Available online at www.sciencedirect.com
ScienceDirect
Journal of Sport and Health Science 11 (2022) 725–730

Original article

Esports players, got muscle? Competitive video game players' physical activity, body fat, bone mineral content, and muscle mass in comparison to matched controls

Joanne DiFrancisco-Donoghue [a,b,*], William G. Werner [c], Peter C. Douris [c], Hallie Zwibel [b,d]

[a] Department of Osteopathic Medicine, New York Institute of Technology College of Osteopathic Medicine (NYIT-COM), Old Westbury, NY 11568, USA
[b] Center for Sports Medicine, NYIT-COM, Old Westbury, NY 11568, USA
[c] Department of Physical Therapy, NYIT, Old Westbury, NY 11568, USA
[d] Department of Family Medicine, NYIT-COM, Old Westbury, NY 11568, USA

Received 3 April 2020; revised 10 May 2020; accepted 18 June 2020
Available online 23 July 2020

Abstract

Background: Esports players, like traditional athletes, practice for long hours and, thus, are vulnerable to the negative health effects of prolonged sitting. There is a lack of research on the physical activity and the health ramifications of prolonged sitting by competitive players. The purpose of this study was to investigate activity levels, body mass index (BMI), and body composition in collegiate esports players as compared to age-matched controls.
Methods: Twenty-four male collegiate esports players and non-esports players between 18 and 25 years of age signed a written consent to participate. Physical activity was examined using daily activity (step count) with a wrist-worn activity tracker. A questionnaire assessing physical activity was also administered. Secondary outcomes included body-fat percentage, lean-body mass, BMI, and bone mineral content measured using dual X-ray absorptiometry.
Results: The step count in the esports players was significantly lower than the age-matched controls (6040.2 ± 3028.6 *vs.* 12843.8 ± 5661.1; $p = 0.004$). Esports players exhibited greater body-fat percentage ($p = 0.05$), less lean body mass ($p = 0.003$), and less bone mineral content ($p = 0.03$), despite no difference in BMI between the esports and non-esports players.
Conclusion: As compared to non-esports players, collegiate esports players were significantly less active and had a higher body-fat percentage, with lower lean body mass and bone mineral content. The BMIs showed no difference between the 2 groups. Esports athletes displayed significantly less activity and poor body composition, which are all correlated with potential health issues and risk of injury. BMI did not capture this difference and should not be considered as an accurate measure of health in competitive esports players.

Keywords: Body composition; Body mass index; Gaming

1. Introduction

The average collegiate esports player can spend 3–4 h a day sitting and practicing in front of a screen. That number can go as high as 8–10 h a day before a tournament or competition.[1] This does not include other forms of screen time, such as mobile phone or television use, which can add significantly more hours of sedentary screen time.[2] This frequent video game play has been linked to negative health effects in competitive esports players, including behavioral problems, sleep abnormalities, digital eye fatigue, musculoskeletal injuries, metabolic disorders, and central obesity.[1,3–5]

Lack of physical activity as well as obesity, in conjunction with or independent of each other, are both major risk factors for many chronic diseases.[6] However, recent literature suggests that lack of physical activity and low lean body mass (LBM) may have more of a health detriment than a higher body fat percent.[7,8] Low skeletal muscle mass independently can be associated with insulin resistance, diabetes, metabolic syndrome, and musculoskeletal injuries.[7,8]

Body mass index (BMI) is a standardized formula that is widely used to classify an individual as being underweight,

Peer review under responsibility of Shanghai University of Sport.
* Corresponding author.
E-mail address: jdonoghu@nyit.edu (J. DiFrancisco-Donoghue).

https://doi.org/10.1016/j.jshs.2020.07.006
Cite this article: DiFrancisco-Donoghue J, Werner WG, Douris PC, Zwibel H. Esports players, got muscle? Competitive video game players' physical activity, body fat, bone mineral content, and muscle mass in comparison to matched controls. *J Sport Health Sci* 2022;11:725–30.

