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A Cluster Analysis and Validation of Health-Related Fitness Tests in College Students

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Abstract Because health-related fitness consists of several domains, understanding clustering of scores from a testing battery can help practitioners derive exercise programs. The purpose of this study was to explore the clustering of health-related fitness test scores in college students and to validate the solution against criterion measures. Participants were college students (Mean age = 19.2 ±0.6 years; N = 523; 342 females, 181 males) recruited from a university in the southwestern U.S. The health-related fitness assessments consisted of BMI, estimated $VO_{2\ Peak}$ from the Astrand-Ryhming cycle ergometer test, and a standard push-up test. Criterion measures consisted of DXA-assessed percent body fat (%BF), measured $VO_{2\ Peak}$ from a maximal treadmill test, and a 1-Repetition Maximum (1-RM) bench press score. A hierarchical cluster analysis was performed to derive groupings. One-way ANOVA tests were used to explore the differences among the derived cluster groups on each criterion measure. Six cluster groups were formed representing various fitness "phenotypes" (Pseudo-F = 179.7). The cluster groups differed in %BF ($F(5, 517) = 44.6$, $p < 0.001$, eta-squared = 0.31), measured $VO_{2\ Peak}$ ($F(5, 517) = 49.7$, $p < 0.001$, eta-squared = 0.33), and 1-RM bench press scores ($F(5, 517) = 17.0$, $p < 0.001$, eta-squared = 0.12), providing validation evidence. Six cluster groups were formed from a health-related fitness test battery in college students that were validated against criterion measures of health-related fitness. The cluster groups can be used to inform current fitness status and for derivation of exercise programs.

Keywords: *exercise, fitness, health, young adult*

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1. Introduction

Health-related fitness has been correlated with chronic disease risk, cognitive functioning, and emotional wellbeing across the lifespan. [1,2,3] Health-related fitness consists of five domains that includes body composition, cardiorespiratory endurance, muscular strength and endurance, and flexibility. [4] Over the past couple of decades, various relationships among health risk factors, incidence of chronic disease, and the domains of body composition, cardiorespiratory endurance, and muscular fitness (i.e., muscular strength and endurance) has been established in various pediatric populations. [5,6,7] Programs such as FITNESSGRAM, the national fitness test battery of the U.S. for children and adolescents, have established a validated series of fitness tests with the aim of communicating to youth the minimum amount of fitness needed for good health and whether a respective child or adolescent has met age and sex-adjusted standards for specific health-related fitness domains. [8,9] The FITNESSGRAM testing battery includes the field tests of Body Mass Index (BMI) to assess body composition, an estimate of aerobic capacity (i.e., $VO_{2\ Peak}$) to assess cardiorespiratory endurance, and the standard push-up test to assess upper body muscular fitness.

Youth physical activity, and subsequently their levels health-related fitness, tends to decline throughout adolescence and into early adulthood. [10,11,12] Late adolescence and early adulthood is an important time to sustain physical activity and health-related fitness levels, [13] and sets the stage for behaviors and physiological traits (e.g., aerobic capacity) that track into middle and late adulthood. College students are individuals within the development stage of late adolescence or early adulthood that tend to have significantly lower levels of health-related fitness compared to when they were younger. [14,15] The lower levels of physical activity and health-related fitness in older adolescents and young adults is thought to be partially influenced by low levels of physical activity motivation. [16] Therefore, understanding a college student's health-related fitness levels and the prevalence of low levels of specific domains of health-related fitness is important for improvement, which can attenuate future disease risk. However, it is often difficult to discern high and low levels and overall fitness because of the different domains that comprise of the health-related fitness construct. Meaning, an individual can have high levels of cardiorespiratory endurance and low levels of muscular fitness, each individual health-related fitness domain linking to specific disease risk factor(s) and health outcomes that can affect physical, psychological, and emotional well-being.

