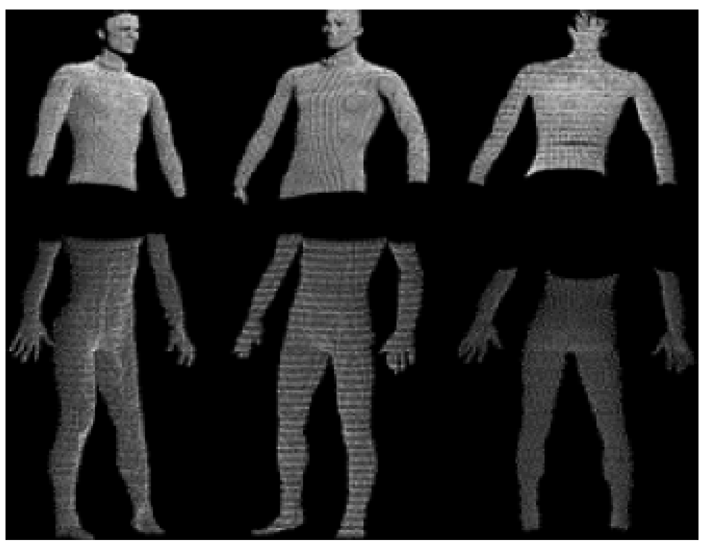


Figure 12. Six Individual views of 3D data points (Demers et al., 1997).

Anthropometric Studies Using 3D Body Scanning

CAESAR (Civilian American and European Surface Anthropometry Resource) was an anthropometric study which used body scanning to obtain body measurements. This study was conducted in the years 1997-2001 in Europe and the U.S. with approximately 4,500 subjects (men and women). Out of the 99 measurements collected, 59 measurements were obtained through body scanning. Governments and commercial industries sponsored the CAESAR study (CAESAR, 2000).

Another study called SizeUSA was conducted in 2004 in the U.S. This study was funded by the U.S. Department of Commerce and conducted by $[TC]^2$ using their 3D body scanner. More than 10,000 subjects were scanned in different locations and with different demographics. The subjects were classified by age, ethnicity, weight, annual household income, marital status, lifestyle, education, employment status, and apparel shopping preferences (SizeUSA, 2004). Similar, studies have been conducted in the United Kingdom and Korea (SizeUK and SizeKOREA) using 3D body scanning systems.

SizeUSA data helped companies to understand their customer base better. JC Penney collaborated with $[TC]^2$ to analyze body shapes of their customers. Approximately 67 female participants wearing sizes from 4 to 16 were scanned and measurements extracted. Results showed that 43% of its customer base was “pear shaped”, 33% was “apple shaped”, and 19% was “rectangle shaped”. This study helped them to provide incremental alterations to their specifications for bust, waist and hip measurements (Sizing up garment fit issues, 2007).

Summary

Based on these literature surveys, it can be observed that there are studies showing significant increases in weight among freshmen. Also, it is obvious that fat distribution is intertwined with physical growth which results in changes in body measurements. This study explored the possible relationship between body measurement changes and weight variations among freshman. It is understood from studies that body shapes are different and that anthropometric data does not always reflect these different body shapes. It has been suggested that grading rules are not in coherence with anthropometric data and hence influence improper fit. This makes the current study significant wherein the changes in body shape according to weight changes can be assessed.

CHAPTER III. METHODOLOGY

Research Design

This study was designed to explore the relationship between weight change and body measurement change for a sample of freshman males and females. It sought to increase understanding of whether there appear to be patterns as to where on the body measurements change with weight gain or loss and what amounts of body measurement change may be associated with weight change.

Sampling Procedure

As part of a longitudinal study of change in the body composition and size of college students, a sample of freshmen (ages 17 to 19) at Auburn University was recruited through a convenience sampling method, at the beginning of fall semester, 2007. Potential participants were contacted via email, posters, and classroom contact in a variety of introductory courses typically taken by freshmen. Volunteers were told that they would be asked to participate in data collection sessions at the beginning of the academic year, at the end of fall semester, and at the end of spring semester. Subjects who were outside the age range, pregnant, married, had children or had a diagnosed eating disorder were not allowed to participate in this study. An incentive of $75 was given for participants who completed all three sessions. The number of participants in August 2007 was 240 freshmen (156 females, 84 males). Among the 240, 214 freshmen

(89% retention rate) participated in data collection at time point #2 in December, 2007, and 205 freshmen (85 % retention rate) participated in data collection at time point #3 in April, 2008.

Data Collection

In order to disconnect the data from being traceable to a subject, each participant was allotted a specific code. Subjects completed a questionnaire which included demographic information, were weighted, had their body fat measured, and then were body scanned. Data collected at two time periods, namely beginning of fall and end of spring, were extracted from the 3D whole body scanner and used for this study. Subjects were weighed but not body scanned at the end of the fall semester time period.

Weight and Body Measurement Technology

A digital weighing balance was used to measure the subjects' weight. Care was taken to keep the balance level with the ground. Measured readings were noted to the nearest 0.1 pound. The NX-16 3D body scanner system, developed by [TC]^2, was used to capture scan images and extract body measurements. The system calculates body measurements using the digital imaging. Subjects were scanned in a standard standing position. Each scan took eight seconds, and a body model with extracted body measurements was developed in less than one minute. The [TC]^2 scanner uses white light technology, which is, "considered to be the safest body scanning technology" ([TC]^2, 2007). Measurements were extracted at any time and as many times as needed following the scan. Point accuracy of the scanner is $<$1mm (0.0394 in.) and circumferential accuracy is $<$3mm (0.1181 in.)

Body Measurements

Normal adults of both sexes tend to accumulate subcutaneous fat in specific body areas. The accumulation of fat occurs in buttocks and flanks, abdomen, anterior and lateral surfaces of the upper thigh, breasts, back of neck and upper arm (Croney, 1971). Studies on female fit preferences have found that most fit problems occurred at the waist, hip and bust. Tightness is a common fitting problem that occurs at the bust, waist, hip, thigh, upper arm and back width (Pisut & Connell, 2007). For these reasons, the bust, waist, hip, stomach, seat, thigh, biceps and abdomen are expected to be the major change-prone measurements with weight change. Hence, the current study was focused on these measurements in combination with weight change.

Body measurements (bust, chest, waist, hip, thigh, biceps, stomach, abdomen and seat) were extracted from the scanner using the embedded software. The definitions of measurement extraction rules and illustrative figure are as follows.

- *Bust*: The bust measurement was taken at the largest protrusion of the bust. The full circumference was taken parallel to floor. (Figure 13)

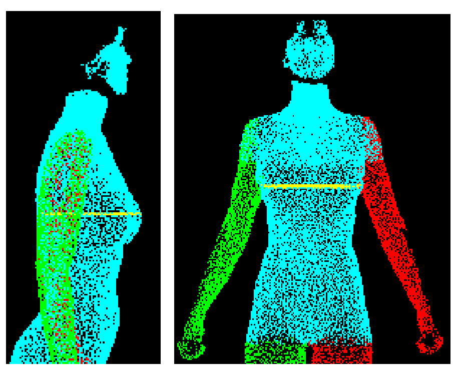


Figure 13. Bust circumference.

- *Waist:* The waist was the smallest circumference between the bust/chest and hips determined by locating the small of the back and then going up and down a predetermined amount to find the waist. (Figure 14)

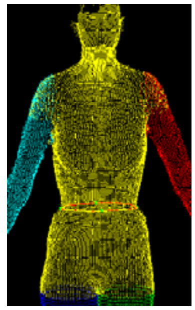


Figure 14. Waist circumference.

- *Hip:* The largest circumference between the waist and crotch was identified as the hip. (Figure 15)

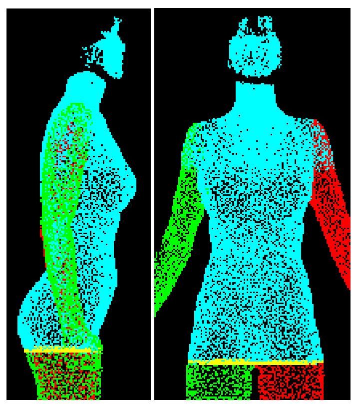


Figure 15. Hip circumference.

- *Thigh:* The largest circumference of the right/left thigh was taken between the knee and two inches below the crotch. (Figure 16)

Figure 16. Thigh circumference.

- *Stomach:* The circumference at the largest protrusion of the front torso was taken between the front waist point and 1/3 of the distance from waist to shoulder. (Figure 17)

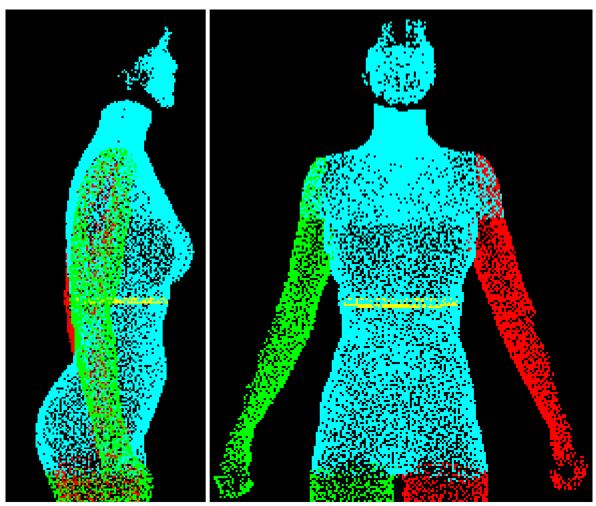


Figure 17. Stomach.