normal weight, overweight, or obese by using height and weight (weight (kg)/height^2 (m^2)).[9] However, it can be an inaccurate measure of health because it does not take into consideration body composition. Body composition includes body fat, LBM, and bone mineral content (BMC). BMI is rarely accurate in elite athletes because it is typically overestimated due to a larger percentage of LBM, and it may be a poor indicator of obesity in adolescent athletes.[9] In 2012 the International Olympic Committee released the BMIs of some of its top competitors. One of the players on the men's French gold medal Olympic team—clearly a fit individual—had a BMI of 26.8, which is categorized as overweight, and another—also clearly fit—had a BMI of 28, which is approaching obesity. A female silver medalist in the 400-meter dash had a BMI over 27, which is categorized as being overweight. Thus, the International Olympic Committee deemed BMI to be an unreliable and invalid tool for measuring health in athletes. It is all too common for athletes to be labeled as overweight or obese using BMI because it does not account for increased muscle mass.

Conversely, in sedentary individuals, it is possible to present with a normal BMI while having high body fat mass and low LBM. As we age, LBM can decrease up to 10% per decade if precautions are not taken to preserve it.[10,11] If this loss is significant enough, it is labeled sarcopenia. This term refers to significant muscle loss and is found predominantly in older adults.[10,11] Individuals with both low LBM and high body fat are characterized as having sarcopenic obesity.[12,13] Sarcopenia obesity is associated with metabolic changes and decreased function and is an indicator of early morbidity in older adults.[12–16] These definitions are now carrying over to a younger population of individuals who sit for prolonged periods of time and have a lack of physical activity.

Kim et al.[17] were among the first researchers to establish that low LBM in non-obese young adults (19−39 years of age) is associated with metabolic syndrome. Below-average LBM has often been overlooked in youth as a risk factor to health. In recent years, prolonged sitting due to electronic use and television viewing has been shown to increase risk of cardiovascular and other chronic diseases, independent of exercise.[6] Having low LBM in conjunction with low physical activity can also negatively influence BMC.[18–20] Muscle and bone are inextricably linked, both molecularly and mechanically. The mechanostat theory explains how bone adapts to the mechanical loads it is chronically exposed to by changing its structure to become more resilient to the load; hence, high-impact activities and sport are widely recognized as leading to increases in BMC.[18–20] Studies have suggested that both muscle and bone release compounds that mediate an intercellular relationship. Dorsey et al.[19] demonstrated that greater skeletal muscle mass was associated with higher BMC in children 6−18 years of age, independent of body-fat percentage.[19] The combination of low LBM and low physical activity in youth can negatively influence bone health in children and young adults.[7,21] Osteoporosis in younger adults is typically associated with sedentary behavior, poor diet, or disease.[18] Among young athletes, osteoporosis is a concern primarily when their sports require a large volume of exercise and emphasize low body weight.[22] Physical activity during adolescence and growth periods during the life course are important in bone development so as to prevent bone loss later in life.[18] Hence, prolonged sitting and lack of physical activity serve as a prelude to low LBM and reduced BMC.[18,19] The lifestyle associated with the average esports player may result in low LBM and BMC; however, there appears to be a gap in knowledge about this topic.

The first specific aim of this study was to compare body composition of esports players (LBM, body fat (%), and BMC) to healthy age-matched controls. The second aim was to compare physical activity levels of collegiate esports players with their non-esports counterparts, utilizing a wrist-worn activity tracker. We hypothesized that esports players would be less active and present with higher body fat, lower LBM, and lower BMC, which would translate misleadingly to lower BMIs in esports players than in non-esports players.

