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A novel validation approach shows new, solid reasons why vertical jump height should not be used to predict leg power*

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A novel validation approach shows new, solid reasons why vertical jump height should not be used to predict leg power

Un novedoso enfoque de validación añade sólidas razones para no utilizar la altura del salto vertical como predictor de la potencia de piernas

Uma nova abordagem de validação acrescenta fortes razões para não usar a altura do salto vertical como um indicador de potência das pernas.

Luis Fernando Aragón-Vargas [1]
María Isabel González-Lutz [2]

Abstract: Jump height continues to be widely used to predict power in humans. Individual progress is often monitored on the basis of estimated power, but prediction equations are based on group data. The objective of the study was to show that vertical jump performance (VJP) and mechanical power are poorly associated, particularly within individuals. Two experiments are presented. First, 52 physically active male college students performed five maximal vertical jumps each. Second, three young male participants performed 50 maximal jumps each. Participants rested for 1 minute between jumps. VJP was calculated from kinematic data as peak body center of mass (BCOM) minus standing BCOM; peak power (PEAKPWR) was calculated from the vertical ground reaction force registered by a force plate, and average power (MEANPWR) during propulsion from the change in potential energy of BCOM. Regression analyses were performed using standardized VJP scores as the predictor variable and standardized power scores as the resulting variables, expecting an identity function of $y = x$ (intercept = 0, slope = 1) and $R^2 = 1$. In experiment 1, the model for zPEAKPWR $R^2 = 0.9707$ ($p < 0.0001$) but slope (0.3452) $\neq 1$ ($p < 0.0001$). The model for zMEANPWR $R^2 = 0.9239$ ($p < 0.0001$); nevertheless, slope (0.4257) $\neq 1$ ($p < 0.0001$). In experiment 2, all individual models for zPEAKPWR and zMEANPWR resulted in poor associations ($R^2 \leq 0.21$) and slopes $\neq 1$ ($p \leq 0.001$). In conclusion, regression analysis for individuals, and even for groups, confirms that VJP is a poor predictor of mechanical power.

Key words: kinematics, biomechanical phenomena, biomechanics, sports, lower limbs, validation, within-subject analysis.

Resumen: La altura del salto se sigue usando ampliamente para predecir la potencia en seres humanos. El progreso individual, a menudo, se monitorea usando una estimación de la potencia, pero las ecuaciones de predicción se basan en datos grupales. El estudio pretende demostrar que la altura del salto vertical (ASV) y la potencia mecánica tienen una pobre correlación, particularmente en un mismo individuo. Se presentan dos experimentos; primero, 52 estudiantes

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universitarios físicamente activos ejecutaron cinco saltos verticales máximos cada uno; segundo, tres participantes masculinos ejecutaron 50 saltos máximos cada uno. Los participantes descansaron 1 minuto entre saltos. ASV se calculó a partir de los datos cinemáticos como posición más alta del centro de masa corporal (CDM) menos CDM de pie; la potencia pico (PEAKPWR) se calculó a partir de la fuerza vertical de reacción registrada por una plataforma de fuerza y la potencia promedio (MEANPWR) durante la propulsión a partir del cambio en la energía potencial del CDM. Se realizaron análisis de regresión usando puntajes estandarizados de ASV como la variable predictora y puntajes estandarizados de potencia como las variables resultantes, con la expectativa de obtener una función de identidad y = x (intercepto = 0, pendiente = 1) y $R^2 = 1$. En el experimento 1, el modelo para zPEAKPWR arrojó $R^2 = 0.9707$ ($p < .0001$) pero la pendiente (0.3452) ≠ 1 ($p = 8.7 \times 10^{-15}$). El modelo para zMEANPWR dio $R^2 = 0.9239$ ($p < .0001$); sin embargo, la pendiente (0.4257) ≠ 1 ($p = 1.15 \times 10^{-5}$). En el experimento 2, todos los modelos individuales para zPEAKPWR y zMEANPWR arrojaron asociaciones débiles ($R^2 \leq 0.21$) y pendientes ≠ 1 ($p \leq .001$). En conclusión, el análisis de regresión para individuos y aún para grupos confirma que la ASV es un pobre predictor de la potencia mecánica.