- *Abdomen:* The circumference was measured from the forward-most protruding point below the waist and above the crotch when viewing the body from the side. (Figure 18)

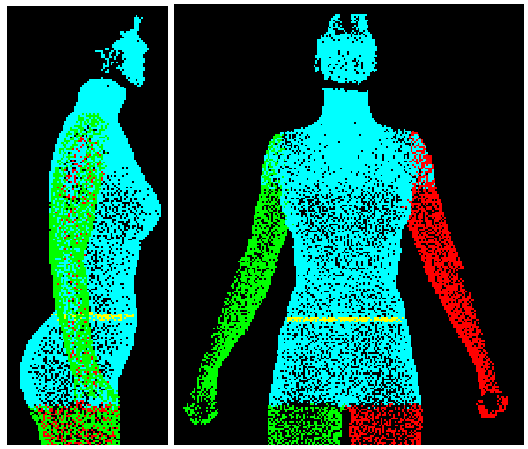


Figure 18. Abdomen.

- *Seat:* The circumference was measured from the rear-most protruding point below the waist and above the crotch when viewed from the side. (Figure 19)

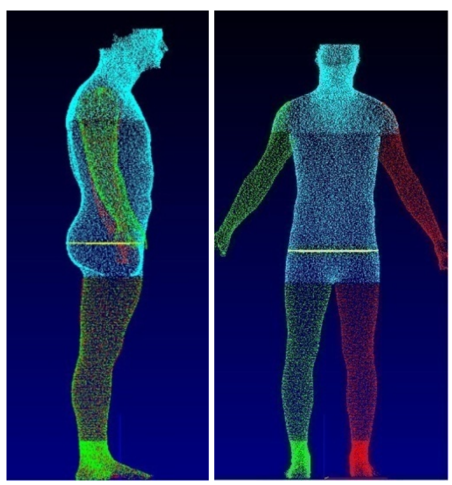


Figure 19. Seat.

- *Biceps:* The circumference of the arm was taken two inches below the armpit. (Figure 20)

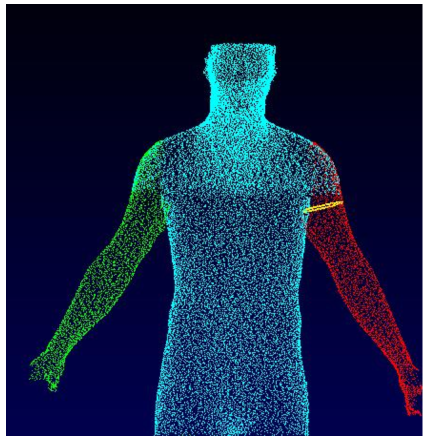


Figure 20. Biceps.

To extract the body measurements a separate Measurement Extraction Profile (MEP) file was created based on the ASTM standard with the above mentioned body measurement.

Data Analysis

1. Research Question 1: Did the body measurements of freshman males and females who gained or lost weight change from the beginning of fall 2007 to the end of spring 2008?

Weight change was considered the independent variable, and body measurement was the dependent variable. The independent variable was grouped into the following three categories: (a) weight increased group, (b) weight decreased group, and (c) no change group.

The weight data was initially categorized as "male" and "female" data. Then, the male data at the two time points was entered in a spreadsheet (as shown in Table 9) to be used for the assessment. The differences in weight were calculated by subtracting the weight at the beginning of fall 2007 from the end of spring 2008 for each individual.

Once the differences were calculated, weight differences greater than 2 lb were segregated as the weight gained group, and weight differences less than -2 lb were grouped as the weight lost group. The weight difference within the range -2 to 2 lb was considered as the no change group. This procedure was followed for the female group as well.

After segregating the male group into the weight increased group and weight decreased group, the body measurements of each were tabulated in separate spreadsheets. An example is shown in Tables 10 and 11. A dependent t-test for paired samples was calculated separately for each body measurement according to the weight change group. The same procedure was carried out for the female weight increased and decreased groups.

Table 9

Weight Difference Spreadsheet Example

Code	Gender	Weight- beginning of fall 2007 (lb)	Weight- end of spring 2008 (lb)	Weight difference end of spring - beginning of fall (lb)	Chest - beginning of fall 2007 (in.)	Chest - end of spring 2008 (in.)
1001	M	142	144	2	42	42.5
1002	M	186	192	6	36	37
1003	M	176	172	-4	32	31
1004	M	189	192	3	29	34
1005	M	133	144	11	40	43

Table 10

Weight Increased Group Body Measurement Spreadsheet Example

Code	Gender	Weight difference end of spring - beginning of fall (lb)	Chest -beginning of fall 2007 (in.)	Chest - end of spring 2008 (in.)
1002	M	6	36	37
1004	M	3	29	34
1005	M	11	40	43
1008	M	5	42	43

Table 11

Weight Decreased Group Body Measurement Spreadsheet Example

Code	Gender	Weight difference end of spring - beginning of fall (lb)	Chest -beginning of fall 2007 (in.)	Chest - end of spring 2008 (in.)
1041	M	-4	42	43
1052	M	-6	33	32
1089	M	-8	35	33
1056	M	-3	36	36

2. *Research Question 2: Were weight increases or weight decreases of freshman males and females related to changes in body measurements?*

To explore the relationship between weight increases or decreases and body measurement changes, the weight increased and decreased group weight difference data and body measurement data from the beginning of fall 2007 and the end of spring 2008 were tabulated in a spreadsheet, as shown in Table 12. The difference between each body measurement was calculated by subtracting the beginning of fall 2007 measurement from the end of spring 2008 measurement. Following this, the differences in weight, bust, waist, thigh, biceps, stomach, abdomen and seat were entered in a separate spreadsheet as shown in Table 13. The data were tested for its dispersion using the Variance-to-Mean Ratio (VMR) test. This test revealed that the data were clumped or clustered in nature (as the VMR values were greater than 1). The weight data were then plotted to visually identify the number of clusters present. Using the standard k-means clustering algorithm, the weight data were clustered into four (or three) groups in accordance with the identified number of clusters. Pearson's correlation was calculated between weight difference and each measurement difference for each cluster. This procedure was followed separately for clusters within the weight increased and decreased groups for males and females.

Table 12

Weight and Body Measurement Spreadsheet Example

Code	Gender	Weight- beginning of fall 2007 (lb)	Weight- end of spring 2008 (lb)	Weight difference end of spring - beginning of fall (lb)	Chest - beginning of fall 2007 (in.)	Chest - end of spring 2008 (in..)	Chest difference end of spring - beginning of fall (in.)
1001	M	142	144	2	42	42.5	0.5
1002	M	186	192	6	36	37	1
1003	M	176	172	-4	32	31	-1
1004	M	189	192	3	29	34	5
1005	M	133	144	11	40	43	3
1006	M	132	129	-3	34	35	1

Table 13

Weight Difference and Body Measurement Difference Spreadsheet Example

Code	Gender	Weight difference end of spring - beginning of fall (lb)	Bust difference end of spring - beginning of fall (in.)	Waist difference end of spring - beginning of fall (in.)	Hip difference end of spring - beginning of fall (in.)
1002	M	6	1	2.5	1
1004	M	3	5	-2	0.5
1005	M	11	3	3	1.8

3. Research Question3: Did the body measurements change for the freshman males and females whose weight was stable?

To identify any changes in the body measurements of participants in the no change group, their body measurements were tabulated in a spreadsheet, as shown in Table 14. The body measurement differences and a dependent t- test for paired sample were calculated. This procedure was followed for males and females.

Table 14

No Change in Weight and Body Measurement Spreadsheet Example

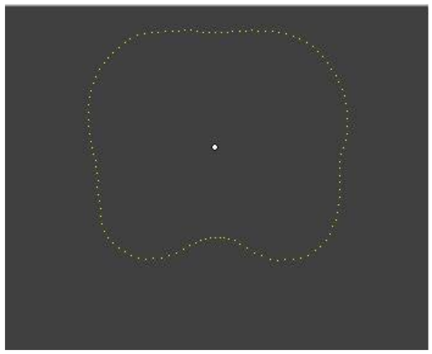
Code	Weight difference end of spring - beginning of fall (lb)	Chest -beginning of fall 2007 (in.)	Chest - end of spring 2008 (in.)
1001	2	42	42.5
1007	-2	36	37
1100	0	32	31
1210	-1	29	34
1123	1.5	40	43

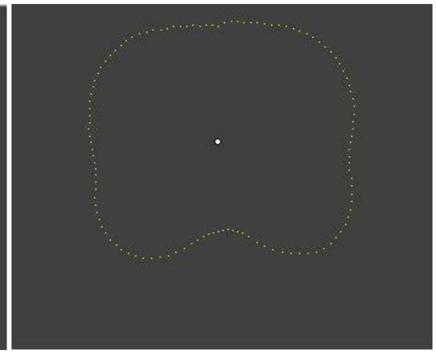
4. Research Question 4: Do changes in body measurements appear symmetrical or asymmetrical around the front, back, and sides of the body when viewed as planar slices?

To visually analyze the symmetry of changes in selected body measurements, e.g., bust measurement, planar slices (cross sections) of measurements were extracted for both periods from the 3D body scanner, and were overlapped to visually analyze the changes in the body measurements. Figure 20 presents an example of the separate and overlaid slices. The three major torso measurements of bust/chest, waist, and hip were selected for analysis.

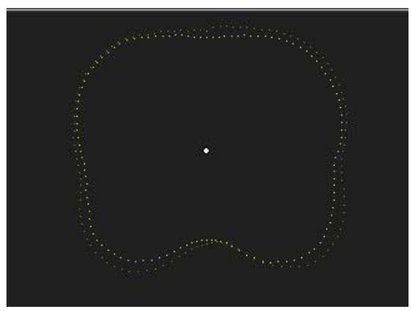
A survey form (ref. Appendix A) was developed which displayed the overlaid images with user selectable choices of analysis decisions. Each image pair was segmented into four quadrants to aid evaluation. The analysis choices were (a) symmetric, where the measurement changes were relatively even around the circumference, or (b) asymmetric, where the measurement changes were not even around the circumference. The asymmetric category was further divided into four more specific choices, viz., (a) more in the back and front than on the sides, (b) most in the back, (c) most in the front and (d) most on the sides. The primary researcher first analyzed all image sets. Then, two subject experts evaluated the cross sectional slices and verified or adjusted the researcher's choices.