2. Methods

2.1. Participants and study design

This age-matched subject design study was approved by the New York Institute of Technology Institutional Review Board in Old Westbury, NY, USA, and conducted on the New York Institute of Technology campus in Old Westbury, NY, USA. Subjects were a convenience sample of 24 male volunteers who signed a written consent to be in this study and who were from the same geographic area and commuter university. All subjects were born male and identified as such. A total of 13 competitive collegiate esports players (age = 20.2 ± 1.7 years) and 11 age-matched controls (age = 19.2 ± 1.3 years) who were not esports players or self-reported gamers participated (Table 1). The choice to use the same university campus to recruit controls was made in order to minimize bias between subjects who might live in a dormitory or who might commute by motorized transportation. All subjects used public transportation or personal vehicles to commute to campus. Inclusion criteria for subjects included: (1) being a woman or man 18−30 years of age, (2) being a competitive member of the campus esports team, if not acting as a control, and (3) having

Table 1
Subject data (n = 24, mean ± SD).

Variable	Esport (n = 13)	Control (n = 11)	p
Age (year)	20.2 ± 1.7	19.2 ±1.3	0.09
Height (cm)	172.7 ± 6.4	174.5 ± 6.9	0.63
Weight (kg)	71.1 ± 7.7	77.4 ± 10.8	0.14
Sleep (min)	388.0 ± 98.0	441.0 ± 103.0	0.07
Playing esports daily (h)	4.6 ± 2.6	N/A	N/A
Playing esports without break daily (h)	4.0 ± 3.2	N/A	N/A
Computer recreational/school use daily (h)	4.3 ± 1.9	1.7 ± 1.0	0.001*
Exercise (day/week)	1.7 ± 1.9	4.8 ± 1.2	0.001*
Exercise (min/session)	39.5 ± 40.4	56.7 ± 26.8	0.29

* Significant difference between Esport group and Control group.
Abbreviation: N/A= not applicable.

a Smartphone. Exclusion criteria for subjects included: (1) having any contraindication for having a dual-energy X-ray absorptiometry scan performed, based on the American College of Radiology's practice guidelines[23] and (2) being a control subject who was a self-proclaimed competitive video gamer. Esports players were members of the American Collegiate East Coast Esports League, which competes competitively in Tespa, the East Coast Conference, and the Overwatch Open Division. The team is ranked as "high platinum/low diamond" in the Overwatch and Platinum 1/Diamond 4 for Multiplayer Online Battle Arenas. All data on the esports players were collected during peak season. Although some universities offer physical training services or nutritional counseling to their esports teams, these services were not provided for our participants at the time of data collection. To avoid seasonal weather influences on physical activity, data for the control subjects and for the esports subjects were collected at the same time.

2.2. Instruments

2.2.1. Activity and sleep

Daily activity was monitored for 24 h for 14 consecutive days by a Fitbit Charge (Fitbit, San Diego, CA, USA). The Fitbit activity monitor is a quantitative tool used to assess steps per day/week, exercise, sleep duration, and quality of sleep. The Fitbit uses sensors to track heart rate, activity, steps, and sleep.[24] Information regarding compliance, sleep latency, sleep time, and awakenings were recorded as well as the number of steps each subject took each day. This tracker works with most mobile devices. All participants had a Smartphone with the Fitbit application. The monitor was placed on the non-dominant wrist of each subject, and each subject was instructed to wear the device all day and night, including during sleep. Fitbit is engineered to detect motion patterns and to look for intensity that may indicate someone is walking or being active. For example, the unit may inaccurately interpret abrupt arm motion as physical activity.[25] For this reason, the esports players were asked to remove the watch only while they were gaming.

Recreational computer use does not involve the action moves and intensity of gaming; therefore, the controls and esports subjects were permitted to wear the device during recreational computer use. The Fitbits were synced to a web-based dashboard designed for collecting data from this particular Fitbit (Fitabase, 2015 Small Steps Labs).

The number of days performing intentional exercise and the duration of exercise was recorded using a self-reported questionnaire. The mode of exercise was not investigated. The subjects were also asked specifically how many hours they played their esports games daily, how many hours they played this game before taking a break, and how many hours they spent doing recreational activities on the computer that did not involve gaming.

