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ASSESSMENT

Comparison of Assessment Methods for Muscular Power in Physical Education

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Abstract

In the process of educating physically literate individuals, physical educators are tasked with assessing health-related fitness of their students. It is essential to identify or develop appropriate field tests of muscular power for use in physical education settings. This study assessed jumping power in a sample of fourth, sixth, and eighth graders via a novel calculation method and compared different field tests and calculations for assessing muscular power. Participants (n = 99), aged 9 to 14 years, were recruited from fourth-, sixth-, and eighth-grade physical education classes in one K–8 school. Three jump measurements were taken within the context of a physical education class: vertical jump (VJ) via a Vertec device, countermovement jump (CMJ) based on flight time via MyJump iOS app, and standing long jump. Vertical jump scores assessed via the Vertec device were significantly greater than those for the CMJ. The mean power for participants in this study was 873 W for a CMJ and 1544 W for a VJ. Standing long jump only had a moderate correlation with power calculated from a CMJ (r = .41). Results confirmed that calculations of power that factor in VJ and body weight provide a better indication of power than does jump performance alone. The equation used to calculate jumping power offers a novel approach for physical education that is accurate and feasible.

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In the process of educating physically literate individuals, physical educators are tasked with assessing health-related fitness of their students (Corbin et al., 2014). Since the 1960s, cardiorespiratory endurance, strength, muscular endurance, flexibility, and body composition have been classified as health-related fitness components (Corbin, Dowell, & Landiss, 1968) and these fitness components are currently included in the FitnessGram test battery (Meredith & Welk, 2010). However, recently there have been calls to include power in the group of health-related fitness components (Corbin, Janz, & Baptista, 2017; Corbin et al., 2014). Power is the ability to exert strength explosively or with speed and is typically classified as a skill-related fitness component. Whereas health-related fitness components are strongly associated with positive health outcomes, the components of skill-related fitness (agility, balance, power, speed, coordination, and reaction time) are more closely associated with athletic performance and are considered to be only loosely associated with health. Research has shown that power is associated with greater bone mineral density and bone health (Baptista, Mil-Homens, Carita, Janz, & Sardinha, 2016; Janz, Letuchy, Burns, Francis, & Levy, 2015; Weaver et al., 2016). As well, a report by the Institute of Medicine (IOM, 2012) concluded that there is adequate experimental and prospective longitudinal evidence to support the relationship between health and a multidimensional construct of musculoskeletal fitness that includes power.

As such, it is essential to identify or develop appropriate field tests of muscular power for use in physical education settings. Indeed, regarding tests of musculoskeletal fitness, the IOM (2012) concluded, "Current literature in this area is too fragmented to permit identification of any specific musculoskeletal fitness test item that is unequivocally linked to health in the general population of healthy youth" (p. 176). The most commonly used tests of power in physical education settings are the vertical jump (VJ) and the standing long jump, with the latter being included in the ALPHA-Fitness assessment (Ruiz et al., 2010) used in Europe. Both of these tests require minimal equipment and involve the explosive propulsion of the body through the lower body musculature. However, these jumping tests have critical flaws that limit their utility in assessing muscular power. For the standing long jump, motor skill proficiency plays a significant role, as takeoff angles, arm swing, and leg positioning during flight affect jumping performance (Corbin et al., 2017). Landing safely on a maximum effort jump can also be problematic for students with heavier body weight, posing a risk for joint pain or injury. For both tests, an outcome measure of jumping height or distance fails to account for the effect of body weight on performance.

The mathematical expression of power is (Force × Distance) / Time. In a jumping motion, the distance and time over which force are applied occur when force is exerted against the ground when the individual extends their hips, knees, and ankles. The distance is the vertical change of distance of the center of mass from the bottom of the preparatory crouch to the moment of maximum extension prior to takeoff (push-off distance).The time is the duration of that phase of the movement. The force in the equation is the force exerted by the musculature to overcome gravity and propel the body into the air. The greater the body mass, the greater the force required to overcome gravity. Therefore, a student who weighs more is going to have to exert more power to move their body weight the same distance as a student who weighs comparably less.

Research has demonstrated that power can be accurately and reliably predicted from VJ when both the individual's body mass and the push-off distance during the jump are accounted for (see Figure 1; Jiménez-Reyes et al., 2017; Samozino, Morin, Hintzy, & Belli, 2008). Push-off distance is the vertical displacement of the jumper's center of mass during the jumping motion while the feet are still on the ground. Measuring push-off distance requires two measurements: the distance from the ground to the greater trochanter of the femur at the bottom of the preparatory crouch, and the distance between the same two points at takeoff, with the difference between these two measurements being the push-off distance. The former distance can be measured by having the individual assume and hold the preparatory crouch position and measuring the distance from the greater trochanter to the ground. The latter can be measured by having the individual lay on the ground with hips, knees, and ankles extended and measuring the distance from the greater trochanter to the tip of the toes.