Illustration:





Cross section of Bust – fall   Cross section of Bust – spring



Overlapped slices

Figure 21. Planar slices of bust.

CHAPTER IV. PRESENTATION AND DATA ANALYSIS

The purpose of this study was to explore possible connections between the weight changes and circumferential body measurement changes of adolescents aged 17-19. Data were collected for a convenience sample of freshman subjects at two time periods, (a) beginning of fall 2007 and (b) end of spring 2008. The collected data were grouped into *weight gained*, *weight lost* and *no change (in weight)* groups. This classification was done separately for both males and females, and was used for the analysis.

Subjects and Data Collection

A sample of freshmen (ages 17 to 19) at Auburn University was recruited through a convenience sampling method at the beginning of fall semester, 2007. Potential participants were contacted via email, posters, and classroom contact in a variety of introductory courses typically taken by freshmen. The participants at the beginning of fall 2007 were contacted again through e-mail at the end of spring 2008. An incentive of $50 ($25 in the fall and $25 in the spring) was given to the participants. Data for a total of 240 freshmen were collected at the beginning of fall semester (August and September), 2007. Of the 240, 205 participants took part in the study again at the end of spring semester (April and May), 2008. Eighteen subjects were dropped from further analysis, and the final sample consisted of 187 participants' data (male = 67 and female = 120). Those 18 subjects who were excluded from further analyses had at least one of the eight measurements missing in the 3D body scanned data due to a digitizing error. Although male and female freshmen were recruited in the same manner through contacting courses taken by freshman students, more women than men volunteered.

Data Analysis and Results

Subjects' Physical Activities

Table 15 shows the mean numbers of days per week and mean hours per day that the subjects exercised. They were asked on the questionnaire they completed how frequently and how long they participated in vigorous, moderate, and strengthening exercise. Male subjects reported doing vigorous physical activities for an average of three days per week; their daily average was 53 minutes. For moderate physical activities like walking or bicycling, they averaged five days per week at 45 minutes per day. In addition to that, they were undertaking strengthening exercises like push-ups, sit-ups or weight lifting for an average two days per week for 35 minutes each day.

Female subjects said that they participated in vigorous physical activities for two days per week, with an average of 35 minutes per day. They reported doing moderate physical activities like walking or bicycling for five days per week, spending 42 minutes per day. Strengthening exercises, like push-ups, sit-ups or weight lifting, were also carried out for an average of one day per week for 15 minutes per day.

Table 15

Physical Activities

Gender	Mean number of days per week of physical activity			Mean minutes per day of physical activity		
	Vigorous	Moderate	Strengthening	Vigorous	Moderate	Strengthening
Male	3	5	2	53	45	35
Female	2	5	1	35	42	15

Weight Change

For analysis, data of male and female subjects were divided into three groups, viz., (a) set of subjects with an absolute weight gain of >2 lbs, called *weight gained group*, (b) set of subjects with an absolute weight loss of >2 lbs, called *weight lost group*, and (c) set of subjects with a weight change between [-2, 2] lbs, called *no weight change group*. Table 16 shows the proportional population in male and female groups who fell under the three categories. The mean weight changes in these three groups were determined and tabulated in Table 17.

More males and females gained than lost weight. Approximately two-thirds of the males gained 6.93 lbs. on average. Just under half of the females gained slightly more, 7.21 lbs. on average. Among males and females, a few more had stable weight than lost weight. The ten males who lost weight average 6.34 lbs. The females who lost weight averaged less, 3.72 lbs.

Table 16

Proportional Subject Population in Weight Lost, Gained and No Weight Change Groups

Group	Subjects	
	Male	Female
Weight lost	10 (14.9%)	29 (24.2%)
Weight gained	43 (64.2%)	57 (47.5%)
No weight Change	14 (20.9%)	34 (28.3%)
Total	67 (100%)	120 (100%)

Table 17

Mean Weight Change

Group	Mean change - Male (lb)	Mean change - Female (lb)
Weight Gained	+6.93	+7.21
Weight lost	-6.34	-3.72
No weight change	±1	±0.705

Research Question 1: Did the body measurements change for freshman males and females who gained or lost weight from the beginning of fall 2007 to the end of spring 2008?

To answer this question, it had to be determined whether the changes in body measurements taken at the two time periods differed significantly in the groups of males and females who gained and lost weight. Weight change was considered the independent variable, and eight selective body measurements were taken as the dependent variable.

The independent variable was grouped according to the three groups categorized earlier as: (a) *weight gained group*, (b) *weight lost group*, and (c) *no weight change group*. Since the research question was relevant to only those groups that had weight changes, the two groups *weight gained* and *weight lost* group were chosen for further analyses.

Before the data were grouped into weight change categories, male and female subjects' data were separated so that an independent analysis based on gender was possible. Body measurement data of male subjects from the two time periods (beginning of fall 2007 and end of spring 2008) were entered in a spreadsheet according to their weight change group. Similarly, the body measurement differences were calculated by finding the difference in measurements taken at the two time periods, with end of spring 2008 measurements as subtrahend. The entire procedure was repeated for the female data set and the results were noted.

Dependent paired t-tests were conducted on the dependent variables for the two groups chosen. The alpha value was chosen as 0.05, and the tests were conducted on the fall-spring paired data sets. Table 18 shows the comprehensive results for all the groups.

Table18

Measurement Changes in Male and Female Subjects Belonging to the Weight Change Groups

Measurement$^{\#}$ (Ins)			Chest/Bust	Waist	Stomach	Abdomen	Hips	Seat	Thigh Max	Biceps
Weight Gained Group	Male	Mean Fall 2007	37.63	32.08	32.02	35.13	38.93	38.04	21.86	11.8
		Mean Spring 2008	38.89	34.02	33.77	36.68	40.45	39.35	22.65	12.41
		Fall-Spring Change	1.26	1.94	1.75	1.55	1.52	1.31	0.79	0.61
		p-value	0.2	0.004**	0.002**	0.021*	0.004**	0.011*	0.016*	0.001***
	Female	Mean Fall 2007	35.58	29.89	29.53	33.34	39.49	38.54	22.51	10.54
		Mean Spring 2008	36.49	31.1	30.42	34.52	40.42	39.43	22.73	11
		Fall-Spring Change	0.91	1.21	0.89	1.18	0.93	0.89	0.22	0.46
		p-value	0.000***	0.000***	0.000***	0.002**	0.000***	0.000***	0.364	0.004**
Weight Lost Group	Male	Mean Fall 2007	38	32.67	32.83	36.2	39.75	38.66	22.1	11.86
		Mean Spring 2008	37.74	32.15	32.1	34.64	39.2	37.83	21.37	12.1
		Fall-Spring Change	-0.26	-0.52	-0.73	-1.56	-0.55	-0.83	-0.73	0.24
		p-value	0.452	0.231	0.149	0.152	0.137	0.011*	0.043*	0.366
	Female	Mean Fall 2007	35.37	29.44	28.93	32.83	38.93	38.02	22.18	10.65
		Mean Spring 2008	35.36	28.96	28.69	33.24	38.67	37.69	21.59	10.27
		Fall-Spring Change	-0.01	-0.48	-0.24	0.41	-0.26	-0.33	-0.59	-0.38
		p-value	0.966	0.104	0.475	0.326	0.229	0.11	0.012*	0.001***

*Note. Significant p values are noted by: *** $p \leq 0.001$, ** $p \leq 0.01$, *$p \leq 0.05$*

Weight gained group: male subjects. Forty-three male participants gained at least two pounds. The calculated results show that the mean circumferential change in all eight body measurements was an increase. With *p*-values ranging between 0.001 and 0.021, the increases were significant for all measurements except the chest. Torso changes ranged from 1.26” at the chest to 1.94” at the waist. The magnitude of change concentrated between the hips and stomach was one and a half to nearly two inches. Limb (biceps and thigh) circumferential changes were between one-half and one inch.

Weight gained group: female subjects. Fifty-seven female participants gained two or more pounds. The calculated results show that except for the Thigh Max, all other *p*-values were less than 0.01, making them significant. Hence, measurement changes in the bust, waist, stomach, abdomen, hips, seat and biceps showed significant change in the end of spring 2008 when compared to the beginning of fall 2007. For females, the significant changes were increases in torso circumference measurements ranging from nearly one inch to nearly one and a quarter inch. The biceps increase was almost one-half inch.

Weight lost group: male subjects. Ten male participants came under the *weight lost group*. The calculated *p*-values for the seat and thigh max measurements were 0.011 and 0.043, which was less than the set alpha value. Thus, these measurements changed significantly (each dropping by approximately three-quarters of an inch) by the end of spring 2008 as compared to the beginning of fall 2007. Chest, waist, stomach, abdomen and hip measurements decreased between fall and spring, but calculated p-values were greater than 0.05, meaning that the changes were not statistically significant. The biceps change was actually an increased measurement, but was also not significant.

Weight lost group: female subjects. The total number of female participants in the *weight lost group* was 29. Except for the measurements of thigh max and biceps, all other measurements showed changes that were not statistically significant when the end of spring 2008 was compared to the beginning of fall 2007. The significant drops in measurements were approximately three-eighths (biceps) and nine-sixteenths (thigh) inch. Except for the abdomen, other measurement changes were decreases, none more than one-half inch.