Cluster analysis may provide a means to disentangle the complex grouping of health-related fitness test scores assessed across the various domains. Understanding the prevalence of certain phenotypes, or observable fitness traits, quantified by fitness assessment can help researchers and practitioners better understand the clustering of individuals across domains and how specific fitness phenotypes relate to disease risk. Specifically, cluster analysis allows for exploration of possible cluster groupings, which are individuals who display similar fitness test scores across the body composition, cardiorespiratory endurance, and muscular fitness domains. If a derived cluster solution can be validated against criterion measures for each health-related fitness domain, the derived fitness phenotypes (i.e., cluster groups) can have utility in characterizing current fitness status and also have utility in the derivation of exercise protocols to improve athletic performance and/or attenuate disease risk. No study to date has explored the clustering of health-related fitness test scores in college students and has validated cluster groupings against criterion measures of body composition, cardiorespiratory endurance, and muscular fitness. Therefore, the purpose of this study was to explore the clustering of health-related fitness scores in college students via the use of hierarchical cluster analysis and to validate the cluster groupings against criterion measures.

Table 1. Descriptive Statistics (means and standard deviations)

	Total Sample (N = 523)	Females (n = 342)	Males (n = 181)
%BF (from DXA)	26.5 (9.9)	**30.7 (8.3)**	18.3 (7.8)
Measured $VO_{2\ Peak}$ (mL / kg / min)	41.9 (7.4)	39.4 (6.2)	**46.9 (6.8)**
Bench Press 1-RM (lbs)	128.1 (74.9)	83.5 (22.8)	**214.4 (70.0)**
BMI (kg / m^2)	24.4 (4.1)	23.8 (4.1)	**25.5 (3.9)**
Estimated $VO_{2\ Peak}$ (mL / kg / min)	43.4 (12.4)	42.3 (12.5)	**45.3 (12.5)**
Push-up Test (repetitions)	36.1 (13.4)	30.1 (10.7)	**45.3 (13.6)**

Note: %BF stands for percent body fat; 1-RM stands for 1-Repetition Maximum; BMI stands for Body Mass Index; bold indicates statistical differences between the sexes, $p < 0.05$.

2. Methods

2.1. Participants

Participants were a convenience sample of college students (Mean age = 19.2±0.6 years; N = 523; 342 females, 181 males) recruited from a university in the southwestern U.S. The recruited college students were mostly enrolled between their 2nd and 3rd year of study (19-21 years old). All participants were enrolled in an exercise science lab course offered either during the Fall, Spring, or Summer semesters. The final sample consisted of participants who were enrolled in courses over six consecutive semesters (approximately two calendar years). All participants were healthy and did not have injury which would have precluded them from participating in health-related fitness testing. Informed consent was obtained from all individual participants included in the study. Research reported in the paper was undertaken in compliance with the Helsinki Declaration.

2.2. Instrumentation

2.2.1. Dual Energy X-ray Absorptiometry

Dual Energy X-ray Absorptiometry (DXA) was the criterion measure for body composition. DXA provides accurate and precise measurements of body bone mineral content and total fat mass. DXA has been validated in adults and children against hydrodensitometry, which has previously been established as the most valid and reliable method for measuring fat mass. [17,18] Body composition was divided into bone mass and soft tissue mass. Soft tissue mass was further divided into fat mass and fat-free mass. Percent body fat (%BF) was calculated by dividing the fat mass by total body mass. DXA procedures were carried out via a trained administrator.

2.2.2. Body Mass Index

Body Mass Index (BMI) was the field assessment for body composition. [19] Height was measured to the nearest 0.5 centimeter using a portable stadiometer (SECA 213; Hanover, MD, USA). With shoes off, weight was measured to the nearest 0.1 kg using a portable medical scale (BD-590; Tokyo, Japan). BMI was calculated taking each participant's weight (in kg) divided by square of height (in meters).

2.2.3. Maximal Graded Exercise Test

Measured $VO_{2\ Peak}$ was the criterion measure for cardiorespiratory endurance. $VO_{2\ Peak}$ was measured using a maximal graded treadmill test to exhaustion. Prior to each maximal test, gas analyzers were calibrated for expired air with certified gases of known standard concentrations (4.00% CO_2, 16.00% O_2). Volume calibration was employed using a 3-Liter calibration syringe (Hans Rudolph, Kansas City, MO, USA). Gas and flowmeter calibration was repeated until error was less than 3%. During the test, VO_2 and VCO_2 were measured continuously via open circuit spirometry and analyzed with the use of the Medical Graphics CardioPerfect metabolic measurement system (Minneapolis, MN, USA). A modified Balke treadmill protocol was used to acquire a VO_{2Peak} score. [20] Meeting two of three criteria determined if a successful $VO_{2\ Peak}$ test was performed: (a) showing signs of intense effort (heavy breathing, facial flushing, unsteady gait, and sweating), (b) a heart rate ≥ 90% age-predicted maximum, and (c) and a respiratory exchange ratio (RER) ≥ 1.1. [21,22] $VO_{2\ Peak}$ was recorded in relative (ml / kg / min) terms.