2.2.2. Body composition

All participants underwent body composition testing on a General Electric Lunar dual-energy absorptiometry machine (LunarI-Dexa General Electric, Atlanta, GA, USA) located in the Academic Health Care Center on the campus of the New York Institute of Technology. Testing was performed by a licensed X-ray technician. This machine routinely goes through a quality control procedure every 3 days before scanning any participants. This unit analyzes whole-body composition that includes total mass, lean mass, fat mass, fat percent, and visceral fat. The unit has the ability to perform individual region analysis. This was separated into left and right arms, left and right legs, and trunk region. Two established methods for defining sarcopenia were conducted. The first method, defined by the International Working Group on Sarcopenia, was calculated using appendicular lean body mass (ALM) divided by height^2 (kg/m^2).[26] The cut-off point for defining sarcopenia was $\leq$ 7.23 kg/m^2 for males. The second equation used was ALM/body mass and was expressed as a percentage of a cut-off score of < 27.1% for males.[27] Although females were included in the protocol, there were no female volunteer participants.

2.3. Statistical analysis

An *a priori* power analysis utilizing G*power (Version 3.1.2; Heinrich Heine Universitat, Dusseldorf, Germany), based on preliminary Lean Body Mass pilot data (SD $\pm$ 8.5) (Lean Body Mass SD $\pm$ 8.5), indicated that a sample size of 10 subjects in each group would provide sufficient power (80%) to observe differences, assuming a moderate effect size. Outcome data were analyzed using IBM's Statistical Package for Social Sciences (SPSS Version 25; IBM, Armonk, NY, USA). Data normality on each variable was tested using a Shapiro-Wilk test, and an independent *t* test was conducted to analyze and compare outcomes between the variables recorded. Results were considered statistically significant when a *p* value was less than or equal to 0.05. All data are reported as mean and SD. Given the documented ways to analyze low muscle mass, analysis was done using 2 formulas: (ALM/height^2(kg/m^2)) and (ALM/weight (%)).[27]

3. Results

Activity measured by weekly step count was significantly higher in the control group than in the esports group ($p = 0.004$), and there was no difference in sleep time between the groups ($p = 0.07$). The control group exercised significantly more than the esports group on a weekly basis (days $p = 0.001$). Recreational computer use outside of esports game play was higher among esports players ($p = 0.001$) (Table 1).

No difference was found between groups in BMI ($p = 0.35$). Despite there being no difference in BMI, the esports players had significantly higher total body fat percentage ($p = 0.05$). Additionally, the esports team demonstrated significantly lower total lean mass ($p = 0.003$). ALM/height^2 (kg/m^2) was significantly lower among the esports players ($p = 0.002$), and ALM/weight (%) was also significantly lower among the esports players ($p = 0.002$). BMC among the esports players was significantly lower as well ($p = 0.03$) (Table 2).

Table 2
Outcome measures ($n = 24$, mean ± SD).

Variable	Esport ($n = 13$)	Controls ($n = 11$)	p
BMI (kg/m^2)	23.7 ± 3.3	24.9 ± 2.1	0.35
Body fat (%)	24.0 ± 6.7	19.1 ± 6.0	0.05*
Visceral fat (kg)	0.34 ± 0.24	0.20 ± 0.13	0.07
Total lean mass (kg)	50.8 ± 4.0	59.8 ± 8.5	0.003*
ALM/height^2 (kg/m^2)	13.7 ± 1.4	16.8 ± 2.5	0.002*
ALM/weight (%)	30.0 ± 0.0	38.0 ± 0.0	0.002*
BMC (kg)	2.9 ± 0.3	3.2 ± 0.4	0.03*
Step count (2 weeks)	6040.2 ± 3028.6	12843.8 ± 5661.1	0.004*

* Significant difference between Esport group and Control group.
Abbreviations: ALM = appendicular lean mass; BMC = bone mineral content; BMI = body mass index.

4. Discussion

Our findings are consistent with our hypothesis that this cohort of collegiate esports players was significantly less active and had higher body fat percentage, lower LBM, and lower BMC than non-esport players; nonetheless, the esports players displayed normal BMIs. Furthermore, a significant difference in recreational computer use between esport players and non-esport players was found (4.3 ± 1.9 h *vs.* 1.7 ± 1.0 h, $p = 0.001$). This may also be a contributing factor to the difference seen in physical activity.