*Summary for Research Question 1.*For males and females who gained weight, all measurements except one in each group (chest for males and thigh for females) increased significantly. However, the same was not true for males and females who lost weight. In each of those groups, only two measurements decreased significantly (thigh for males and females, seat for males, and biceps for females). In the case of females, it seems likely that different results for the *weight gained* and *weight lost* groups could be attributed to the fact that the average weight gain was 7.21 lb while the average weight loss was only 3.72 lb. These changes showed up as significant increases in all but one body measurement but significant decreases in only two locations. However, no such reasoning was possible in the case of male subjects, as their mean weight gain and loss numbers differed only marginally, 6.93 and 6.34 lb, but they, too, had significant increases in inches in all but one location and significant decreases in only two locations. The magnitude of the males' decrease in inches was slightly higher than the females. In sum, the research question can be answered mostly in the affirmative for the *weight gained* groups but results were less definitive for the *weight lost* groups.

Research Question 2: Were weight gains or weight losses of freshman males and females related to changes in body measurements?

Changes in weights and body measurements for the male and female groups were tabulated previously to answer Research Question 1. In order to explore any possible statistical relationships between weight gains or losses and body measurement changes, correlation analysis was done. Pearson's correlation coefficients were calculated for the data set with one column being the weight difference data and the other column having the measurement difference data. The coefficients were calculated for the *weight gained* and *weight lost* groups, with male and female subjects assessed separately. However, the correlation coefficients were less than 0.5 in most of the cases. This poor correlation could have been attributed to the fact that the data was over-dispersed, meaning that the data set had the characteristics of clumps or clusters. The degree of dispersion was estimated using the variance-to-mean ratio (VMR) test.

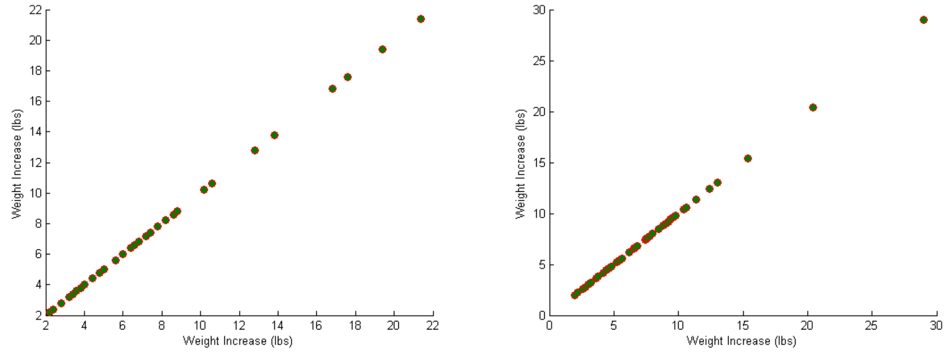
VMRs were calculated for the male and female data sets, and the results are tabulated in Table 19. From the VMR results, it was concluded that the data were clumped. Hence, the data in each group needed to be clustered before evaluating the correlation coefficients. Standard k-means clustering algorithm was used to cluster the data sets.

Table 19

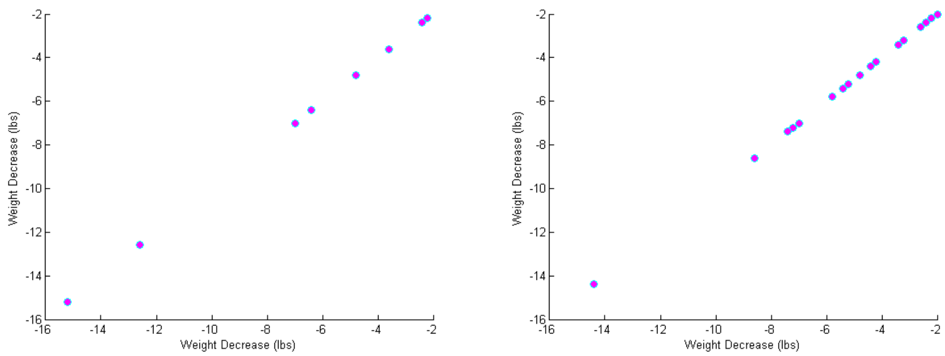
VMR Index

Measurements		VMR value for weight change
Weight gain	Male	3.301382
	Female	3.180168
Weight loss	Male	3.1238
	Female	1.555196

Cluster analysis. The male and female weight gained and lost subdivisions were subjected for cluster analysis. The data were arrayed in scatter plots (see Figure 22) to be used for a visual examination to determine the number of clusters 'n' within each group. The parameter 'n' was used as an argument for the k-means clustering. Then the k-means clustering algorithm was used to determine the actual clusters. Figure 23 shows the subdivisions, resulting from the k-means clustering algorithm, that were formulated for the correlation analysis. Table 20 lists the results of clustering, including the range of pounds changed in each cluster and the cluster centroid. In some cases, the cluster with the greatest weight change had only one subject in it and therefore could not be used for correlation analysis. This was true for the fourth cluster in the female weight gained group; because it was significantly deviant from its preceding cluster (centroid of cluster 3 was at 17.07 and centroid for cluster 4 was 29.4) the subject was considered an outlier. The fourth cluster for the male and female weight lost groups also had only one subject.

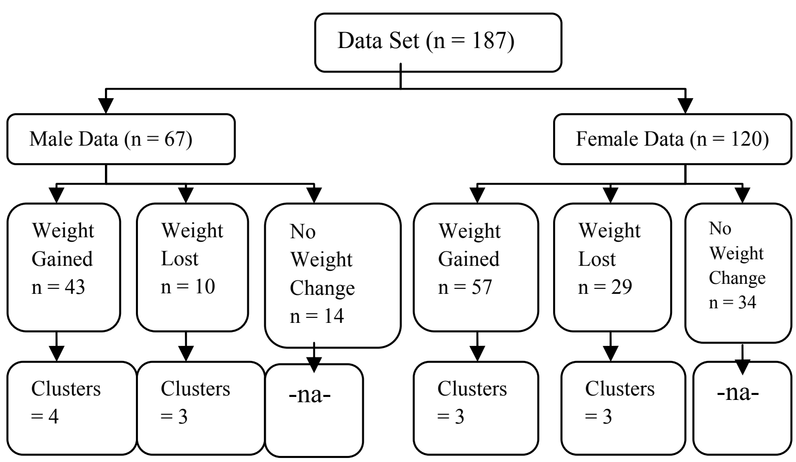


Weight Gained Group (a) Male Subjects (b) Female Subjects



Weight Lost Group (a) Male Subjects (b) Female Subjects

Figure 22. Scatter plot of weight changes in male and female subjects.



-na- refers to the data set not included for the current analyses

Figure 23. Subdivisions formulated for correlation analysis.

Table 20

Weight Range and Centroid for Male and Female Subjects Belonging to the Weight Change Groups

Cluster Number			1	2	3	4
Weight Gained Group	Male	Cluster Span in terms of weight difference (lb)	2.2-5	5.6-10.6	12.8-17.6	19.4-21.6
		Cluster Centroid	3.49	7.61	15.25	20.4
		Number of Subjects	21	16	4	2
	Female	Cluster Span in terms of weight difference (lb)	2-6.6	6.8-13	15.4-20.4	-na-
		Cluster Centroid	4.165	9.1818	17.0667	-na-
		Number of Subjects	31	22	3	-na-
Weight Lost Group	Male	Cluster Span in terms of weight difference (lb)	2.2-3.6	4.8-7	12.5-15.2	-na-
		Cluster Centroid	2.6	6.3	12.6	-na-
		Number of Subjects	4	4	2	-na-
	Female	Cluster Span in terms of weight difference (lb)	2-3.4	4.2-5.4	5.8-8.6	-na-
		Cluster Centroid	2.41	5.14	7.433	-na-
		Number of Subjects	12	9	7	-na-

Correlation analysis. Weight change in the clusters of each group was correlated against the eight measurement changes, and the Pearson's correlation coefficients were determined. The following guidelines ("The strength and significance of the coefficient," 2001) were used to interpret the strength of relationships:

0.0 to 0.2 Very weak to negligible correlation
0.2 to 0.4 Weak, low correlation (not very significant)
0.4 to 0.7 Moderate correlation
0.7 to 0.9 Strong, high correlation
0.9 to 1.0 Very strong correlation

Weight gained group: male subjects. Table 21 shows the correlation analyses results for the male subjects who were in the *weight gained* group. The correlation results showed that in Cluster 3 (containing four subjects who gained from 12.8-17.6 lb) there was a very strong and significant positive correlation between weight changes and changes in abdomen and hip measurements (respective *p*-values of 0.025 (r =0.951) and 0.044 (r = 0.912)). Although there was a strong association between weight change and seat and waist measurement changes, it was not statistically significant (a calculated *p*-value of 0.145 (r = 0.855) and 0.186 (r = 0.814), respectively). Moderate negative correlations were seen in the cases on chest and biceps changes; they were not statistically significant. Clusters 1 and 2 containing those subjects who gained 2-10.6 lb, showed weak correlations in all cases. While the results showed that the correlation was perfect for all the measurements in Cluster 4, the data size of two was too limited for meaningful interpretation.

