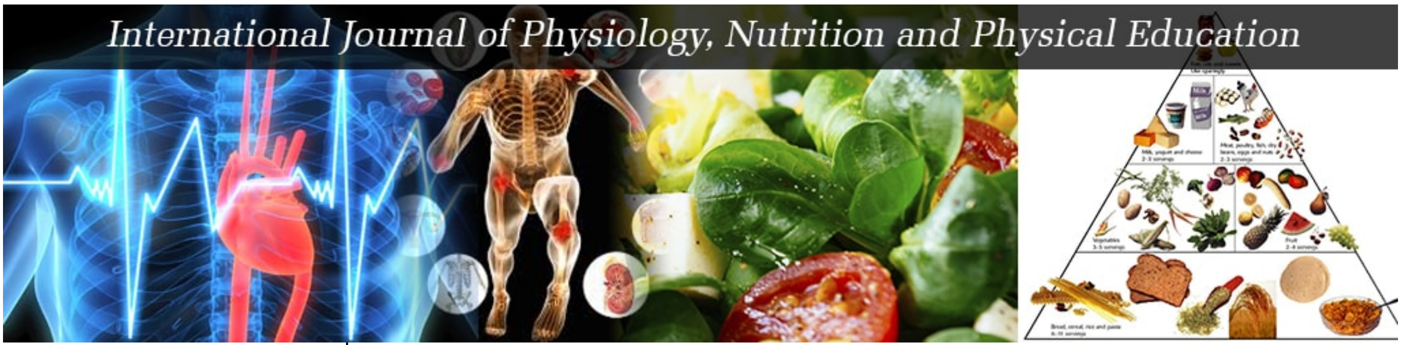

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Evaluation of possible anthropometric advantage in Sit-Up test

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Abstract
The players of Pro Football Academy are as part of its quarterly-annual physical fitness in order to assess the abdominal muscular endurance of service-members. However, there is speculation that sit-up performance may be associated with anthropometric proportions thereby affording certain service-members with a biomechanical advantage. To test this theory, anthropometric measurements were taken at various sites (i.e., humerus, torso, femur, and tibia) across a convenience sample of 30 male participants to include players from the Pro Football Academy. Humerus length (r = .297), tibia length (r = .385) and sex (r = .314) were all found to be moderately correlated with sit-up performance. These findings, coupled with well-documented concerns of the sit-ups in terms of safety and relevance in the literature, make a compelling argument for the identification and implementation of other potential field tests to assess abdominal muscular endurance.

Keywords: military physical fitness test, sit up test, anthropometric measurements

Introduction
As a result of a presidential mandate, the U.S. Navy developed and implemented its first physical fitness test in 1980 [6]. The test included sit-ups, flexed-arm hang (females only), push-ups, pull-ups (optional push-up alternative for males), 1.5-mile run/walk, and a 3-min run-in-place (optional run/walk alternative). Although the Navy Physical Readiness Test (PRT) has undergone several changes since its initiation, the U.S. Navy continues to employ sit-ups (curl-ups) as part of its semi-annual physical fitness test.
Sit-ups were added to the PRT to assess muscular endurance and specifically chosen due to a potential link between regular sit-up training and low-back pain prevention as documented in some of the available literature at the time [6]. Since its implementation, however, the safety and operational relevance of the sit-up has been called into question. For example, rarely do service-members perform repetitive spinal flexion as part of any specific job task [14]. In fact, service-members more often use their trunk musculature for stabilization in order to lift, push, pull, and carry. Additionally, current research now shows that performing high volume sit-up training may actually lead to low-back pain and injury instead of preventing them [1, 3, 4, 10, 11, 12, 14].
Another possible concern with the sit-up is the possibility for an unfair biomechanical advantage. For example, some service-members seem to be able to complete the required range of motion of the sit-up (i.e., lift the upper torso until the elbows contact the thighs) with modest effort, while for others it is far more difficult. Specifically, some service-members are able to touch their elbows to their thighs while keeping their low backs in contact with the ground. Conversely, other service-members must lift their entire torso several inches off the ground in order for their elbows to make contact with their thighs. This disparity in execution led the authors to suspect that certain anthropometric dimensions of an individual may offer a biomechanical advantage or disadvantage thereby influencing the level of ease or difficulty in performing maximum sit-ups. It is possible that this biomechanical advantage may be a result of differences in limb length (i.e., humerus, femur, and tibia) and torso length.
Although concerns associated with the sit-up in terms of safety and operational relevance are well documented in the literature [14], the impact of certain anthropometric variables (e.g., weight, height, and limb length) on performance appear to be less well known.