2.2.4. Sub-maximal Astrand-Ryhming Cycle Ergometer Test

The sub-maximal Astrand-Ryhming cycle ergometer test was used to estimate VO_{2Peak} and was the field assessment for cardiorespiratory endurance. [23] Participants completed the standard protocol for the sub-maximal Astrand - Ryhming cycle ergometer test prior to the maximal treadmill test. The Astrand - Ryhming sub-maximal cycle ergometer protocol was performed in six-minutes. Heart rate was recorded using Polar Heart Rate Monitors (Polar Electro, Lake Success, NY, USA). The procedures for acquiring estimated $VO_{2\ Peak}$ were aligned with standard procedures using the heart rate extrapolation method. [23] Maximum heart rate was estimated using the equation 220 – age. Before testing, participants rested quietly for 5 minutes so that heart rate could lower to approximate resting levels. The Astrand - Ryhming cycle ergometer test has been validated against measured $VO_{2\ Peak}$ from a maximal treadmill exercise test. [24] $VO_{2\ Peak}$ was recorded in relative (mL / kg / min) terms.

2.2.5. 1-Repetition Maximum Bench Press

The 1-Repetition Maximum (1-RM) scores from the bench press was the criterion measure of upper-body muscular fitness. All trials leading up to a 1-RM score had at least at five-minute rest period in between to allow for muscle recovery. All tests required a peer spotter to reduce risk of injury and were carried out with a flat bench and free-weight barbell. The procedures for acquiring 1-RM scores were aligned with the recommendations provided by the American College of Sports Medicine. [25]

2.2.6. Standard Push-up Test

The field assessment for upper-body muscular fitness was a standard push-up test. [26] The push-up test was administered using an audio compact disk providing a cadence of 20 pushups/min. Participants were asked to assume the standard push-up position and then required to flex their elbows to an angle of 90° followed by full extension in accordance to the given cadence. The test was terminated if a participant either twice stopped to rest, did not achieve the required 90° bend in the elbow, or did not fully extend their elbows in accordance to the cadence. The push-up test score was recorded as the number of successfully completed repetitions.

2.3. Procedures

All participants completed the testing over one semester during an exercise science lab section. Each domain of health-related fitness was assessed during separate weeks. Week one was cardiorespiratory endurance, week eight was body composition, and week nine was muscular fitness. The field measurements were collected first and the criterion measures were collected second during each respective assessment week. When multiple tests requiring physical effort was needed (i.e., during cardiorespiratory fitness and muscular fitness testing) sufficient time was allowed in between tests to allow for muscle recovery (> 5 minutes). The final sample consisted of participant data collected over six semesters (approximately two calendar years).

2.4. Statistical Analysis

Differences between sexes on each measure and assessment score were analyzed using independent t-tests, assuming unequal variances. There were differences between sexes on all measures, therefore data were transformed into sex-adjusted z-scores. Adjusted z-scores were calculated by regressing each measure onto sex, calculating individual residual scores, and then standardizing the residuals. A hierarchical cluster analysis with centroid linkage was then performed to derive clusters using the BMI, estimated $VO_{2\ Peak}$, and push-up test field assessments. The Calinski-Harabasz pseudo-F statistic and dendrograms were used to help determine the number of clusters (i.e., groups) within the final solution. To validate the cluster solution, one-way ANOVA tests were performed to examine the cluster differences on %BF, measured $VO_{2\ Peak}$, and the 1-RM bench press. Differences between sexes were not explored because the z-scores were already sex-adjusted. Although there was higher level clustering within the data structure, as participants were clustered within semesters, semester was not used as a higher level because of the small number of clusters (n = 6). A Bonferroni post hoc test was performed if there was a significant F-statistic, with appropriate alpha level adjustment. Pair-wise comparison effect sizes were calculated using Cohen's d with d < 0.2 representing a small effect size, d = 0.5 representing a medium effect size, and d > 0.8 representing a large effect size. [27,28] Alpha level was initially set at $p \leq 0.05$ and all analyses were conducted using STATA v14.0 statistical software package (College Station, TX, USA).