Palabras clave: cinemática, fenómenos biomecánicos, biomecánica, deporte, tren inferior, validación, análisis intra-sujeto.

Resumo: A altura do salto ainda é amplamente usada para prever a potência em humanos. O progresso individual é frequentemente monitorado usando a estimativa de potência, mas as equações de previsão são baseadas em dados de grupo. O objetivo do estudo é demonstrar que a altura do salto vertical (ASV) e a potência mecânica têm uma correlação débil, principalmente em um mesmo indivíduo. São apresentados dois experimentos: primeiro, 52 estudantes universitários fisicamente ativos realizaram cinco saltos verticais máximos cada um; segundo, três participantes do sexo masculino realizaram 50 saltos máximos cada um. Os participantes descansaram por 1 minuto entre os saltos. A ASV foi calculada a partir de dados cinemáticos como a posição mais alta do centro de massa corporal (CMC) menos o CMC em pé; a potência de pico (PEAKPWR) foi calculada a partir da força de reação vertical registrada por uma plataforma de força e a potência média (MEANPWR) durante a propulsão a partir da mudança na energia potencial do CMC. As análises de regressão foram realizadas usando os escores da ASV padronizados como variável preditora e os escores de potência padronizados como variáveis de resultado, com a expectativa de obter uma função de identidade y = x (interceptação = 0, inclinação = 1) e $R^2 = 1$. No experimento 1, o modelo para zPEAKPWR produziu $R^2 = 0,9707$ ($p < 0,0001$), mas a inclinação (0,3452) ≠ 1 ($p = 8,7 \times 10^{-15}$). O modelo para zMEANPWR apresentou $R^2 = 0,9239$ ($p < 0,0001$); no entanto, a inclinação (0,4257) ≠ 1 ($p = 1,15 \times 10^{-5}$). No experimento 2, todos os modelos individuais para zPEAKPWR e zMEANPWR apresentaram associações débeis ($R^2 \leq 0,21$) e inclinações ≠ 1($p \leq 0,001$). Em conclusão, a análise de regressão para indivíduos e até mesmo para grupos confirma que a ASV é um indicador débil da potência mecânica.

Palavras-chave: cinemática, fenômenos biomecânicos, biomecânica, esporte, parte inferior do corpo, validação, análise intrassujeito.

1. Introduction

Human power testing has fascinated exercise scientists for decades. Mechanical power is an important factor in sports performance, but its measurement requires sophisticated and expensive equipment. The gold-standard power test commonly used in the laboratory uses a cycle ergometer: the Wingate test (Bar-Or, 1987), although better cycling power tests have been devised, particularly for peak power (Del Coso & Mora-Rodríguez, 2006). Cycling tests are often criticized because they don't resemble sports involving running or jumping; hence the desirability of measuring power during a vertical jump. Nevertheless, the latter also requires expensive, sophisticated laboratory equipment, such as force platforms or motion capture systems. Testing for vertical jump height or vertical jump performance (VJP), on the other hand, is practical, reliable, and precise (Aragón-Vargas, 2000). The vertical jump is a simple, clearly defined task with one clear, objective result: the height of the jump, synonymous with vertical jump performance. Furthermore, VJP has been widely used to predict power in humans (Harman et al., 1991; Kirkendall et al.,1987; Morin et al., 2019; Samozino et al., 2008). Despite the apparent logic of a strong association between mechanical power of the lower limbs and vertical jump height, there are important limitations involved in the calculation and prediction of the former from the latter.