Table 21

Correlation Coefficient for Weight Gained Group Males

Cluster ↓	Measurement[#] →	Chest	Waist	Stomach	Abdomen	Hip	Seat	Thigh max	Biceps
1	Range	(-5.93) - 7.28”	(-4.53) - 7.57”	(-4.84) - 7.57”	(-5.57) - 8.81”	(-3.17) - 8.10”	(-2.97) - 7.00”	(-3.18) - 6.21”	(-1.29) - 3.01”
	r	0.054	-0.06	0.151	0.05	0.035	0.075	-0.023	-0.034
	p-value	0.815	0.98	0.513	0.829	0.882	0.746	0.922	0.883
2	Range	(-6.02) - 5.45”	(-2.41) - 21.06”	(-4.65) - 15.79”	(-4.06) - 20.94”	0.26 - 17.87”	0.47 - 18.40”	(-0.67) - 8.03”	(-.19) - 5.51”
	r	-0.215	-0.36	-0.332	-0.273	-0.264	-0.332	-0.429	-0.226
	p-value	0.424	0.171	0.209	0.306	0.323	0.209	0.097	0.4
3	Range	1.27 - 2.70”	0.99-2.72”	1.59-2.33”	1.04-3.36”	0.61-2.59”	0.94-2.89”	0.80-1.42”	0.37-0.91”
	r	-0.699	0.814	0.012	0.951	0.912	0.855	0.461	-0.681
	p-value	0.301	0.186	0.988	.025*	.044*	0.145	0.539	0.319
4	Range	2.28-7.83”	1.70-1.83”	2.54-2.62”	2.88-8.23”	2.30-2.32”	2.04-2.36”	1.29-1.30”	0.59-1.28”
	r	1	1	-1	1	1	1	-1	-1
	p-value	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***

Note. *Significant p values are noted by: **** $p \le 0.001$, **** $p \le 0.01$, ***$p \le 0.05$

Weight gained group: female subjects. Similar to the male data, female subjects' weight change data were subdivided into four clusters using the k-means clustering algorithm. Three usable clusters emerged (see Table 22). In the cases of Clusters 1 and 2 (respectively, gains of 2-6.6 and 6.8-13 lb), the associations between weight and measurement change were weak for all the measurements and were not statistically significant. For Cluster 3, in which the three subjects gained 15.4-20.4 lb, the associations between weight change and changes in abdomen and biceps were strong and positive, whereas the association between weight change and changes in bust was strong and negative. All other relationships between weight change and changes in waist, hip, seat and thigh max were moderately strong and positive. Although this cluster exhibited some strong associations, none of them were statistically significant.

Table 22

Correlation Coefficient for Weight Gained Group females

Cluster ↓	Measurement# →	Chest	Waist	Stomach	Abdomen	Hip	Seat	Thigh max	Biceps
1	Range	(-0.88) -2.85”	(-1.81) -3.20”	(-2.56)- 4.65”	(-8.19) - 6.29”	(-2.60) -6.23”	(-2.14) -3.93”	(-5.69)- 6.72”	(-0.92)- 1.23”
	r	0.142	0.292	0.212	0.136	-0.024	0.017	0.26	0.034
	p-value	0.446	0.111	0.253	0.466	0.898	0.929	0.157	0.854
2	Range	(-3.48) -2.95”	(-2.16) -2.76”	(-2.81) - 2.33”	(-7.31) - 6.74”	(-3.30) -2.24”	(-2.67) -2.65”	(-3.43) -1.76”	(-1.65) - 1.27”
	r	0.148	0.285	0.225	0.026	0.151	0.173	-0.08	0.016
	p-value	0.511	0.199	0.314	0.908	502	0.442	0.722	0.945
3	Range	1.12- 3.19”	0.10- 5.01”	0.05- 5.77”	2.71-5.30”	1.46- 2.48”	1.80- 2.51”	0.16- 2.15”	0.21- 1.05”
	r	-0.868	0.451	-0.143	0.947	0.626	0.576	0.585	0.761
	p-value	0.33	0.702	0.909	0.209	0.569	0.609	0.603	0.449

Note. Significant p values are noted by: $*** p \leq 0.001$, $** p \leq 0.01$, $*p \leq 0.05$

Weight lost group: male subjects. For males who fell into the *weight lost* group, three usable clusters were formed using the k-means clustering. In Cluster 1 (see Table 23) with four subjects who lost 2.2-3.6 lb, a very strong negative relationship existed between weight loss and change in stomach circumference and a very strong positive relationship between weight loss and change in biceps circumference. The *p*-value for stomach was 0.004 and for biceps 0.007, making them statistically significant. A strong positive relationship existed between losses in weight and waist circumference, and a moderate positive relationship existed between weight loss and decreases at the abdomen, hip and seat. These moderate to strong relationships were not significant.

In the case of Cluster 2, which was composed of four subjects who lost 4.8-7 lb, changes in waist and biceps had a very strong positive relationship with weight change. Their *p*- values of 0.015 and 0.020 (respectively) were statistically significant. No other relationships in this cluster were significant. However, changes in abdomen, hip and seat measurements had strong positive relationships with weight change. A strong negative association existed between weight and chest measurement changes. Cluster 3 had only two subjects.

Table 23

Correlation Coefficient for Weight Lost Group Males

Cluster ↓	Measurement[#] →	Chest	Waist	Stomach	Abdomen	Hip	Seat	Thigh max	Biceps
1	Range	(-0.75) - 0.40”	(-0.82) - (-.18)”	(-0.21) - 1.30”	(-6.78) - (-0.21)”	0.04- 0.98”	(-1.31)- 0.79”	(-0.51)- (-0.12)”	(-0.66)- 0.33”
	r	0.045	0.81	-0.996	0.564	0.422	0.619	-0.213	0.993
	p-value	0.955	0.19	.004**	0.436	0.578	0.381	0.787	.007**
2	Range	(-2.36) - 0.28”	(-2.16)- 0.40”	(-3.09) - 0.02”	(-1.63)- (-0.55)”	(-2.19)- (-0.22)”	(-1.84)- (-0.19)”	(-1.42) - 0.91”	(-0.27)- 1.02”
	r	-0.784	0.985	0.622	0.731	0.721	0.882	-0.059	0.98
	p-value	0.216	.015*	0.378	0.269	0.279	0.118	0.941	.020*
3	Range	(-0.93)- 1.59”	(-0.92)- 2.44”	(-1.70)- 0.47”	(-1.94)- 4.49”	(-1.48)-(- 0.54)”	(-1.12)-(- 0.69)”	(-2.77)-(- 0.22)”	(-0.28)- 3.12”
	r	-1	-1	-1	-1	-1	-1	-1	-1
	p-value	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***

*Note. Significant p values are noted by: *** $p \leq 0.001$, ** $p \leq 0.01$, *$p \leq 0.05$*

Weight lost group: female subjects. Table 24 shows the Pearson correlation coefficients for the three usable clusters in the females *weight lost* group. Both positive and negative relationships between weight and measurement change were weak for the 12 subjects who lost 2-3.4 lb. in Cluster 1. For Cluster 2 (nine subjects who lost 4.2-5.4 lb), positive and moderate associations existed between weight and abdomen, hip and seat changes. The *p*-value for the seat association was 0.046, thereby making the relationship between weight change and seat statistically significant. The relationship between weight and waist change was moderate and negative. It and all other relationships were not significant. Finally, for Cluster 3 (seven subjects who lost 5.8-8.6 lb), a moderate negative relationship was seen between weight and all measurement changes except thigh max, which had a strong and significant (p=0.012) negative relationship with weight change.

Table 24

Correlation Coefficient for Weight Lost Group Females

Cluster ↓	Measurement# →	Chest	Waist	Stomach	Abdomen	Hip	Seat	Thigh max	Biceps
1	Range	(-1.02) - 0.93”	(-1.52)- 1.62”	(-1.22)- 1.24”	(-2.11)- 3.69”	(-0.71)- 0.53”	(-0.55)- 0.02”	(-0.80)- 0.54”	(-0.91)- 0.06”
	r	0.286	0.161	0.016	-0.015	-0.075	-0.126	-0.097	-0.179
	p-value	0.368	0.618	0.961	0.963	0.817	0.695	0.764	0.578
2	Range	(-1.06)- 2.85”	(-1.18)- 0.52”	(-0.91)- 1.72”	(-2.01)- 4.30”	(-1.04)- 2.96”	(-1.21)- 2.26”	(-5.40)-(- 0.50)”	(-1.70) - 0.25”
	r	-0.266	-0.319	-0.3	0.454	0.654	0.674	-0.417	-0.062
	p-value	0.488	0.403	0.432	0.22	0.056	.046*	0.265	0.873
3	Range	(-1.36)- (-0.10)”	(-4.70)- (-0.52)”	(-4.87)- (-0.51)”	(-3.54)- (-0.26)”	(-1.37)- (-0.27)”	(-1.28)- (-0.18)”	(-0.81)- (-0.37)”	(-1.36)- (-0.65)”
	r	-0.605	-0.421	0.513	-0.531	-0.682	-0.671	-0.786	-0.505
	p-value	0.15	0.347	0.239	0.22	0.092	0.099	.012*	0.248

Note. Significant p values are noted by: *** $p \leq 0.001$, ** $p \leq 0.01$, *$p \leq 0.05$

Summary for Research Question 2. Among male and female weight gained and weight lost groups, correlation results were both positive and negative. Thus, those who gained and lost weight had increased and decreased measurements, although the changes could be small. There were a limited number of significant relationships, and these occurred primarily among the limited number of subjects who gained or lost more than the smallest cluster of weight. Significant positive correlations were found in the following cases:

- For increases at the abdomen and hip for males who gained 12.8-17.6 lb.
- For a decrease at the biceps for males who lost 2.2-3.6 lb.
- For decreases at the chest and biceps for males who lost 4.8-7 lb.
- For a decrease at the seat for females who lost 4.2-5.4 lb.

Significant negative correlations were found in the following cases:

- For an increase at the stomach for males who lost 2.2-3.6 lb.
- For a slight decrease at the thigh for females who lost 5.8-8.6 lb.

The mixed results for the data analyses do not allow a clear affirmative or negative response to the research question. They suggest that changes in circumference measurements can be related changes in weight, but that may not always be in the same direction.

Research Question 3: Did the body measurements change for the freshman males and females whose weight was stable?

To identify any changes in the body measurements of participants in the no weight change group, their body measurements were tabulated in a spreadsheet. Weight losses and gains of up to two pounds were considered as *no change*. A dependent t-test was done to determine whether or not any significant changes in body measurements taken at beginning of fall 2007 and end of spring 2008 occurred. This procedure was followed for male and female groups. The results for male and female groups are tabulated in Table 25.

The results show that the *p*-values for all the measurements were greater than the set alpha value (0.05). There were no significant changes in the measurements of male participants having stable weight. Similar to the male group, females with stable weight also had no significant changes in their body measurements. Based on these results, the response to the research question was negative.