3. Results

The descriptive statistics are reported in Table 1. Males had lower %BF (Mean difference = 12.3%, $p < 0.001$, d = 1.48), higher measured $VO_{2\ Peak}$ (Mean difference = 7.64 mL/kg/min, $p < 0.001$, d = 1.04), higher 1-RM bench press scores (Mean difference = 130.9 lbs, $p < 0.001$, d = 1.87), higher BMI (Mean difference = 1.62 kg/m^2, $p < 0.001$, d = 0.41), higher estimated $VO_{2\ Peak}$ (Mean difference = 2.89 mL/kg/min, $p = 0.013$, d = 0.23), and a performed a greater number of push-ups (Mean difference = 15.1 reps, $p < 0.001$, d = 1.11) compared to females. Six cluster groups yielded a relatively high Calinski-Harabasz pseudo-F statistic and was the most parsimonious solution, therefore, six cluster groups were chosen as the most appropriate cut-point for interpretation. Figure 1 presents a dendrogram depicting the hierarchical six cluster solution. Table 2 displays the health-related fitness test z-scores across the six derived cluster groups. Within Table 2, a "phenotype" was assigned for each cluster grouping, given the relative magnitude of z-scores. In the current study, "phenotype" is defined a set of observable fitness traits. When identifying phenotypes for a respective fitness domain, "low" was defined as a z-score < -1, moderate as -1≤ z-score ≤ 1, and high as a z-score > 1 (see Table 2). The word "very" was given to z-score with an absolute magnitude > 2.

Results from the one-way ANOVA tests yielded differences among the cluster groups in %BF (F(5, 517) = 44.6, $p < 0.001$, eta-squared = 0.31), measured $VO_{2\ Peak}$ (F(5, 517) = 49.7, $p < 0.001$, eta-squared = 0.31), and 1-RM bench press scores (F(5, 517) = 17.0, $p < 0.001$, eta-squared = 0.12). Bonferroni post hoc tests revealed that there were differences between Group3 and Group4 with the rest of the cluster groups on %BF, with the differences representing medium to large effect sizes (Mean differences = 7.45% - 19.29%, $p < 0.001$, d = 0.63 – 1.72). There were no differences between Group3 and Group4 on %BF. Regarding measured $VO_{2\ Peak}$, there were differences between Group3 and Group5 with the rest of the cluster groups (Mean differences = 7.45 - 19.29 mL/kg/min, $p < 0.001$, d = 0.63 – 1.72). There were no differences between Group3 and Group5 on measured $VO_{2\ Peak}$. Finally, for 1-RM bench press scores, there were differences between Group5 and Group6 with the rest of the cluster groups (Mean differences = 32.9 – 201.9 lbs, $p < 0.001$, d = 0.26 – 2.68). There were no differences between Group5 and Group6 on 1-RM bench press scores. Figure 2 - Figure 4 show the differences across cluster groups in %BF, measured $VO_{2\ Peak}$, and 1-RM bench press scores, respectively.