Initial attempts incurred a basic mistake: using the flight time of the vertical jump in the mathematical calculation of power. This has been called "the Lewis formula" and has been shown to calculate the power of the falling jumper (Harman et al., 1991), a useless value (more on this common error below). The association between VJP and mechanical power is not a simple mathematical function. Vertical jump height depends mostly on the vertical take-off velocity of the body center of mass (BCOM), but also on the position of BCOM at the instant of take-off (Aragón-Vargas & Gross MM, 1997a, 1997b). Even if researchers focus on take-off velocity alone, this velocity is a function of the mechanical work performed during push-off, not of the mechanical power. The measurement of that additional variable necessary for the calculation of power, namely, time of propulsion or push-off, requires laboratory-grade equipment and cannot be calculated from VJP.

Bosco et al. (1983) proposed a mathematical function intended to calculate average mechanical power from a series of vertical jumps on a simpler timing device. This jumping ergometer method is also widely used, but Herbert Hatze (1998) carefully showed that because of a series of invalid assumptions used in deriving the formulae, together with an average error of about 5% associated with a 4.48% standard deviation, this method cannot be considered reliable or valid for evaluating serial rebound jumps.

An alternative strategy is to use regression equations; these are widely used in exercise science (Canavan & Vescovi, 2004; Lara-Sánchez et al., 2011; Sayers et al., 1999), although their validity has been questioned by the following authors: a descriptive study (Tessier et al., 2013) showed that even for their own carefully developed equation (R^2 = 0.94) using highly trained athletes, the minimal difference in estimated power necessary to consider that two individuals were different, was too large (689.3 W). They concluded that the height of the jump should not be used to accurately predict the actual mechanical power of an individual. Most recently, Morin et al. (2019) published a solid critique of the use of VJP in the prediction of mechanical power, demonstrating that individual body mass, push-off distance, optimal loading, and the force-velocity profile are important variables that confound the relationship between jump height and power; they proceeded to propose a different testing method and calculations that look promising, but further evaluation is necessary.

Meanwhile, better regression equations continue to be based on jump height as the main predictor; there is a need for a stricter evaluation of the validity of using VJP for this purpose. In a conventional regression approach, the strength of the association is evaluated for larger or smaller groups of participants using the coefficient of determination, that is, what proportion of the variation in the dependent variable can be explained by the predictor variable(s). But even if high coefficients of determination (R^2) were found, they would only show a group effect, not a within-subject effect. In other words, most regression equations for mechanical power are based on group data (Canavan & Vescovi, 2004; Hatze, 1998; Lara-Sánchez et al., 2011); however, their results are used to predict individual performance and monitor individual progress. The issue was hinted at by Tessier et al. (2013), who ran a preliminary analysis on four jumps by the same participant but did not probe deeper into it. The key question is: how good is the association between vertical jump performance and mechanical power at the individual level? This should be addressed by having a few individuals perform multiple maximal vertical jumps.

Therefore, the purpose of the present study was to use two existing vertical jump databases to confirm the validity of using vertical jump performance as a predictor of mechanical power for individuals and to propose a new methodology for evaluating performance prediction models in exercise science.

2. Methods

This study used two datasets from previous experiments, originally designed to investigate the kinesiological factors that distinguish good jumpers from poor jumpers (Aragón-Vargas & Gross MM, 1997a), and to understand what a jumper does differently from one jump to another resulting in different jump heights, even when instructed to always jump as high as possible (Aragón-Vargas & Gross, 1997b). Informed consent was obtained for all participants, in accordance with the protocol approved on September 21, 1993, by the Human Subjects Review Board, School of Education, The University of Michigan. For experiment 1, 52 physically active male college students performed five maximal vertical jumps each, starting from the position of their choice, with their hands on their hips. All jumps involved a countermovement. Participants completed three practice jumps before data collection and were required to wait for 1 min after each trial. They performed the jumps barefooted, wearing only a swimsuit or pair of shorts.

For experiment 2, three young males performed 50 maximal jumps each on the force platform; they were required to sit and rest for 1 minute after each jump. These were the worst, average, and best jumpers (according to their VJP) in a larger, separate study with ten subjects looking at VJP differences within individuals (Aragón-Vargas & Gross, 1997b).