In a physical education setting, accurately measuring push-off distance could prove problematic. The overall procedure is time consuming, which is a valid consideration for any field test designed to be administered in a physical education class. Also, the accuracy with which school-age children will be able to assume and hold the bottom of the preparatory crouch position is likely to be highly variable. However, push-off distance is likely largely a function of overall height. It may be that a fraction of overall height could be substituted into the power calculation, rather than a measurement of push-off distance. Therefore, this study compared different field tests and calculations for assessing muscular power; assessed jumping power in a sample of fourth, sixth, and eighth graders using the aforementioned method; and specifically tested if substituting a percentage of overall body height for push-off distance in a calculation of power yields accurate and reliable results.

Method

Participants (n = 99), aged 9 to 14 years, were recruited from fourth-, sixth-, and eighth-grade physical education classes in one K–8 school. Because of an uneven response rate from different grade levels (fourth grade, n = 40; sixth grade, n = 12; eighth grade, n = 47), analyses were only performed on the complete sample and not by grade level. Table 1 shows descriptive statistics for the sample. Parental consent forms were sent home with students. The research study was then explained to students with signed and returned parental consent forms, and they were asked to sign an assent form if they agreed to participate in the study. These procedures were approved by the university institutional review board and the school district research review board. Four body measurements were obtained from participants. Body weight was measured via a standard scale and height via a stadiometer. Leg length, measured from the hip to the tip of the toe, and floor-to-hip height, measured with the student standing in a prejump crouch position, were also assessed.

Table 1
Sample Descriptives and Jumping Performance Measures

Descriptive	Overall ($M \pm SD$)	Female (n = 45) ($M \pm SD$)	Male (n = 54) ($M \pm SD$)
Age (years)	11.88 ± 1.91	11.44 ± 1.82	12.24 ± 1.92
Height (m)	1.58 ± 0.14	1.54 ± 0.13	1.60 ± 0.14
Weight (kg)	49.61 ± 17.57	47.74 ± 18.19	51.17 ± 17.04
VJ: Vertec (m)	0.36 ± 0.09	0.33 ± 0.06	0.39 ± 0.10
VJ: Flight time CMJ (m)	0.22 ± 0.06	0.20 ± 0.05	0.23 ± 0.06
Long jump (m)	1.60 ± 0.49	1.42 ± 0.46	1.76 ± 0.46

Note. VJ = vertical jump; CMJ = countermovement jump.

Three jump measurements were taken within the context of a physical education class. For the flight time–based VJ calculation, participants were video recorded from the waist down while performing a countermovement jump (CMJ) with hands on the hips using the MyJump iOS application. Research has shown this app to provide valid and reliable results for assessing VJ (Balsalobre-Fernández, Glaister, & Lockey, 2015; Gallardo-Fuentes et al., 2016). Three jumps were recorded for each participant. The app then calculates the participant's VJ based on flight time by marking on the video the points of takeoff and landing and also calculates power using the formula shown in Figure 1.

$$\bar{P} = mg\left(\frac{h}{h_{\mathrm{PO}}} + 1\right)\sqrt{\frac{gh}{2}}$$

where
$\bar{P}$ = mean vertical power (in W),
m = body mass (in kg),
g = gravitational acceleration (9.81 m s^{-2}),
h = jump height corresponding to the vertical distance covered by the body center of mass during aerial phase (in m), and
h_{PO} = vertical push-off distance (in m).

Figure 1. Formula utilized to calculate power (Samozino et al., 2008).

VJ was also assessed via a Vertec device. Standing reach was established and then the device was positioned to allow the participant to contact the highest vane possible. A standing 2-ft takeoff VJ with free arm swing was utilized. Three attempts were measured, with the highest recorded.

Standing long jump was measured via standard testing procedures. The participant stood behind a line marked on the ground. A 2-ft takeoff and landing was used, with swinging of the arms and bending of the knees to provide drive. The participant attempted to jump as far as possible, landing on both feet. Three attempts were assessed, with the farthest recorded. The measurement was taken from takeoff line to the nearest point of contact on the landing.

Results

Table 1 shows the descriptive statistics for the sample, including means and standard deviations for the three jumping measures. A paired-samples t test compared the two methods of VJ assessment. Vertec-assessed VJ scores were significantly greater that flight time–assessed CMJ scores, $t(88) = 20.85$, $p < .001$, $d = 2.09$.