Vanderburgh [16] reported that current physical fitness tests employed by the U.S. military tend to be biased against larger service-members (regardless of body composition) and instead favor lighter service-members. Kranick [8] reported limb circumference, height and weight as determining factors on maximal muscle strength in college-aged (i.e., 20-28 years old) males (n = 7); although similar findings were not reported in college-aged females. As a result, Kranick [8] concluded that maximal strength is not influenced by an individual's height or limb length, but rather their build. Radu *et al.* [15] reported a correlation between anthropometric dimensions and physical fitness characteristics in college students (n = 67; 44 male / 23 female). Specifically, Radu *et al.* [15] found a moderately positive correlation between abdominal strength and sitting height-to-height ratio (SHR) in males (r = 0.352); although similar findings were not reported in females. Luz *et al.* [9] reported a relationship between body size and motor fitness especially in 8 year old girls (n = 74) when performing a variety of physical tasks (i.e., 2-kg medicine ball throw, hand grip strength, sit-ups, standing long jump, sit-and-reach, 25-m dash, 10 x 5-m shuttle run, 20-m endurance shuttle run). Specifically, Luz *et al.* [9] found moderately negative correlations between sitting height-to-stature ratio and fitness (r = -0.77) and stature and fitness (r = -0.56). Esco *et al.* [5] reported that there are a number of anthropometric variables (e.g., skinfolds, weight, height, body mass index (BMI), waist and hip circumferences, and waist/hip ratio (WHR)) that are predictive of sit-up performance in adults (n = 100; 40 male / 60 female).

Unfortunately, as depicted above, current research has yet to show a clear connection between certain anthropometric measurements and performance on various physical fitness tests. This lack of consensus provided additional rationale and justification for the current study. If a clear connection between an individual's anthropometrics and performance could be found, it could influence which physical fitness tests should be used as well as how they are to be administered and graded.

The purpose of this study was to evaluate the impact of limb and torso length on sit-up performance in active duty personnel, recently retired from active duty personnel and students from the United States Naval Academy (USNA). The authors hypothesized that individuals with longer limbs have a certain biomechanical advantage and thus will have higher maximum sit-up scores than individuals with shorter limbs.

Methods

Participants were recruited from students, active duty, and recently retired military personnel from the United States Naval Academy. Of the 69 participants, 32 were female and 37 were male. The mean age of females tested was 24 and the mean age of males tested was 27. Height and weight were measured on each participant. Statistical analysis was conducted via IBM SPSS Statistics 23. Descriptive data for each participant is provided in Table 1.

Table 1: Descriptive Statistics (n = 69)

Sex	Male (n = 37)
	Female (n = 32)
Ethnicity	Caucasian (n = 49)
	Asian (n = 8)
	Hispanic (n = 2)
	Multi-Race (n = 6)
	Declined to Report (n. = 4)
	Mean ± SD
Age	25 ± 10
Height (in.)	67.7 ± 3.6
Weight (lbs.)	161 ± 26.3
Humerus (cm)	38 ± 2.8
Torso (cm)	45 ± 4
Femur (cm)	46 ± 3.2
Tibia (cm)	41 ± 3.6
No. of Sit-Ups	97 ± 24

Prior to participation in maximum sit-ups in two minutes, participants were measured at four sites: humerus, torso, femur, and tibia. Humerus measurements were collected from the acromion to lateral epicondyle (Figure 1). Torso measurements were collected on the posterior side of the body, alongside the back by palpation of the spinous process of the C7 vertebra to midline between iliac crests (Figure 1). Femur measurements were collected from the greater trochanter to the lateral epicondyle (Figure 2). Tibia measurements were collected from the medial condyle to the medial malleolus (Figure 2). Participants were then asked to perform the sit-up portion of the Navy PRT, completing maximum sit-ups in two minutes. Formal testing procedures were taken and read verbatim from the Navy's Physical Readiness Test (PRT) procedures guide [13].