Both experiments were performed using the same equipment: ground reaction forces and moments of force were collected with a Bertec force plate (Model 4060A), sampled at 300 Hz. A video-based real-time, three-dimensional motion analysis system (Motion Analysis Corp.) was used to collect and process kinematic data at 60 Hz; these data were filtered with a low-pass, fourth-order Butterworth filter with an effective cutoff frequency of 8Hz. The biomechanical model used, marker placement, and all analytic procedures have been described in detail elsewhere (Aragón-Vargas & Gross, 1997a). Briefly, because the major motion during a vertical jump as described here occurs in the sagittal plane, the human body was modeled as a planar (2-D), rigid-body system comprising four segments linked by frictionless, hinge joints: one single segment each representing both feet, both shanks, and both thighs; the head, arms, and trunk treated as a fourth segment. This model assumed that the task was performed symmetrically by the right and left extremities. It also assumed that during a vertical jump with hands on the hips, the head, arms, and trunk (HAT) behave as a single segment.

Vertical Jump Performance (VJP) was calculated for each jump from the kinematic data (see Eq. 1), using the 2-D model, where $BCOM_{peak}$ is the position of the body center of mass at the highest point during the flight, and $BCOM_{standing}$ is the position of the body center of mass with the participants standing still:

$$\text{Eq. 1} \qquad VJP = BCOM_{peak} - BCOM_{standing}$$

Mechanical Power was calculated for the same jumps from the vertical ground reaction force and from the change in potential energy of the whole body. Mean power (MEANPWR, or $\bar{\dot{W}}$ in the equation) during propulsion was derived from the change in potential energy of the whole body, according to Eq. 2, where m is the body mass for each individual in Kg, g = 9.81 $m{\cdot}s^{-2}$, $Z_{takeoff}BCOM$ is the vertical coordinate of the body center of mass at the instant of takeoff, $Z_{low}BCOM$ is the vertical coordinate of BCOM at the lowest point during push-off, and t_{prop} is the time of push-off in seconds (Aragón-Vargas & Gross, 1997a):

$$\text{Eq. 2} \qquad \bar{\dot{W}} = mg(z_{takeoff}BCOM - z_{low}BCOM)/t_{prop}$$

PEAKPWR was obtained from the instantaneous mechanical power of the whole body ($\dot{W}$), calculated according to Eq. 3, where Fz is the vertical ground reaction force and $\dot{z}BCOM$ is the vertical component of the instantaneous velocity of the body center of mass (Aragón-Vargas & Gross, 1997a):

$$\text{Eq. 3} \qquad \dot{W} = F_z \times \dot{z}BCOM$$

Experiment 1 involved a traditional approach with 52 participants and 5 trials each. Data were analyzed using standardized (z) results, which allow for the comparison of variables that use different units of measurement but theoretically should give identical results; data were standardized to the group average. Each model included participants and trials as random effects. One model was used to predict zPEAKPWR, and another model to predict zMEANPWR, using zVJP as the major predictor. According to the validation objective, an identity function of y = x (intercept = 0, slope = 1) and $R^2 = 1$ were expected for a model zVARIABLE = k + s (zVJP) + participant + trial + Error.

An individualized approach with 3 participants and 50 trials each was used for experiment 2. A single model was attempted first, including all three participants and their trials. Afterward, individual models were fitted standardizing the variables using the 50-jump average for each individual. Regression analyses used standardized VJP scores (zVJP) as the predictor variable and standardized peak power (zPEAKPWR) or mean power (zMEANPWR) scores as the resulting variable, expecting an identity function of y = x (intercept = 0, slope = 1) and $R^2 = 1$ for model zVARIABLE = k + s (zVJP) + participant + Error. All regression models were tested using JMP Pro v.15.1.0 (SAS Institute, Inc.).