4.1. BMI, body composition, and clinical relevance

In the current study, when BMI was used to classify obesity, 18% of esports participants compared to 55% of the controls would be classified as obese. However, when body fat percentage was examined, the results looked considerably different. Although there are no universally accepted norms for body-fat percentage, researchers have typically considered > 25% in males and > 30% in females as being overly fat or obese.[28,29] Observing these guidelines, 30% of the esports participants would be classified as obese, whereas none of the controls would be. Thus, low muscle mass and high body fat percent that results in a normal BMI can give a false clinical interpretation of health in sedentary individuals.

Low LBM is a growing health concern among a sedentary population, and the body of evidence concerning its negative consequences is growing. Recently, research has started to establish age- and sex-specific percentiles of total LBM using the same instrument utilized in this study (General Electric dual X-ray absorptiometry machine).[30−32] When comparing the results of our study to age- and sex-specific norms of the general population, as defined by Imboden et al.,[32] the esports players are categorized below the 10th percentile for LBM, whereas the control subjects are categorized in the 30th percentile for LBM.

Interestingly, from these results, using BMI as the clinical interpretation places both groups in the "normal range" category and at a reduced risk of disease. When we interpret body fat percentage according to the American College of Sports Medicine guidelines, the esports players (for sex and age) would be in the 15th to 20th percentile and classified as "very poor" and at an increased risk of disease. The control group would be categorized as "fair" and in the 40th percentile, with less risk of disease.[29] If the BMI measure were used as an indicator, the esports players in our study would not be classified as being at risk for disease. However, if LBM and lack of physical activity were used, the esports players would be classified as being at higher risk of disease and injury than the general population. Thus, clinicians and researchers should evaluate esports athletes with caution, and multiple measures should be utilized in examining their health status.

4.2. Prolonged sitting and sedentary behavior

Prolonged sitting and lack of physical activity has independently been shown to result in a significantly higher risk of mortality, regardless of muscle strength.[33] Kim and colleagues[17] were the first to demonstrate the relationship between low lean body mass and metabolic syndrome in young adults, independent of being overly fat or obese.

The American Heart Association and the American College of Sports Medicine both have similar activity guidelines for adults and set them at a minimum of 150 min of moderate exercise a week, including 2 or more days of strength training.[34] This translates into a minimum of 30 min of moderate exercise daily at least 5 days/week. The non-gaming control subjects in our study attained these guidelines (4.8 ± 1.2 days/week; 56.7 ± 26.8 min/day), whereas the esports players were significantly less active than the recommended minimum requirements (1.7 ± 1.9 days/week; 39.5 ± 40.4 min/day). Kari et al.[35] recently showed that professional esports athletes practice gaming approximately 5 h/day, year-round, and participate in approximately 1 h of physical exercise every day (5 h/week or 350 min/week).[35] The motivation behind the physical activity was for overall health, although a majority of the players felt that it helped their gaming performance as well.[35] Interestingly, Rudolf et al.[36] showed similar findings. They found that 50% of German professional male gamers participated in more than 5 h per week of physical activity, whereas 35% of amateur players participated in 2.5−5 h per week of physical activity.[36] DiFrancisco-Donoghue et al.[1] demonstrated that, on a collegiate level, the average gamer plays approximately 5.5 h daily, and 40% did not participate in any physical activity. The differences reported on a professional level and an amateur level are not surprising. Professional teams often have more structure in their routines, have access to more resources, and are more incentivized to stay healthy by a team of coaches and health professionals.[35] Esports is expanding rapidly on the collegiate level and the types of health services available to these players varies greatly across colleges and universities. Some collegiate teams have health services available, but most collegiate esport teams do not have access to the same resources as professional teams or the same time to commit to physical exercise.