Table 25

Weight No Change Group

	Measurement	Chest/Bust	Waist	Stomach	Abdomen	Hip	Seat	Thigh	Biceps
Weight no change male N= 14	Mean - Beginning of fall 2007	36.88	31.95	32.06	35.65	39.39	38.43	22.13	12.03
	Mean- End of spring 2008	38.2	32.39	32.91	36.4	39.74	38.71	22.17	12.75
	Magnitude of change between the two time points	1.32	0.44	0.85	0.75	0.35	0.28	0.04	0.72
	p - value	0.078	0.236	0.11	0.456	0.264	0.329	0.806	0.321
Weight no change female N = 34	Mean - Beginning of fall 2007	35.59	29.61	29.37	33.3	39.08	38.11	22.58	10.42
	Mean- End of spring 2008	35.62	29.59	29.18	33.41	39.4	38.3	22.19	10.4
	Magnitude of change between the two time points	0.03	-0.02	-0.19	0.11	0.32	0.19	-0.39	-0.02
	p - value	0.078	0.236	0.11	0.456	0.264	0.329	0.806	0.321

Note. Significant p values are noted by: $*** p \leq 0.001$, $** p \leq 0.01$, $*p \leq 0.05$

Research Question 4: Do changes in body measurements appear symmetrical or asymmetrical around the front, back, and sides of the body when viewed as planar slices?

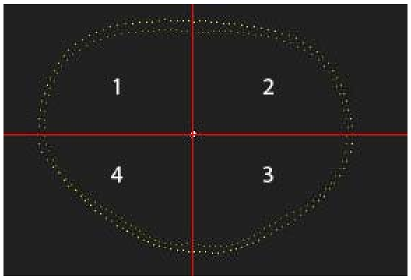
To visually analyze the symmetry of changes in body measurements, e.g., to see if an individual's original and new circumferences were shaped the same, indicating an equality of change around the body, planar slices (cross-sections) of three key circumferences (bust/chest, hip and waist) were extracted for fall and spring scans and overlaid. To analyze the changes, a form for recording answers relative to each slice was developed. It contained the overlapped planar images and the following user-selectable (multiple choice) responses for each slice:

Symmetrical: Relatively even change around body circumference

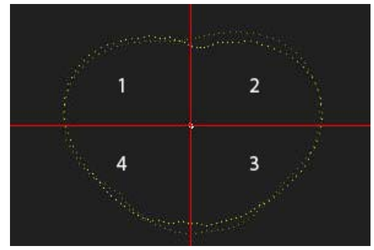
Asymmetrical:

1. More in the back and front than on the sides
2. Most in the back
3. Most in the front
4. Most on the sides

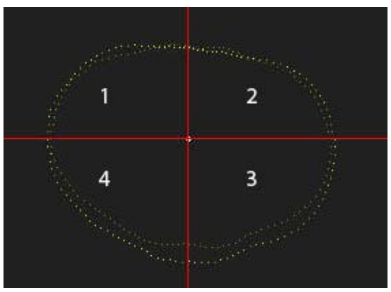
The analysis was done for males and females who either gained or lost weight. The *no change* group was not included for analyses. Each pair of overlaid slices was visually assessed for symmetry or type of asymmetry by the researcher. Subsequently, his major professors reviewed each assessment to affirm or change it. When the researcher's assessment was changed, it was a consensus discussion and decision by the major professors. A symmetrical designation did not imply perfect symmetry; rather, it implied that the overlaid slices were more symmetrical than they were asymmetrical. Examples of each designation are shown in figure 24.



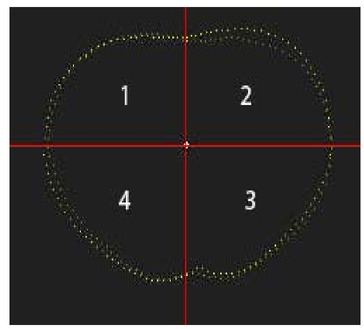
Symmetry



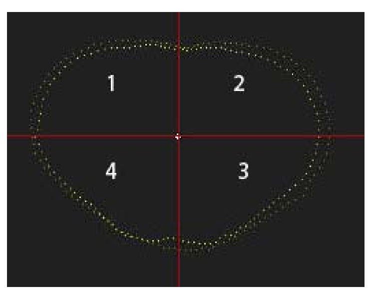
More in the back and front than on the sides



Most in the front



Most in the back



Most on the sides

Figure 24. Examples of symmetrical and asymmetrical shapes of waist measurement.

Weight gained group: male subjects. Table 26 shows the number of subjects classified as symmetrical and asymmetrical, with the later being broken out into the options for asymmetry; the incidence percentage was included to ease within and across group comparisons. At the chest, 65% of the subjects were symmetrical. At the hip and waist, more were asymmetrical (55.8% and 53.5% respectively) than symmetrical. The most common type of asymmetry differed at each circumference location. At the chest, 16.3% showed the most change on the sides. At the At the hip, 20.9% showed the most change at the front and back rather than on the sides. At the waist, 25.6% showed the most change in the front.

Table 26

Number of Subjects in Each Shape Classification for Weight Gained Males

Subjects in symmetric and asymmetric classifications						
N = 43	Relatively even change around body circumference	Asymmetrical	More in the back and front than on the sides	Most in the back	Most in the front	Most on the sides
Chest	28 (65.1%)	15(34.9%)	1(2.3%)	3(7%)	4(9.3%)	7 (16.3%)
Hip	19 (44.2%)	26(55.8%)	9 (20.9%)	5(11.6%)	3(7%)	7(16.3%)
Waist	20 (46.5%)	23(53.5%)	5(11.6%)	5(11.6%)	11 (25.6%)	2(4.7%)

Weight gained group: female subjects. Table 27 shows the number of subjects in symmetrical and asymmetrical categories for weight gained females. About half (50.9%) of the subjects were symmetrical at the bust. Hip and waist measurements showed asymmetric changes in 70.2% and 63.2% of the subjects. In the cases of asymmetric changes, no pattern emerged as to the most common type of asymmetry. At the bust, 24.6% showed the most change in the front. At the hip, 26.3% showed the most change at the front and back than on the sides. In the waist changes, 29.8% showed the most in the back.

Table 27

Number of Subjects in Each Shape Classification for Weight Gained Females

Subjects in symmetric and asymmetric classifications						
N=57	Relatively even change around body circumference	Asymmetrical	More in the back and front than on the sides	Most in the back	Most in the front	Most on the sides
Bust	29 (50.9%)	28(49.1%)	7(12.3%)	4(7%)	14 (24.6%)	3(5.3%)
Hip	17 (29.8%)	40(70.2%)	15 (26.3%)	8(14%)	5(8.8%)	12 (21.1%)
Waist	21 (36.8%)	36(63.2%)	3(5.3%)	17 (29.8%)	9(15.8%)	7(12.3%)

Weight lost group: male subjects. Table 28 shows the number of *weight lost* male subjects in different classifications of symmetry or asymmetry. About 70% and 50% of the subjects were symmetrical at the chest and hip. At the waist, more were asymmetrical (60%) than symmetrical. In this group of subjects too, the most common type of asymmetry varied at each circumferential measurement. At the hip, most changes occurred on the sides (30% of the subjects) and at waist, 30% showed most changes in the front.

Table 28

Number of Subjects in Each Shape Classification for Weight Lost Males

Subjects in symmetric and asymmetric classifications						
N=10	Relatively even change around body circumference	Asymmetrical	More in the back and front than on the sides	Most in the back	Most in the front	Most on the sides
Chest	7 (70%)	3(30%)	0	1(10%)	1(10%)	1(10%)
Hip	5 (50%)	5(50%)	1(10%)	0	1(10%)	3 (30%)
Waist	4 (40%)	6(60%)	1(10%)	1(10%)	3 (30%)	1(10%)

Weight lost group: female subjects. For the *weight lost* female group, symmetrical and asymmetrical changes at the bust were almost equally distributed among the subject population (48.3% and 51.7%, respectively; ref. Table 29). The most common asymmetric changes were at the front in the cases of bust and waist. A notable 72.4% were asymmetrical at the hip, with front and back asymmetry being the most common.

Table 29

Number of Subjects in Each Shape Classification for Weight Lost Females

	Subjects in symmetric and asymmetric classification					
N= 29	Relatively even change around body circumference	Asymmetrical	More in the back and front than on the sides	Most in the back	Most in the front	Most on the sides
Bust	14 (48.3%)	15(51.7%)	4(13.8%)	3(10.3%)	8 (27.6%)	0
Hip	8 (27.6%)	21(72.4%)	11 (37.9%)	2(6.9%)	6(20.7%)	2(6.9%)
Waist	15 (51.7%)	14(48.3%)	1(3.4%)	5(17.2%)	8 (27.6%)	0

Summary for research question 4. Among males who gained and lost weight, 65-70% showed symmetrical change at the chest; approximately one-half of the females had symmetrical change at the bust. At the hip, 44-50% of the males had symmetrical change, whereas slightly less than 30% of the females did. At the waist, 40-46.5% of the males had symmetrical change. Approximately half of the females who lost weight showed symmetrical change at the waist, but fewer who gained weight, 37%, had symmetrical change. Thus, symmetrical change appears to have been more common at the chest or bust than at the hip or waist.

The placement of asymmetry was not consistently patterned across locations for males or females. In the only case where a single asymmetry category was more commonly found than symmetry, it was at the front and back of the hip for females who lost weight. This placement was also more common for males and females who gained weight, but not the few males who lost weight. At the waist, asymmetry placement was more often in the front except for females who gained weight, where placement was more often in the back. Just three of the ten males who lost weight showed asymmetry at the chest, each at a different area. Males who gained weight showed more change at the sides of the chest, whereas females who gained and lost weight showed the most asymmetry in the front of the bust.