The 52 males in experiment 1 had the following characteristics: age = 20.2 ± 2.1 y.o. (mean ± s.d.), height = 1.79 ± 0.06 m, and weight = 74.3 ± 8.6 kg. Vertical jump = 506 ± 70 mm (range: 372 to 663 mm). Their peak power was 3863.2 ± 687.7 W. The three participants from experiment 2 were very similar in body weight: 70.9, 71.1, and 65.5 kg for the worst, average, and best jumpers, respectively. They had a VJP (mean ± s.d.) of 301±9, 439±17, and 586±14 mm, respectively; corresponding peak powers were 2079.3±56.6, 3706.0±136.1, and 4085.0±74.2 W, respectively.

3. Results

The first set of analyses (figure 1) corresponds to experiment 1 (Aragón-Vargas & González-Lutz, 2023a). Figure 1a shows the adjusted line for zPEAKPWR as predicted by zVJP, according to model zPEAKPWR = k + s(zVJP) + participant + trial + Error. The association is strong: $R^2 = 0.9707$ ($p < 0.0001$) and the intercept (-0.0027) is not different from 0 ($p = 0.8238$). Nevertheless, the slope (0.3452) is significantly different from 1 ($p = 8.7 \times 10^{-15}$). Figure 1b shows the adjusted line for zMEANPWR as predicted by zVJP, according to model zMEANPWR = k + s(zVJP) + participant + trial + Error. The association shows a strong $R^2 = 0.9239$ ($p < 0.0001$) and the intercept (0.0243) is not different from 0 ($p = 0.2343$). Nevertheless, the slope (0.4257) is significantly different from 1 ($p = 1.15 \times 10^{-5}$).

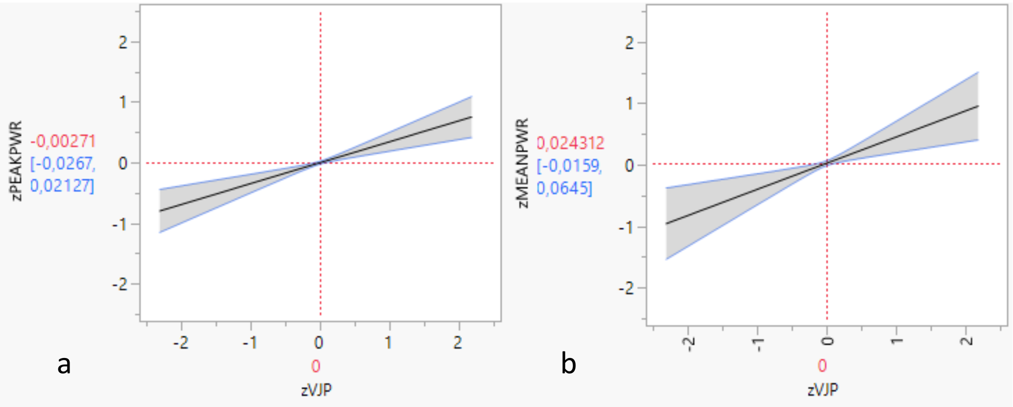

Figure 1. Prediction of normalized power from normalized vertical jump performance. Experiment 1, between-subjects design, participants and trials as random effects. Participants = 52; trials = 5. (a): Peak mechanical power. Total valid data points = 256; $R^2 = 0.9707$; Intercept = -0.0027; Slope = 0.3452. (b): Mean mechanical power. Total valid data points = 252; $R^2 = 0.9239$; Intercept = 0.0243; Slope = 0.4257. Source: the authors. Figures were created using JMP Pro v.15.1.0 (SAS Institute, Inc.).

The second set of analyses corresponds to experiment 2 (Aragón-Vargas & González-Lutz, 2023b). Figure 2a shows the adjusted line for zPEAKPWR as predicted by zVJP, according to model zPEAKPWR = k + s(zVJP) + participant + Error. The association is strong with an $R^2 = 0.9891$ ($p < 0.0001$); the intercept (0.0109) is not different from 0 ($p = 0.2101$). The slope (0.2010), however, is different from 1 ($p = 8.58x10^{-20}$). Figure 2b shows the adjusted line for zMEANPWR as predicted by zVJP, according to model zMEANPWR = k + s(zVJP) + participant + Error. The association is strong with an $R^2 = 0.9617$ ($p < 0.0001$); the intercept (0.0075) is not different from 0 ($p = 0.6465$). The slope (0.4285), however, is different from 1 ($p = 8.8x10^{-5}$).