The American Heart Association has publicly announced that exercise might not be enough to undo the negative health effects of sitting.[33] As Kari and colleagues[35] have demonstrated, although an individual may fulfill the recommended exercise guidelines, sitting for prolonged periods of time may negate any health benefits.[35] Ekelund and colleagues[6] have found that moderate activity for 60−75 min/day seemed to eliminate the increased risk of death associated with prolonged sitting. However, 60−75 min a day may not be scheduled reasonably for many individuals. Researchers and health professionals in the esports community should address the issue of how to increase physical activity in conjunction with reasonable breaks during prolonged game play.

A major strength of this study is that it is the first to describe the separate health concerns that need to be addressed for esports players and excessive video gamers. Although qualitative data exist on lifestyle behaviors of esports players, this is the first study to collect objective data from competitive esports players and demonstrate the differences that exist in physical activity among this younger population compared to age-matched peers. Furthermore, we examined the effects of decreased physical activity and prolonged sitting on body composition and demonstrated that weight and BMI are not appropriate assessment tools for health in this population.

Some limitations to our study that need to be addressed include the lack of research on women esports players and the lack of muscle-quality assessment. The study protocol did not exclude women esports players; however, on some campuses women esports players at the collegiate level are a minority or nonexistent. Unfortunately, these circumstances resulted in there being no female volunteers in our study. Women were not included, so we cannot assume that the same differences that existed among men would occur in women. Because of the large differences normally seen in LBM, abdominal visceral fat, and subcutaneous fat between sexes, experimentation should be performed with a female cohort only. Muscle quality is defined as muscle strength per power per unit of muscle mass.[37] We failed to collect muscle strength data in our subjects and, therefore, cannot truly define muscle quality among these players. Last, this was a small cohort of subjects from a commuter university in 1 geographic area. Our results may not reflect the results that would be found for esports players from other collegiate teams who have access to trainers and nutritionists or from the larger esports community.

This study identifies many issues for clinicians and for future research. Coaches, therapists, and physicians should use caution when utilizing standardized measures of health for the general population. The consequences of a sedentary lifestyle on health, mobility, and function among esports players are just starting to be explored, and we simply do not know the ramifications that their sedentary behavior will have on their future health. Henriksson and colleagues,[38] using a cohort of 1.2 million men, found that muscular weakness in adolescent males was associated with disability 30 years later. There have been few, if any, guidelines set forth for esports players because insufficient research has been conducted to provide the basis for such guidelines. This study establishes a framework for much-needed research in this population and for health professionals who wish to establish esports guidelines that promote healthy behaviors.

5. Conclusion

Research on esports is still in its infancy. This study suggests that playing esports on a collegiate level is associated with sedentary behavior, low LBM, low BMC, and high body fat. Even if the esports players in our study attained the minimal recommended guidelines for physical activity set forth by health organizations, we simply do not know whether meeting these guidelines would negate the effects of prolonged sitting that result from esports gaming.

Acknowledgment

We thank the New York Institute of Technology Center for Sports Medicine, Old Westbury, NY, for its assistance with and support for this project.

Authors' contributions

JDD planned and executed the study, was the primary writer, and submitted the study; WGW planned the study and assisted in editing the manuscript; PCD helped plan the study and assisted in analyzing statistics and editing the manuscript; HZ planned and executed the study and contributed to the writing and editing. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests

The authors declare that they have no competing interests.