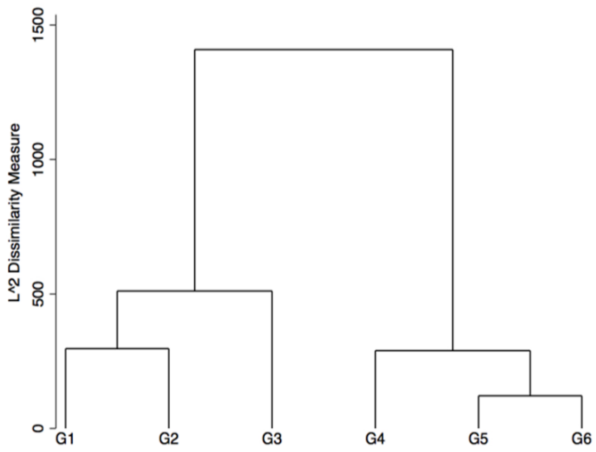

Figure 1. Dendrogram from the hierarchical cluster analysis

Table 2. Cluster analysis of derived group z-scores and phenotypes

	n	z-BMI	z-estimated $VO_{2\ Peak}$	z-Push-up Test	Phenotype
Group 1	326	-0.1	-0.4	-0.1	Moderate BMI, Aerobic Capacity, and Muscular Fitness
Group 2	166	0.2	0.6	1.1	Moderate BMI and Aerobic Capacity, HighMuscular Fitness
Group 3	9	-2.3	2.2	-2.3	Very Low BMI, Very High Aerobic Capacity, Very Low Muscular Fitness
Group 4	6	-2.7	0.4	-1.9	Very Low BMI, Moderate Aerobic Capacity, Low Muscular Fitness
Group 5	9	1.2	2.2	1.5	High BMI, Very HighAerobic Capacity, High Muscular Fitness
Group 6	6	2.9	-1.2	2.5	Very High BMI, LowAerobic Capacity, VeryHigh Strength

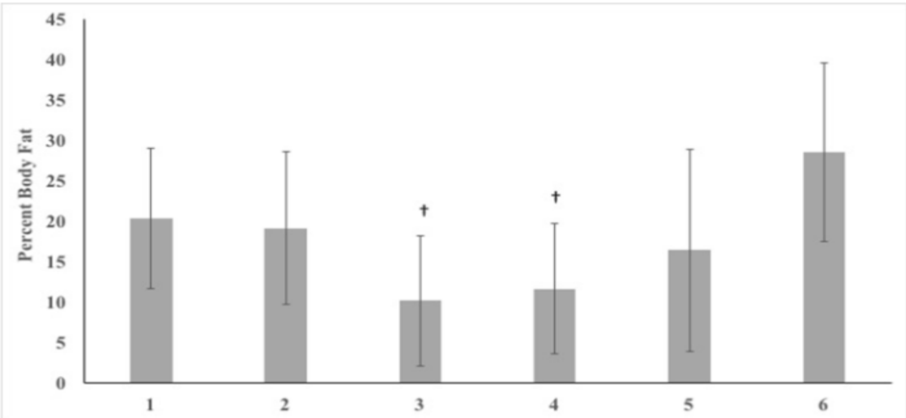

Figure 2. Cluster grouping mean differences on measured percent body fat from Dual Energy X-ray Absorptiometry

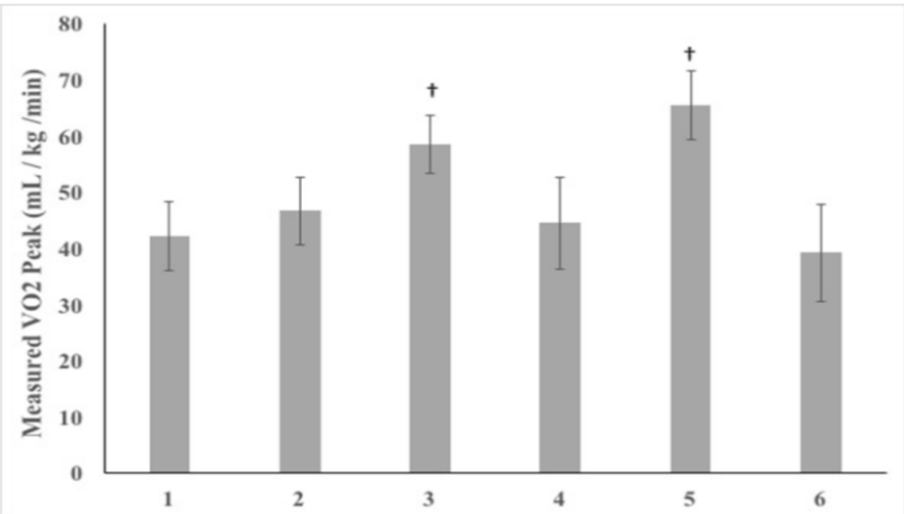

Figure 3. Cluster grouping mean differences on measured $VO_{2\ Peak}$ from a maximal graded treadmill test