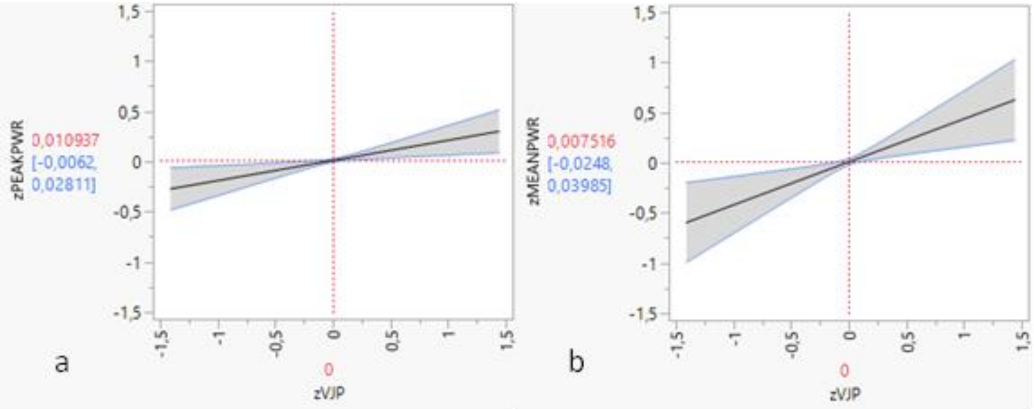

Figure 2. Prediction of normalized mechanical power from normalized vertical jump performance (zVJP). Experiment 2, within-subjects design, participants as random effects. Participants = 3. Trials = 50. (a) Peak mechanical power. Total valid data points: 147; $R^2 = 0.9891$; Intercept = 0.0109; Slope = 0.2010. (b) Mean mechanical power. Total valid data points: 147; $R^2 = 0.9617$; Intercept = 0.0075; Slope = 0.4285. Source. the authors. Figures were created using JMP Pro v.15.1.0 (SAS Institute, Inc.).

Figure 3 shows the individual bivariate adjustments for zPEAKPWR as a function of zVJP for experiment 2. These individual models all resulted in Slopes $\neq 1$: 0.396, 0.116, and 0.352, for participants DI07, DI10, and DI09, respectively ($p<0.0001$). Models for DI07 and DI09 were statistically significant ($p<0.05$), but model for DI10 was not ($p=0.4311$). The intercept was not different from 0 ($p=1.000$) in any of the models.

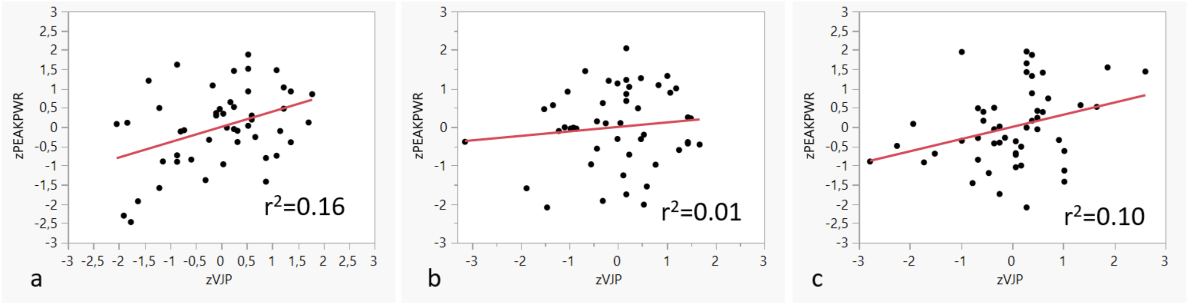

Figure 3. Individual bivariate adjustments for zPEAKPWR as a function of zVJP, experiment 2. (a) Participant DI07. (b) Participant DI10. (c) Participant DI09. Source: the authors. Figures were created using JMP Pro v.15.1.0 (SAS Institute, Inc.).