References

1. DiFrancisco-Donoghue J, Balentine J, Schmidt G, Wibel H. Managing the health of the esports athlete: An integrated health management model. *BMJ Open Sport Exerc Med* 2019;**5**:e000467. doi:10.1136/bmjsem-2018-000467.
2. Common sense media. *Quarterly Survey Series 2019*. Available at: https://www.commonsensemedia.org/research/quarterly-survey-series. [accessed 06.07.2020].
3. Biddle SJH, Garcia Bengoechea E, Wiesner G. Sedentary behaviour and adiposity in youth: A systematic review of reviews and analysis of causality. *Int J Behav Nutr Phys Act* 2017;**14**:43. doi:10.1186/s12966-017-0497-8.
4. Mario S, Hannah C, Jonathan WCK, Jose L. Frequent video-game playing in young males is associated with central adiposity and high-sugar, low-fibre dietary consumption. *Eat Weight Disord* 2014;**19**:515–20.
5. Yin K, Zi Y, Zhuang W, et al. Linking Esports to health risks and benefits: current knowledge and future research needs. *J Sport Health Sci* 2020;**9**:485–8.
6. Ekelund U, Steene-Johannessen J, Brown WJ, et al. Does physical activity attenuate, or even eliminate, the detrimental association of sitting time with mortality? A harmonised meta-analysis of data from more than 1 million men and women. *The Lancet* 2016;**388**:1302–10.
7. Moon SS. Low skeletal muscle mass is associated with insulin resistance, diabetes, and metabolic syndrome in the Korean population: The Korea National Health and Nutrition Examination Survey (KNHANES) 2009-2010. *Endocr J* 2014;**61**:61–70.
8. Fabbri E, Chiles Shaffer N, Gonzalez-Freire M, et al. Early body composition, but not body mass, is associated with future accelerated decline in muscle quality. *J Cachex Sarcopen Muscle* 2017;**8**:490–9.
9. Etchison WC, Bloodgood EA, Minton CP, et al. Body mass index and percentage of body fat as indicators for obesity in an adolescent athletic population. *Sports Health* 2011;**3**:249–52.
10. Janssen I, Heymsfield SB, Ross R. Low relative skeletal muscle mass (sarcopenia) in older persons is associated with functional impairment and physical disability. *J Am Geriatr Soc* 2002;**50**:889–96.