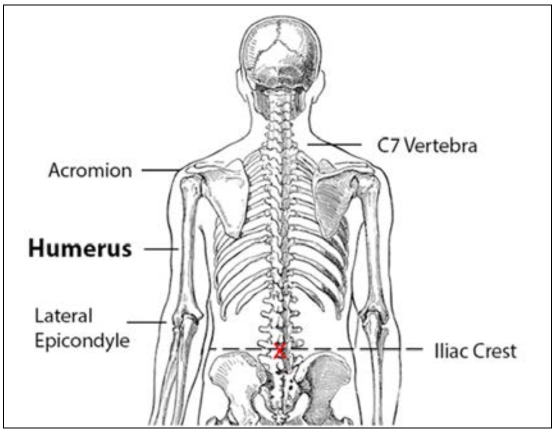

Fig 1: Humerus and torso landmarks

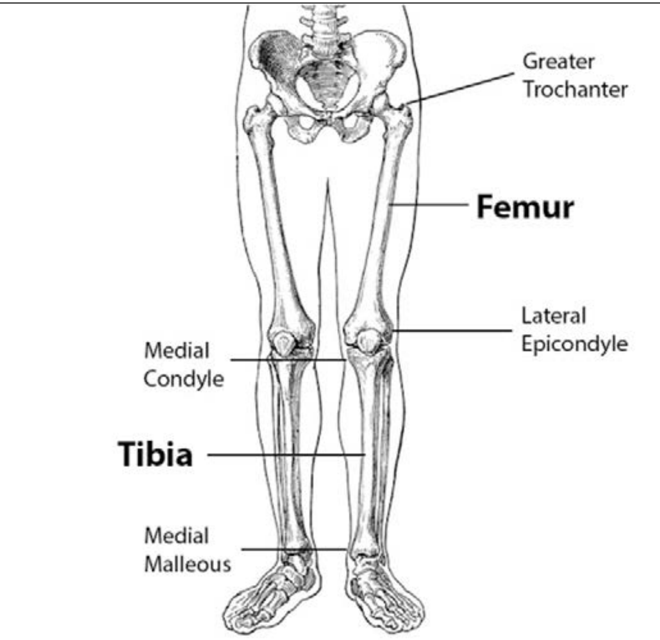

Fig 2: Femur and tibia landmarks

Testing ended at the completion of two minutes, or sooner if the participant stopped, lowered legs, lifted feet off the floor, lifted buttocks off the floor, or failed to keep arms folded across the chest and or lowered arms. Measurements and sit-up scores were recorded and compared using various statistical analyses to evaluate relationship between the certain anthropometric measurements and sit-up performance.

Results

The authors hypothesized a relationship between torso and limb lengths with sit-up performance. As shown in Table 2, there was a moderate positive correlation between humerus (r = .297; p = .013) and tibia (r = .385; p = .001) length and sit-up performance; however the small positive correlations between torso (r = .191; p = .115) and femur lengths (r = .088; p = .470) and sit-up performance were not statistically significant. Correlational analysis also showed a moderate positive relationship between height and sit-up performance (r = .306; p = .011). However, because the positive correlation between torso and femur length and sit-up performance was small and statistically insignificant, the correlation between height and sit-up performance is likely attributed to the inclusion and influence of the tibia length.

Table 2: Correlation with Number of Sit-ups

Limb	Correlation coefficient *	P-Value
Humerus	.297	.013
Torso	.191	.115
Femur	.088	.470
Tibia	.385	.001
* Pearson's R		

Because the results supported the authors' hypothesis that humerus and tibia length could improve sit-up performance, the authors wanted to determine the practical degree to which performance was improved. In other words, how many more sit-ups could a long-limbed person complete in 2 minutes? The results of this analysis can be found in Table 3. By dividing limb length at its mean (humerus at 38 cm and tibia at 41 cm), the authors found that a longer-limbed person could perform between 15 and 20 more sit-ups in 2 minutes.