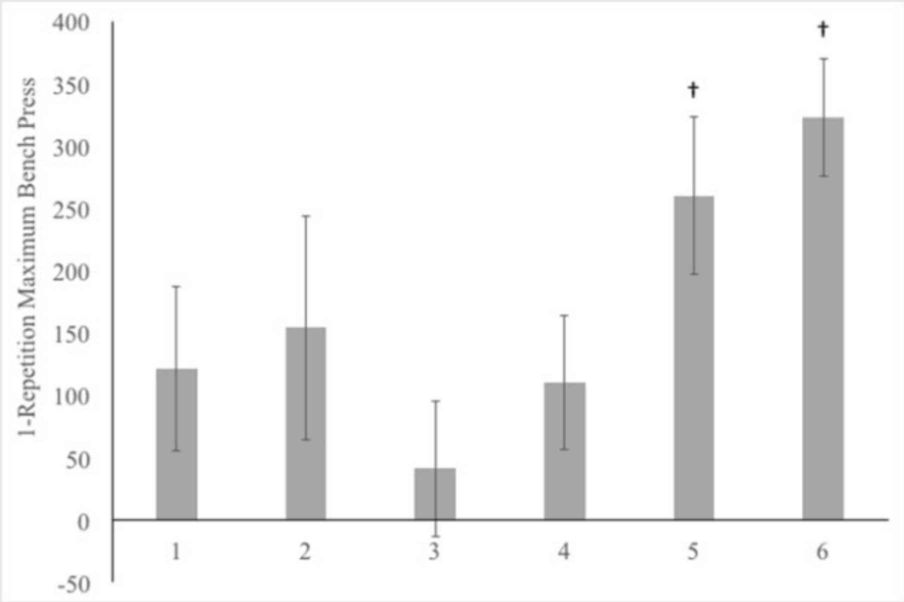

Figure 4. Cluster grouping mean differences on 1-Repetition Maximum bench press

4. Discussion

The purpose of this study was to explore the clustering of health-related fitness test scores in college students via the use of a hierarchical cluster analysis and to validate the cluster groupings against criterion measures of body composition, cardiorespiratory endurance, and muscular fitness. The results yielded a 6 cluster group solution, with each cluster group displaying a unique fitness phenotype (a set of observable fitness traits) that varied in prevalence. Because the cluster solution was validated against DXA-assessed %BF, measured $VO_{2\ Peak}$, and 1-RM bench press scores, there may be utility for the derived solution in practical and research settings. A description of the phenotypes, implications of the findings, and future research directions are discussed further.

The cluster analysis yielded a 6 cluster group solution. The number of clusters in the solution was determined to be most parsimonious with a high pseudo-F-statistic, indicative of distinct clustering. Each cluster group within the solution displayed a fitness phenotype that varied in prevalence across the entire sample. Expectantly, the cluster group with the highest prevalence were individuals who had moderate levels of overall fitness. The prevalence of this cluster group (Group 1) was approximately 62%. This cluster group displayed assessment scores that were within one standard deviation from the sex-adjusted mean in BMI, estimated aerobic capacity, and muscular fitness. The second cluster group (Group2) were participants who had moderate levels of BMI and aerobic capacity but who displayed higher levels of muscular fitness compared to Group1. The prevalence of this cluster group (Group2) was approximately 32%. Many activities require a certain amount of muscular fitness combined with moderate cardiorespiratory endurance. From a health perspective, higher levels of muscular fitness have been associated with lower incidence of sports-related injury and have also been related to more favorable cardio-metabolic risk profiles, independent of body composition and cardiorespiratory endurance. [29,30]

The more varied phenotype groups that displayed lower prevalence included Group3 and Group4. Individuals in Group3 displayed a very low BMI, high levels of aerobic capacity, but very low levels of muscular fitness. This cluster group displayed a fitness phenotype similar to long-distance endurance athletes, and thus displayed a series of fitness traits that will aid in activities and sports that require a relatively low bodyweight, high levels of cardiorespiratory endurance, and low muscular fitness. A plethora of studies have shown that low levels of body fat and high levels of cardiorespiratory endurance are protective against the incidence of chronic disease risk factors and also relate to low morbidity and mortality rates in various populations. [31,32] Therefore, individuals who displayed the phenotypes in Group3 can be assumed to have a favorable cardio-metabolic risk profile. However, because muscular fitness was low, the incidence of sports-related injury and incidence of musculoskeletal chronic conditions such as low back pain may be elevated. [33,34] The prevalence of Group3 was approximately 1.7%. Group4 displayed a slightly different phenotype than Group3, with only moderate levels of aerobic capacity and low levels of muscular fitness. The interpretation of the phenotypes displayed in Group4 can be similar to that communicated for Group3's phenotype; however, because aerobic capacity was only moderate, there may be marginally higher incidence of cardio-metabolic risk factors. The prevalence of Group4 was very low, at approximately 1.1% of the total sample size.