Thus, the results for this research question were mixed. It appears that either symmetrical or asymmetrical change can be more or equally common. Additionally, placement of asymmetry appears to vary.

CHAPTER V. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This research studied the impact of weight change on body circumference measurements in freshman students. One impetus was the "Freshman 15", the hypothetical phenomenon that freshmen gain 15 lb of weight in their first year of college. A limited number of other researchers have studied the phenomenon. While there has been no conclusive evidence that this degree of weight gain actually occurs across a significant number of students, most of the studies (Anderson et al., 2003; Delinsky & Wilson, 2008; Drawdy, 2007; Hoffman et al., 2006; Holm-Denomo, et al., 2008; Levitsky et al., 2004; Mihalopoulus et al., 2008; Morrow et al., 2006; Saunders, 2008) have found significant weight increases (ranging from 1.7 lb to 6.82 lb) among freshman students. The research reported here was part of a larger study of weight change in college students that incorporated additional physical, psychological, and environmental measures. The purpose of the segment discussed here was to increase understanding of whether there appear to be patterns as to where on the body measurements change with weight gain or loss and what amounts of body measurement change may be associated with weight change.

Summary and Discussion

Data Collection and Sample

Data collection was done at Auburn University, Alabama, at two time periods: (a) the beginning of fall semester 2007 and (b) the end of spring semester 2008, from male and female subjects; the results were analyzed separately. All subjects were entering freshmen who were 17-19 years old. A total of 240 subjects (156 females, 84 males) volunteered for the study at the beginning of fall 2007 semester. At the end of spring semester, 205 subjects returned for the follow-up assessments. Of the 205 subjects, 18 subjects were dropped from the analysis due to missing body measurements. Thus, 187 subjects (120 females, 67 males) were used in the data analysis.

Data collected on both sexes were categorized into the following three groups for analysis: (a) weight gained group, (b) weight lost group, and (c) no weight change group. The no weight change group was defined as those whose weight was within a 2 lb increase or decrease range.

Changes in Weight and Body Circumference Measurements

Fall to spring weight gain and loss. Between the beginning of fall 2007 and the end of spring 2008, 64.2% of male subjects (43) and 47.5% of female subjects (57) gained weight. Their respective weight gains, on average, were 6.93 and 7.21 lb. A relatively smaller proportion of the participants [14.9% of the male subjects (10) and 24.2% of the female subjects (29)] showed weight loss. The mean weight loss in male subjects was 6.34 lb and that of female subjects was 3.72 lb. After the data for those who gained and lost weight were evaluated using the VMR test, they were clustered using K-means clustering algorithm. Among those who changed weight, this resulted in three to four segments within each of the weight gained and weight lost groups; these were as follows:

1. Among males who gained weight: 21 who gained 2-2.5 lb; 16 who gained 5.6-10.6 lb; four who gained 12.8-17.6 lb, and two who gained 19.4-21.6 lb.

2. Among females who gained weight: 31 who gained 2-6.6 lb; 22 who gained 6.8-13 lb; three who gained 15.4-20.4 lb.

3. Among males who lost weight: four who lost 2.2-3.6 lb; four who lost 4.8-7 lb; two who lost 12.5-15.2 lb.

4. Among females who lost weight: 12 who lost 2-3.4 lb; nine who lost 4.2-5.4 lb; seven who lost 5.8-8.6 lb.

Fall to spring body measurement differences. Eight body circumferences were analyzed for change. Two were limbs (thigh and biceps), and the other six were torso locations (chest/bust, waist, stomach, abdomen, hips, and seat). Among the subjects whose weight was stable, mean changes in body circumferences were under an inch in all but one case (males' chest increased 1.32 in.). Among males and females who gained weight, seven of eight measurements increased significantly between fall and spring. The chest for males and the thigh for females increased but not significantly. Thus, mean weight gains of approximately 7 lb seemed to appear as recognizable body measurement increases at nearly all locations identified for possible change.

Among male and female subjects who lost weight, two of the eight measurements (seat and thigh max for males, and biceps and thigh max for females) showed significant decreases. Slight increases of approximately 0.24 in. at the biceps for male subjects and 0.41 in. at the abdomen for female subjects were also seen. Male subjects reported doing strengthening exercises, such as push-ups, sit-ups and weight lifting, for 2 days per week with an average of 35 minutes per days. Since these forms of exercise can simultaneously increase muscular measurements and influence weight loss, they may explain the biceps measurement increase. In weight lost females, there was an increase in the abdomen measurement. This could be an example of shifting fat distribution patterns mentioned by Croney (1971).

Association between weight and body measurement changes. In addition to assessing the significance of measurement differences over time, the association of measurement and weight changes was analyzed. Correlation analysis on the clustered segments within the weight gained and weight lost groups showed mixed results. Both male and female weight gained and lost groups showed positive and negative relationships, and most of those were not statistically significant. The mixture of results could be attributed to the fact that the sample sizes in each of the clusters were small, and some of the measurement changes were minimal. Among the clusters with the least weight gain or loss (±2-6.6 lb.), there were only two significant relationships. The other six cases of significant correlations were found in the second or third clusters of weight change (±4.2-20.4 lb.).

Positive correlations were seen for three cases of male subjects: (a) between weight gain and measurement changes at the abdomen and hip (Cluster 3, 12.8-17.6 lb);

(b) between waist and biceps changes for weight loss (Cluster 2, 4.8-7 lb); and (c) between biceps changes and weight loss (Cluster 1, 2.2-3.6 lb). In the case of female subjects, no significant correlations were found between weight gain and measurement changes. However, weight lost females (Cluster 2, 4.2-5.4 lb) showed a positive correlation with seat measurement changes. Significant negative correlations were seen in the case of weight lost (Cluster 1, 2.2-3.6 lb) males for stomach measurements and in the case of weight lost females (Cluster 3, 5.8-8.6 lb) at the thigh max.

Implications of body measurement changes. Poehlman et al. (1995) reported an average increase in waist circumference of 0.28 cm (about 1/8 in.) per year for women and 0.18 cm (about 1/16 in.) per year for men. Among males and females in this study who gained weight, the largest incremental change was at the waist (+1.92 in. and +1.21 in. respectively). The stomach (+1.75 in., measured between waist and chest) was second for males, and the abdomen (+1.18 in., measured at the fullest frontal location between the waist and the crotch) was second for females. Among males who lost weight, the largest decrease (-1.56 in.) was at the abdomen, and for females who lost weight, at the thigh (-0.59 in.). Past research on fat distribution patterns has suggested that fat is redistributed from the limbs to the trunk during adolescence, and fat can continue to build in that area during the adult years (Baumgartner et al., 1986; Brozek, 1952; Croney, 1971; Mueller, 1982; Ramirez, 1993; Ramirez & Mueller, 1980; Thibodeau, 1990). The freshmen in this study were older adolescents moving towards adult maturation.

The American College Health Association and U.S. Department of Health and Human Services formulated 178 health-related objectives specifically for college students (“Healthy Campus 2010: Making it Happen”, 2002). Of the ten major health issues quoted by these organizations, “Physical Activity” and “Overweight and Obesity” were at the top. While growth is a natural phenomenon, abnormal changes in body fat and fat accumulated measurement changes are considered health disparities. For example, an increase in abdominal circumference was found to be one of the indicators for mild cardiac risks (Atsumi, Tetsuro & Hiroyuki, 2005). Researchers (Santos, Cintra & Martini, 2008) found a correlation between accumulated trunk fat and insulin resistance, a metabolic disorder. Wells, Treleaven, and Cole (2007) studied the relationship between various body measurements in the context of health and disease risk factors. They used the 3D body scanner to extract body circumference measurements. They found that chest and waist measurements were significantly associated with BMI in the male subjects. BMI of female subjects was shown to have a significant association with hip and bust measurements. The research results reported here showed that circumference measurements from the stomach to the seat increased significantly in the male and female weight gain groups; these findings are related to health researchers’ focus on measurement changes in the trunk region.

When measurements changed, the amounts were not consistently similar at different circumference locations. An average of a 0.91 in. increase in the bust, 1.21 in. increase in the waist, 1.18 in. in the abdomen, and 0.93 in. at the hips for weight gained females would mean that a woman with those changes could find her apparel size changing by one or two increments at different locations, according to the ASTM Misses Standard Table (ASTM, 2001). Similarly, a man with the average increases of 1.26 in. at the chest, 1.94 in. at the waist, 1.55 in. at the abdomen, and 1.52 in. at the hips ,would have uneven changes in his garment size (ASTM, 2004). Among females who on average lost 3.72 lb, changes in bust, waist, abdomen and hips were less than ½ in.; this would not alter their size. Weight lost males (6.34 lb) had an average decrease of 0.26 in. at the chest, 0.52 in. at the waist, 1.56 in. at the abdomen, and 0.55 in. at the hips. According to the ASTM standard tables ("D6240-98", ASTM, 2004), a 1.56 in. decrease at the abdomen could change apparel size by one or two increments, but the waist measurement decrease 0.52 in. could obviate the need for a size change.

Relating measurement differences and associations. Weight gain occurred in both male and female subjects (6.93 lb, and 7.21 lb, respectively). These amounts showed an impact on body measurement changes. In males all trunk measurements increased by at least one inch; chest measurement, the only change that was not statistically significant ($p = 0.2$). increased by 1.26 in. The two limb measurements showed at least a ½ in. incremental change. Despite largely significant measurement differences, the abdomen and hip changes were the only places where positive correlations with weight gain were found. In the case of female subjects with weight gain, all the measurements except thigh max showed significant increases. The entire trunk region increased somewhere between ¾ and 1¼ in. However, no significant correlations were found between weight and measurement changes.