11. Iannuzzi-Sucich M, Prestwood KM, Kenny AM. Prevalence of sarcopenia and predictors of skeletal muscle mass in healthy, older men and women. *J Gerontol A Biol Sci Med Sci* 2002;**57**:M772–7.
12. Hsu KJ, Liao CD, Tsai MW, Chen CN. Effects of exercise and nutritional intervention on body composition, metabolic health, and physical performance in adults with sarcopenic obesity: A meta-analysis. *Nutrients* 2019;**11**:2163. doi:10.3390/nu11092163.
13. Waters DL, Baumgartner RN. Sarcopenia and obesity. *Clin Geriatr Med* 2011;**27**:401–21.
14. Rolland Y, Czerwinski S, Abellan Van Kan G, et al. Sarcopenia: Its assessment, etiology, pathogenesis, consequences and future perspectives. *J Nutr Health Aging* 2008;**12**:433–50.
15. Li R, Xia J, Zhang XI, et al. Associations of muscle mass and strength with all-cause mortality among US older adults. *Med Sci Sports Exerc* 2018;**50**:458–67.
16. Kim YH, So WY. A low arm and leg muscle mass to total body weight ratio is associated with an increased prevalence of metabolic syndrome: The Korea National Health and Nutrition Examination Survey 2010-2011. *Technol Health Care* 2016;**24**:655–63.
17. Kim BC, Kim MK, Han K, et al. Low muscle mass is associated with metabolic syndrome only in nonobese young adults: The Korea National Health and Nutrition Examination Survey 2008-2010. *Nutr Res* 2015;**35**:1070–8.
18. Bielemann RM, Martinez-Mesa J, Gigante DP. Physical activity during life course and bone mass: A systematic review of methods and findings from cohort studies with young adults. *BMC Musculoskelet Disord* 2013;**14**:77. doi:10.1186/1471-2474-14-77.
19. Dorsey KB, Thornton JC, Heymsfield SB, Gallagher D. Greater lean tissue and skeletal muscle mass are associated with higher bone mineral content in children. *Nutr Metab (Lond)* 2010;**7**:41. doi:10.1186/1743-7075-7-41.
20. Rauch F, Bailey DA, Baxter-Jones A, Mirwald R, Faulkner R. The "muscle-bone unit" during the pubertal growth spurt. *Bone* 2004;**34**:771–5.
21. Koedijk JB, van Rijswijk J, Oranje WA, et al. Sedentary behaviour and bone health in children, adolescents and young adults: A systematic review. *Osteoporos Int* 2017;**28**:2507–19.
22. Tosi M, Maslyanskaya S, Dodson NA, Coupey SM. The female athlete triad: a comparison of knowledge and risk in adolescent and young adult figure skaters, dancers, and runners. *J Pediatr Adolesc Gynecol* 2019;**32**:165–9.
23. The American College of Radiology. *Practice parameters by modality*. Available at: https://www.acr.org/Clinical-Resources/Practice-Parameters-and-Technical-Standards/Practice-Parameters-by-Modality. [accessed 07.07.2020].
24. Sushames A, Edwards A, Thompson F, McDermott R, Gebel K. Validity and reliability of fitbit flex for step count, moderate to vigorous physical activity and activity energy expenditure. *PLoS One* 2016;**11**:e0161224. doi:10.1371/journal.pone.0161224.
25. Fitbit Inc. *How does my fitbit device count steps taken?* Available at: https://help.fitbit.com/articles/en_US/Help_article/1141#steps. [accessed 08.05.2020].
26. Dent E, Morley JE, Cruz-Jentoft AJ, et al. International clinical practice guidelines for sarcopenia (ICFSR): screening, diagnosis and management. *J Nutr Health Aging* 2018;**22**:1148–61.
27. Mayhew AJ, Amog K, Phillips S, et al. The prevalence of sarcopenia in community-dwelling older adults, an exploration of differences between studies and within definitions: A systematic review and meta-analyses. *Age Ageing* 2019;**48**:48–56.
28. Okorodudu DO, Jumean MF, Montori VM, et al. Diagnostic performance of body mass index to identify obesity as defined by body adiposity: A systematic review and meta-analysis. *Int J Obes (Lond)* 2010;**34**:791–9.
29. American College of Sports Medicine. *ACSM's guidelines for exercise testing and prescription*. 8th ed. Philadelphia, PA: Wolters Kluwer/Lippincott Williams & Wilkins Health; 2010.
30. Fan B, Shepherd JA, Levine MA, et al. National health and nutrition examination survey whole-body dual-energy X-ray absorptiometry reference data for GE Lunar systems. *J Clin Densitom* 2014;**17**:344–77.
31. Kelly TL, Wilson KE, Heymsfield SB. Dual energy X-Ray absorptiometry body composition reference values from NHANES. *PLoS One* 2009;**4**:e7038. doi:10.1371/journal.pone.0007038.
32. Imboden MT, Swartz AM, Finch HW, Harber MP, Kaminsky LA. Reference standards for lean mass measures using GE dual energy x-ray absorptiometry in Caucasian adults. *PLoS One* 2017;**12**:e0176161. doi:10.1371/journal.pone.0176161.
33. Young DR, Hivert MF, Alhassan S, et al. Sedentary behavior and cardiovascular morbidity and mortality: A science advisory from the American Heart Association. *Circulation* 2016;**134**:e262–79.
34. 2018 Physical Activity Guidelines Advisory Committee. *2018 Physical Activity Guidelines Advisory Committee Scientific Report*. Washington, DC; U.S. Department of Health and Human Services. Available at: https://health.gov/sites/default/files/2019-09/PAG_Advisory_Committee_Report.pdf. [accessed 07.07.2020].
35. Kari T, Karhulahti V. Do E-Athletes Move? *Int J Gaming Comput Mediat Simul* 2016;**8**:53–66.
36. Rudolf K, Bickmann P, Froböse I, Tholl C, Wechsler K, Grieben C. Demographics and health behavior of video game and eSports players in Germany: The eSports study 2019. *Int J Environ Res Public Health* 2020;**17**:1870. doi:10.3390/ijerph17061870.
37. Lees MJ, Wilson OJ, Hind K, Ispoglou T. Muscle quality as a complementary prognostic tool in conjunction with sarcopenia assessment in younger and older individuals. *Eur J Appl Physiol* 2019;**119**:1171–81.
38. Henriksson H, Henriksson P, Tynelius P, Ortega FB. Muscular weakness in adolescence is associated with disability 30 years later: A population-based cohort study of 1.2 million men. *Br J Sports Med* 2019;**53**:1221–30.