Table 3: Differences in Number of Sit-Ups based on Limb Length

Limb	Limb Length (cm)	No. of Sit-Ups	P-Value
Humerus	38 (n = 35) versus 5 37.9 (n = 34)	104.9 ± 25.6 89.5 ± 19.8	.007
Tibia	41 (n = 35) versus S 40.9 (n = 34)	106.5 ± 23.5 86.8 ± 20.2	.000

As was to be expected, the authors also found a significant difference in humerus and tibia lengths between males and females. As shown in Table 4, there was a statistically significant difference in both humerus (p = .000) and tibia (p = .000) lengths between males and females, which was consistent with the significant difference (p = .009) in their sit-up performance of about 15 sit-ups.

Table 4: Independent sample t-test to determine sex differences

	Male	Female	P-Value
No. of Sit-Ups	104 ± 26	89 ± 18.6	.009
Humerus (cm)	39.6 ± 2.4	36.1 ± 2.1	.000
Tibia (cm)	42.8 ± 3.2	39.1 ± 3.0	.000

Discussion

Based on personal experience of observing hundreds of naval officers complete their physical fitness test, the authors hypothesized that an individual's anthropometric measurements would have a positive correlation with sit-up performance, and the results of this study supported that hypothesis. One explanation for how limb length influences sit-up performance is illustrated in Figure 3. Two male subjects who participated in the study were identified as having very different sit-up performance (i.e., subject A = 65 sit-ups; subject B = 113 sit-ups). These subjects' humerus, torso, femur and tibia lengths were then entered into Adobe Illustrator for visual comparison. This illustration makes it clear how limb length changes the distance the elbows have to travel in order to make contact with the thighs. It is very possible that a shorter distance allows for less fatigue and thus better sit-up performance.

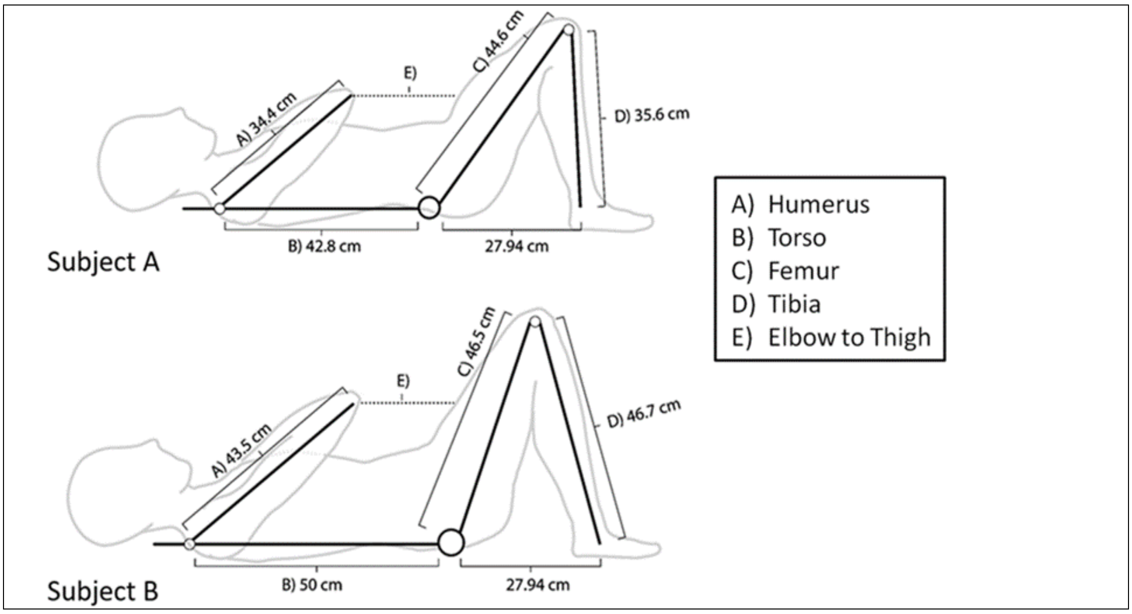

Fig 3: Impact of humerus and tibia length on elbow to thigh distance (E)

The authors believe there is good internal and external validity to this study. Because all participants were either active duty, recently retired from active duty, or students in a military service academy, they were familiar with the testing criteria and had experience performing sit-ups. Furthermore, all subjects were given the same instructions before performing their sit-ups, thus providing strong inter-rater reliability. Finally, there was equal distribution of male (n = 37) and female participates (n = 32), providing a representative sample of those serving in military service academies and the armed forces.