Figure 4 shows the individual bivariate adjustments for zMEANPWR as a function of zVJP, also for experiment 2. These individual models all resulted in Slopes ≠ 1: 0.152, 0.281, and 0.457, for participants DI07, DI10, and DI09, respectively (p<0.0001). The only significant model was for participant DI09 (p = 0.0009). The intercept was not different from 0 in all three models (p=1.000).

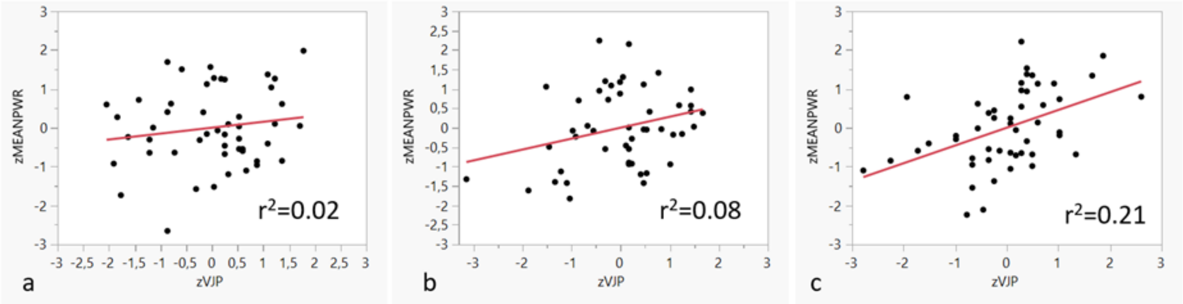

Figure 4. Individual bivariate adjustments for zMEANPWR as a function of zVJP, experiment 2. (a) Participant DI07. (b) Participant DI10. (c) Participant DI09. Source: the authors. Figures were created using JMP Pro v.15.1.0 (SAS Institute, Inc.).

4. Discussion

This study used regression analysis techniques to validate the use of vertical jump performance, that is, jump height, as a predictor of lower limb mechanical power in humans. We conclude that vertical jump performance is not a valid predictor of power. In line with previous studies evaluating regression equations based on VJP (Canavan & Vescovi, 2004; Sayers et al., 1999; Tessier et al., 2013), the association between VJP and mechanical power for 52 participants doing 5 vertical jumps each was shown to be statistically significant and, more than that, considerably high, with coefficients of determination higher than 0.92. Even with a small sample of three participants, who performed 50 vertical jumps each, the models were statistically significant and showed coefficients of determination higher than 0.96. Nevertheless, the models in the present study were evaluated using standardized scores (zVJP, zPEAKPWR, and zMEANPWR), and therefore were expected to result in an intercept = 0 and a slope = 1. Intercepts were indeed not statistically different from 0, but the slopes were different from 1 in all cases for these group regressions. This is an important finding of our study, providing additional evidence to support the recent claim that VJP is not an accurate predictor of mechanical power (Morin et al., 2019; Tessier et al., 2013); these two groups used theoretical arguments and conventional regression analysis for group data to make their point. The most important finding from our study, however, is that when regression analysis is focused on individuals, the association between jump height and mechanical power in humans is extremely weak.

This manuscript used Vertical Jump Performance (VJP) as the predictor variable. VJP was calculated very precisely, but in daily life, common practice by coaches and trainers involves estimating vertical jump height (JUMPAIR) from time in the air, that is, the flight time during the jump, a much more practical test. We performed the same analyses as those described for experiment 1, but using zJUMPAIR as the major predictor. The results were very similar to those obtained from zVJP, showing excellent coefficients of determination for both the zPEAKPWR (r^2=0.97) and the zMEANPWR (r^2=0.92) models ($p < 0.0001$), while the slopes for these models were also statistically different from 1: 0.548 and 0.601, respectively ($p < 0.0001$). Therefore, the problem we have highlighted when predicting mechanical power from VJP occurs also if one uses a jump height calculated from time in the air as the predictor.