To test if a fraction of overall height could be substituted for the measured push-off distance, a height fraction was calculated by dividing the mean measured push-off distance by the mean overall height of the sample (0.273 m / 1.579 m = 0.173). The estimated push-off distance was then calculated by multiplying each participant's height by the height fraction. A paired-samples t test tested if the estimated push-off distance was significantly different from the measured push-off distance. These two values were not significantly different from each other, $t(98) = -0.13$, $p > .05$.

A 2 × 2 (VJ Method × Push-Off Assessment) repeated-measures ANOVA compared the four methods of power calculation (CMJ + Measured Push-Off, Vertec + Measured Push-Off, CMJ + Estimated Push-Off, Vertec + Estimated Push-Off). Table 2 shows the means and standard deviations. There was a significant main effect for VJ method, Wilks's Lambda = .330, $F(1, 88) = 178.75$, $p < .001$, multivariate partial $\eta^2 = .67$, such that the power estimates based on CMJ were significantly lower than power estimates based on Vertec measurement. The main effect for push-off assessment method (measured vs. estimated) and the interaction effect were not significant.

Table 2

Estimates of Power (W) From Vertical Jump

	Overall		Female		Male	
Jump	***M***	**± *SD***	***M***	**± *SD***	***M***	**± *SD***
Flight time–assessed CMJ						
Measured push-off distance	873.56	± 328.66	785.23	± 215.13	1003.89	± 408.46
Estimated push-off distance	850.98	± 315.38	787.24	± 246.87	973.16	± 407.29
Vertec-assessed VJ						
Measured push-off distance	1544.20	± 722.88	1331.90	± 612.68	1743.42	± 752.04
Estimated push-off distance	1500.95	± 697.23	1336.68	± 634.39	1633.10	± 709.16

Note. CMJ = countermovement jump; VJ = vertical jump.

To compare different methods of estimating power, differences between correlation coefficients were tested using the Williams-Hotelling test (Williams, 1959). For these tests, power calculated from CMJ with a measured push-off distance was the standard from which other measures were correlated. In adults, this power calculation has a correlation of $r = .98$ with force platform–assessed power (Samozino et al., 2008). Table 3 shows correlations of all jumping measures and power calculations. To test if VJ provided a better measure of power than standing long jump, the correlations of those two variables with the power calculation based on the CMJ with measured push-off were compared. VJ correlated better with the power calculation than standing long jump did, $t(86) = 2.178$, $p < .05$. To test if the calculation of power using the estimated push-off distance provided a favorable measurement compared to VJ alone, the correlations of those two variables with the power calculation based on the CMJ with measured push-off were compared. The correlation of the power calculation using the estimated push-off distance ($r = 0.77$) was greater than that of VJ alone ($r = 0.60$), $t(86) = 3.59$, $p = .001$.

Table 3

Correlations Among Jumping Measurements and Power Calculations

	Jumping measurements and power calculations	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1	Vertec-assessed VJ	1						
2	Flight time–assessed CMJ	.60	1					
3	Long jump	.51	.39	1				
4	Power: CMJ + Measured PO	.60	.63	.41	1			
5	Power: CMJ + Estimated PO	.68	.68	.41	.94	1		
6	Power: Vertec + Measured PO	.69	.23	.39	.84	.79	1	
7	Power: Vertec + Estimated PO	.77	.27	.40	.77	.85	.93	1

Note. VJ = vertical jump; CMJ = countermovement jump; PO = push-off. All correlations are significant at the 0.05 level (2-tailed).

Discussion

This study assessed 9- to 14-year-olds' jumping performance, compared some methods of estimating muscular power from jumping performance, and examined if simplifying one of the measurements for calculating power yielded accurate results. The mean power for participants in this study was 873 W for a CMJ and 1544 W for a Vertec-measured VJ. Only a few other studies have assessed jumping power in similar-aged samples, all using a CMJ with no arm swing. Baptista et al. (2016) found a mean jumping power in a sample of 7- to 9-year-olds (M_{age} = 8.5 years) of 817 W for boys and 702 W for girls. These power values were estimated from jump height and body weight via a regression-based estimation equation. Duncan, Hankey, and Nevill (2013) found a mean jumping power of 2452 W in a sample of 12- to 16-year-olds (M_{age} = 14.3 years), and Gomez-Bruton et al. (2017) found a mean jumping power of 2136 W in a sample of 9- to -17-year-olds (M_{age} = 13.6 years), with both studies assessing power with a force platform. Both the age group and power assessments found in the present study fall in the middle of these values (greater power than younger sample, less power than older samples), supporting the validity of the findings. Across studies, there is a large increase in power in the two older samples relative to the two younger ones. More research is needed to more precisely describe how muscular power changes with age.