Although their weight loss was only approximately ½ lb less than their weight gain, males' weight loss was reflected as significant measurement decreases (between ¾ and 7/8 in.) only at the seat and thigh max. The greatest actual measurement decrement was found at the abdomen ($M = -1.56$), but it was not a significant change. Significant positive correlations between weight and measurement loss were found at still different locations, the waist and biceps. The females lost less weight, showing significant measurement decreases just above and below ½ in. at thigh max and biceps. However, the only significant correlation between weight and measurement change was a negative one at the thigh for the females who lost the most weight (5.8-8.6 lb).

Symmetry of changes around body circumferences. This study found some significant changes in measurements and some significant correlations between weight and body circumference changes. Because of the use of 3D body scanned measurements, it was also possible to study changes in shape. To explore whether measurement changes were even around major circumference locations, planar slices of the bust or chest, hip and waist were visually analyzed for males and females who gained and lost weight. No other known study has done this.

Changes in circumferential measurement at the chest among the male subjects who gained and lost weight were mostly symmetric (65-70% of the cases). At the same (bust) location among females who gained or lost weight, the distribution of symmetric and asymmetric changes was almost equal. Among those females who showed asymmetric changes, greater change at the front of the bust location was most common. At the hip, weight gained or lost males' changes were evenly or nearly evenly divided between symmetric and asymmetric patterns. Among women who gained or lost weight, hip changes were more often asymmetric than symmetric, but the locations of asymmetry differed somewhat between the gained and lost groups. Changes at the waist among men who gained or lost weight were slightly skewed towards the asymmetric side (53.5-60% of the cases) with the change most commonly showing more in the front. Females who gained weight showed more asymmetry at the waist than those who lost weight; among those who gained, the asymmetry appeared more at the back, but it was more at front for those who lost.

Conclusions

This was the first known study that used 3D body scanning to explore if and where body measurements change in connection with college freshman year weight change. Of the sample of 187 students, 100 gained weight, and 39 lost weight. Significant findings on circumference measurement changes (six around the trunk, plus the thigh and biceps) appeared more when assessed as fall to spring differences than when correlated with weight changes. Seven of eight measurements increased significantly for males and females who gained weight, but only two of eight decreased significantly for those who lost weight. However, the male subject numbers were small in the weight loss group, and the mean weight lost by females was relatively small.

For average weight gains of approximately 7 lb, the range of measurement changes were approximately 5/8 in. (biceps) to nearly 2 in. (waist) for males, and approximately ¼ in. (thigh) to 1¼ in. (waist) for females. Male weight loss was approximately 6 lb; the largest measurement loss was 1½ in. around the abdomen, and their biceps actually increased by about ¼ in. Neither were significant, but there were only 10 subjects, and the two significant changes were approximately ¾ in. Twenty-nine females lost under 4 lb; the greatest incremental change (significant) they had was approximately 5/8 in. in the thigh.

Findings on measurement changes were not always parallel across trunk locations, and although there were a few significant positive correlations between weight and body measurement changes, there were also some negative ones. Thus, weight increases and decreases did not always show clear patterns of body measurement increases and decreases. A larger sample size might be needed to better explore correlations. Although students reported how often and for how long they exercised, further probing of types of exercise and muscles worked might help better explain measurement change ranges.

Along with easily deriving body measurements, the 3D body scanner software allowed for planar slices at the chest/bust, waist, and hip to be viewed. Qualitative visual analysis suggested that although both males and females who gained and lost weight displayed symmetric and asymmetric changes, males more frequently showed symmetric patterns than women. Evidence of asymmetric change (more in the front, back, front and back, or at the sides) was found at all three locations, just more often for women.

Limitations

While this study produced results that contribute to building understanding of body measurement change, its findings are limited in several ways. First, the sample was not random. Subjects were a convenience sample of the freshman population of Auburn University, a campus of approximately 25,000 students in the Southeast U.S. The findings cannot be broadly generalized. Although the sample size was larger than many of the freshman 15 weight change studies, it was still relatively small in terms of interpretability, particularly when the data were subdivided for statistical analysis.

Results showed some relationships between weight changes and body measurement changes, but the small sample sizes of the clusters were one possible reason that more or stronger relationships were not identified. The process for selecting the clusters also could have been a limitation. Scatter plots of the weight data were visually examined to identify the clusters. Particularly with a larger sample size, in future research an automated algorithm could be devised to detect the number of possible clusters.

The determination of symmetry or asymmetry of circumference slices for the same individual from the two time periods was made through visual analysis. With a digital image processing procedure, this would be more consistent and quantitatively objective in nature (discussed in next section). As the evaluation proceeded, it could be observed that bodies might have slightly different stances in each scan; this had to be considered in making the evaluation. It also appeared in some comparisons of female bust slices that the subject may have worn a different bra in each scan, and this could affect assessment of the overlaid circumference shapes.

Implications and Recommendations for Future Research

The research results supported the findings of other studies showing freshman weight gain of less than 15 lb on average, but more importantly, they offered preliminary evidence where and how much these changes may be reflected in body measurement changes. Findings from this research can be applied to a broader spectrum ranging from possible impacts on garment design and possible implications for health studies.

One possible methodological change that could be tried could relate to either apparel or health issues. To assess the symmetry of circumference changes, analysis which was done visually in this study might be automated using digital-image processing. The cross-sectional grey scale image of each planar slice can be considered a two-dimensional matrix which could be converted in a binary image so that the resultant image would have a black background with a white cross-sectional silhouette. Images from two time periods for a particular cross section could be overlapped using any standard image processing software. Prior to overlapping, the individual images could be segmented into four quadrants, as they were in this study, and the area occupied by each quadrant calculated. The relative changes in area by quadrant could be deduced to determine a quantitative value indicating symmetric or asymmetric changes.

Garment Design Implications

Apparel fit is an important factor in consumer garment acceptance. Fit is impacted by decisions on the body measurements used in product development; size variants across size ranges are governed by pattern grading practices. Pattern grading systems are often static, meaning that the measurement increments are increased or decreased by fixed magnitudes for a given size range. The actual incremental amounts often used today are based on old anthropometric data and established assumptions about how bodies change. This study found that the changes in several trunk circumference measurements are not necessarily even, and that even within a particular circumference, the change around the body circumference may not be symmetrical. Further exploration could lead to better understanding of how body measurements and shapes change with weight gain or loss (size change). This could alter and improve grading rules through their reformulation, and, thus, potentially enhance fit for consumers and businesses' success in meeting consumer demand. Expanding research to a larger sample, and, perhaps to a wider age range would be beneficial.

Health Research Implications

Trunk fat accumulation, perhaps especially at specific locations such as the waist, has been found to be a risk factor for several syndromes. Researchers who are interested in fat-related diseases can use further research along the lines of this study to generate more data to better understand patterns of trunk fat accumulation among older adolescents as they approach adulthood and set patterns of eating and exercise. This and further research with more or larger samples could provide insights into educating consumers on the potential body areas that may be prone to fat accumulation and body measurement changes. Additionally, since this research was part of a larger study which also collected information such as body fat content and eating patterns, the body measurement data can be further analyzed in relation to these factors.

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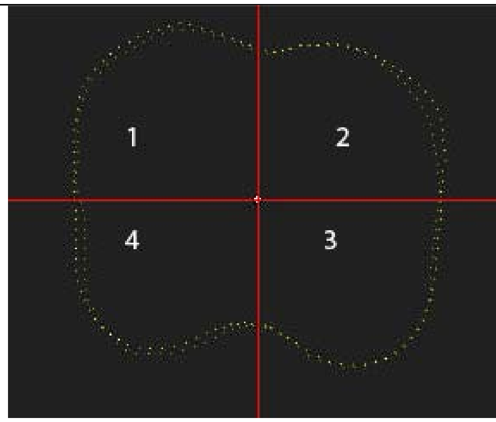
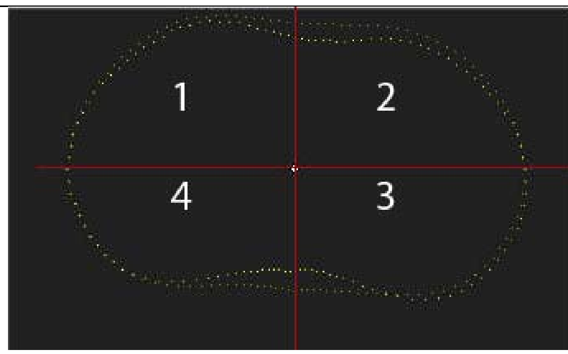
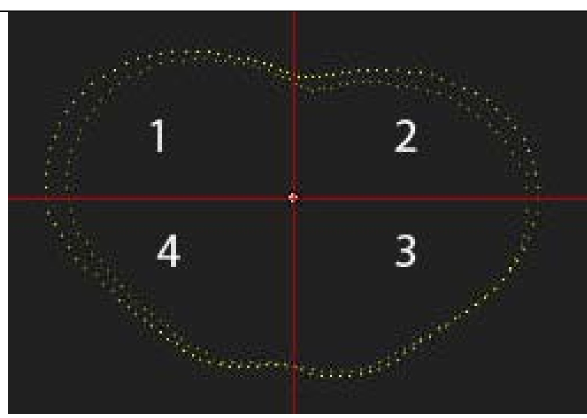
APPENDIX

SAMPLE SLICE SYMMETRY/ASYMMETRY SURVEY FORM

CODE-GENDER Bust		☐ **Symmetrical**: Relatively even change around body circumference **Asymmetrical** ☐ More in the back and front than on the sides ☐ Most in the back ☐ Most in the front ☐ Most on the sides
Hip		☐ **Symmetrical**: Relatively even change around body circumference **Asymmetrical** ☐ More in the back and front than on the sides ☐ Most in the back ☐ Most in the front ☐ Most on the sides
Waist		☐ **Symmetrical**: Relatively even change around body circumference **Asymmetrical** ☐ More in the back and front than on the sides ☐ Most in the back ☐ Most in the front ☐ Most on the sides