Group5 and Group6 both displayed high levels of BMI, however Group5 displayed a fitness phenotype characteristic of the "fat-fit" phenomenon. [35] Specifically, individuals in Group5 displayed high BMI, but very high levels of aerobic capacity and muscular fitness. These types of individuals displayed a fitness phenotype characteristic of athletes with a both high level of fat mass but also high levels of fat-free mass and who are aerobically trained. This phenotype is typical to what is found in American football and rugby athletes in males and volleyball and softball athletes in females. [36,37] From a health perspective, high levels of body fat correlates with higher cardio-metabolic health risk and a higher incidence of cardiovascular disease, cerebrovascular disease, and metabolic diseases such as type II diabetes. [38] However, the higher levels of aerobic capacity and muscular fitness, as found in individuals who are in Group5, have shown in studies to have a protective effect in relative risk for disease and decreased morbidity and mortality in the adult population, regardless of body composition status. [39,40] In Group6, however, aerobic capacity was found to be low but muscular fitness was very high. This cluster group is characteristic of athletes who participate in sports involving muscular strength and/or power, such as powerlifters and competitive strongmen. The health risk in Group6 would be assumed to be relatively higher compared to all other groups because of the high BMI combined with low levels of aerobic capacity. [39,40] The high levels of muscular fitness may have a protective effect on musculoskeletal injury and possibly lowered risk for cardio-metabolic risk compared to if muscular fitness was lower, however the evidence for these more complex relationships is currently lacking and should be a priority for future research. The prevalence for Group5 and Group6 was 1.7% and 1.1%, respectively.

The aforementioned interpretation of each derived phenotype relationship with sport performance and various health outcomes is partially speculative and should be explored with future research. Although there has been work exploring the relationships among the various health-related fitness domains and health outcomes, [41,42,43] no study has used a validated cluster solution to derive the cluster groups and a paucity of studies have explored relationships with three health-related fitness domains. Additionally, it is questionable the reproducibility of the cluster groupings derived in this study and whether fewer or more cluster groupings would yield a more interpretable solution. However, evidence for the practical utility of the cluster groupings in this study is theoretically and statistically defensible, due to the validation evidence, especially for body composition and cardiorespiratory endurance.

There are limitations to this study that must be considered before the results can be generalized. The participants were a convenience sample of college students recruited from a university from the southwestern U.S.; therefore, the external validity of the results is questionable if the results are to be generalized to younger or older populations or to populations located in different geographical regions. Also, cluster analyses are exploratory, therefore no causal inferences can be made. Furthermore, the college students who participated were individuals who regularly engaged in physical activity and thus were more likely to be physically fit; therefore, there is potential for selection bias. Finally, muscular fitness is comprised of both muscular strength and muscular endurance. Validated testing batteries use the push-up test as a field assessment of both muscular strength and endurance. The muscular fitness criterion measure in the current study was the 1-RM bench press, which may relate stronger to muscular strength rather than muscular endurance. Therefore, the construct validity of the derived clusters with respect to muscular endurance is questionable. In defense, there is no consensus on criterion measures for upper-body muscular endurance in adolescents.

In conclusion, a 6 cluster group solution was derived from health-related fitness assessments in college students. The cluster groups with the highest prevalence included those participants who displayed moderate levels of overall fitness and those who displayed moderate levels of body composition and cardio-respiratory endurance but high levels of muscular fitness. There was a cluster that displayed a “fat-fit” phenotype, specifically high BMI but high levels of aerobic capacity and high levels of muscular fitness, however the prevalence of this phenotype was low. Additionally, there was a phenotype with high BMI and low levels of aerobic capacity, but with very high levels of muscular fitness, however the prevalence of this phenotype was also low. Each derived cluster grouping (i.e., phenotype) may relate differently to various health markers and/or sport performance measures and should be explored with future research. This research supports the complexity of health-related fitness testing classification and may spur additional research related performance on common health-related fitness tests in individuals who are in late adolescence or early adulthood.

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