However, there was one limitation to this study the authors identified regarding the lack of standardization in the distance between the participant's heels and buttocks. Per the Navy's PRT instruction, participants are to position their heels about 10 inches from the buttocks [13]. Although the official PRT testing criteria was read aloud prior to the test, subjects were allowed to adjust their body position thereby changing the distance (increasing or decreasing) between their heels and buttocks. This was done to afford participants the ability to employ the same body position they use during official semi-annual PRT testing.

By allowing participants to adjust their body position, some participants opted to employ a distance greater than 10 inches from heels and buttocks while others employed a shorter distance. It is unknown whether the disparity in distance from the heels and buttocks would have altered the angle of the knee and hip enough to change the distance their elbow had to travel to make contact with the thigh. As mentioned previously, the authors speculate that a shorter elbow to thigh distance decreases the level of difficulty in performing maximum sit-ups whereas a greater distance increases the level of difficulty. To address this limitation, the authors recommend that additional testing be conducted where the distance between the heels and buttocks either be controlled between participants, or measured for each participant so that it can be statistically taken into account.

Conclusions

Although the authors hypothesized that all anthropometric measurements (i.e., torso, femur, tibia, and humerus) would be significantly correlated to sit-up performance, the results showed that only the humerus and tibia lengths were significantly correlated. This is likely due to the humerus' effect on the elbow to thigh distance and the tibia's effect on changing the height and angle of the knee. In both cases, these measurements help to determine the distance the elbow has to travel in order to make contact with the thigh. Additionally, the results also showed that sex was also correlated to sit-up performance, which makes sense since the females in the study measured shorter tibia lengths on average than the males (Table 3).

Collectively, the results show a potential for a slight biomechanical advantage in maximum sit-up performance for certain individuals. This, coupled with well-documented concerns regarding the safety and lack of operational relevance of sit-ups in the literature, make a compelling argument for identifying and implementing alternative field tests for assessing abdominal muscular endurance. Tests like the standard front plank, side bridge and/or the flexor endurance test show promise in effectively evaluating abdominal muscular endurance without possessing many of the concerns and limitations currently associated with sit-ups [7, 11, 14]. Even so, additional research would be needed in order to determine appropriate age- and gender-specific performance standards for these tests if the intent is to outright replace sit-ups in many of the current physical fitness tests used by the military, public education and/or health and fitness industry.

Applications in sport

Even though the sit-up test is a common field test used in the military, public education, and health and fitness industry, the implications for performance among these various entities are vastly different. For example, failing the sit-up portion of the PRT in the U.S. Navy can have severe ramifications in terms of promotion and retention. Failing the sit-up test repeatedly at military service academies such as USNA, can also result in expulsion as well as profound financial consequences in terms of recoupment. Additionally, a USNA Midshipman's overall PRT score is factored into the physical education grade, aptitude grade and overall order of merit. For all Midshipmen, order of merit is their primary factor in service assignment, which ultimately places them into their respective military career track following graduation and commissioning as officers in either the U.S. Navy or Marine Corps.

Additionally, the results of this study suggest that using age-adjusted standards alone for the sit-up may not be enough to ensure fairness and impartiality. For example, height and sex, in addition to age, also appear to be significant factors that influence maximum sit-up performance. With that in mind, the authors recommend that the U.S. military and service academies consider revising current sit-up standards to take into account these other physiological differences. For example, through the development and implementation of gender-specific performance standards for the sit-ups, just as there are for the push-ups and 1.5-mile run. These recommendations are both warranted and necessary when considering the aforementioned ramifications associated with service-member performance on semi-annual physical fitness tests in terms of career promotion and retention.

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