Calculations of VJ and power assessed by Vertec were higher than those assessed by CMJ. This runs counter to other research that found Vertec assessment underreports VJ compared to CMJ (Buckthorpe, Morris, & Folland, 2012; Leard et al., 2007). However, some research suggests that the presence of a vertical target can improve jump performance (Ford, Myer, Smith, & Byrnes, 2005). For the younger population used in this study, the visual target of the Vertec vanes may be highly salient, especially when compared to the relatively foreign movement of jumping as high as possible with one's hands on the hips. It should be noted that in this study the estimates of power based on these jumping measures were highly correlated (r = .84–.85). Given the high correlation, either method could be used in a fitness test battery; however, different health-referenced criteria standards would need to be established for each. Assessing

CMJ height requires technology to determine flight time; therefore, traditional VJ assessment may be more viable for physical education.

Standing long jump only had a moderate correlation with power calculated from a CMJ ($r = .41$), indicating that VJ and standing long jump are evaluating power differently. Future research should compare how these measures correlate with health-related measures, such as bone mineral density, to determine which is more relevant to be included in a health-related fitness battery.

The results confirm that calculations of power that factor in VJ and body weight provide a better indication of power than does VJ performance alone. This result is not surprising, given that a person's body weight provides the resistance during a jumping task. However, if the goal of fitness testing in physical education is to provide students with accurate feedback regarding how their fitness relates to their health, it is essential to use a measure of power that accounts for body weight. The use of raw jumping scores could give lighter students false positive feedback and heavier students false negative feedback.

While the Samozino et al. (2008) power calculation has been shown to be highly accurate, the process of measuring students' leg length and crouching floor-to-hip height to determine push-off distance may make this assessment less feasible in a physical education setting. As such, most of the other estimation equations proposed in the research literature only utilize jump height and body weight (for a summary, see Gomez-Bruton et al., 2017). In this sample, estimating push-off distance as a fraction of overall height yielded highly accurate results. As students age, their body proportions change. Therefore, future research will need to determine if different fractions of overall height based on age, as well as on sex, are more accurate. Because of the relatively small sample size in this study, no attempts were made to calculate these finer delineations. Once these height fractions are known, they could be included in the power calculation equation, and the only values that would need to be input by the physical education teacher would be the student's height, weight, and jumping score.

It is important to note that the power calculation method developed by Samozino et al. (2008) that was used in this study differs conceptually from the regression-based power estimation calculations developed in other research (Duncan et al., 2013; Gomez-Bruton et al., 2017). Regression-based equations attempt to predict the variable of interest (power) from other measured variables, usually body weight and jump height, by regressing these variables on an assessed measurement of the outcome, most often power assessed via a force platform. The estimation equation mathematically manipulates the measured variables to try to estimate the outcome variable and, in the case of power estimations, typically results in some form of systematic bias (Gomez-Bruton et al., 2017). Essentially, the process involves working backward to try to predict a specific outcome. In contrast, this study used an equation derived from an analysis of the mechanical principles involved in jumping (e.g., work, force, gravitational acceleration) to arrive at a calculation of power. Since it was derived from physical laws, rather than being an abstract estimation, it is less likely to be subject to the biases seen in the prediction equations. Research has confirmed that this method is valid and reliable for calculating power and force-velocity profiles for squat and CMJ (Jiménez-Reyes et al., 2017).

There are limitations to this research study. The criterion measure of power calculated from CMJ has been shown to be highly accurate in adults compared to force platform measurements; however, this has not yet been evaluated in youth. While the physics underlying the calculation would not be different in children, it is possible that children’s jumping form has more variability, leading to a less accurate estimation. Future research should validate the equation used to calculate power in children and could also use force platform–assessed power as a criterion measure. This study also utilized a convenience sample of mostly fourth and eighth graders. Future research should examine these jumping power calculations in other age groups and in diverse populations.

In conclusion, this research adds to the body of literature on youth jumping power by documenting the muscular power of children aged 9 to 14 years by showing differences in jumping power via different jumping methods and by implementing a novel power calculation equation in a youth sample. The results support the use and feasibility of the Samozino et al. (2008) power calculation method in physical education settings. More research needs to further validate this method with other age groups and diverse samples and to establish relationships of muscular power with bone health for purposes of developing health-referenced criterion fitness test items.

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