The results were even more troublesome when each of the three individuals who performed 50 jumps was analyzed separately: all coefficients of determination were considerably attenuated, despite using standardized scores for the models; the zPEAKPWR model was not significant for one of the participants, while the zMEANPWR model was not significant for two participants. To make matters worse, all the slopes for these models were statistically different from 1. These results are solid evidence that the association between jump height and mechanical power in humans is much weaker than previously shown. This individual analysis approach in exercise science is particularly relevant, because there is considerable within-subject variability in key performance variables that is otherwise obscured by looking at average values (Mann, 2011). When the individual responses to a training regime have been studied, performance changes differently from one individual to another (Barquero & Salazar, 2020; Mann et al., 2014). These individual responses are lost when performance variables are estimated using regression equations based on group data. For different jumps, the amplitude of the push-off movement, and the corresponding time, can be shorter or longer, but if the work performed is the same, the power will be higher or lower, respectively (Morin et al., 2019); meanwhile, VJP will stay the same. Each individual has different strategies for achieving the same jump height (Aragón-Vargas & Gross, 1997b), but this fact is masked by the large differences between participants in conventional regression analysis with groups. Given that the main use of power tests is to monitor individual progress, applying the strength of the association from large groups to individuals makes no sense.

An additional comment is warranted regarding the mistake of using flight time for the mathematical calculation of power, due to its prevalence. The logic is as follows: to obtain power, you may divide the work performed during push-off (propulsion) by the time required to perform it. If you know the participant's vertical jump height (h) and body mass (m), and the value of g (the acceleration due to gravity), you can calculate work because the kinetic energy at takeoff (identical to the work performed during the positive phase of pushing against the ground, or push-off) is all converted to potential energy at the instant of peak height, that is, $m*g*h$. This is correct, but the problem is introduced in the next step: the time from takeoff to the highest position during flight (or the time from the highest position to landing) is typically estimated from 1/2 of flight time. However, as has been pointed out before, when this time is used in the calculation the result does not represent the power exerted by the jumper during push-off, but the average power of the falling jumper (Harman et al., 1991). The calculation is useless because flight time is necessarily associated with the height of the jump, according to the free-fall mathematical equation $h = (g*t_f^2)/2$, where t_f is the time from peak to landing. The power thus calculated has nothing to do with the mechanical power exerted by the muscles during push-off, the variable of interest, because the incorrect time is used; push-off time can only be obtained using sophisticated equipment. Unfortunately, this basic mistake is widespread, even in textbooks (Rodríguez Zárate et al., 2018) (page 57, figure 20). The preceding error is compounded by the fact that the time the body center of mass moves up or down during flight is not ½ of the time in the air, as typically assumed, because jumpers normally leave the ground with their knees and hips in full—or close to full—extension, but they land with their knees and hips partially flexed (Hatze, 1998). This is confirmed by our own unpublished calculations: with 256 jumps performed by 52 different participants, the time of flight up (0.276 ± 0.027 s) is significantly different from the time of flight down (0.302 ± 0.170 s, $p = 0.0155$).

5. Conclusions

In conclusion, vertical jump height should not be used to predict leg power because regression models using standardized values of vertical jump and mechanical power for group data fail to meet the criterion of a slope not different from 1, even though they result in high coefficients of determination. Furthermore, common prediction equations are based on group data but are predominantly used to monitor individual progress; prediction equations for individuals performing multiple jumps failed to meet the criterion of a slope not different from 1 and result in poor coefficients of determination ($R^2 \leq 0.21$). Morin et al. (2019) recommend some practical solutions to human power testing, based on previous publications by Samozino et al. (2008) and Jiménez-Reyes et al. (2017); their approach should be evaluated using the same procedures we have presented, with an emphasis on within-subject analysis. Such analysis may prove that the use of Morin et al.'s approach is sound and useful for monitoring individual athletes. Meanwhile, we recommend that whenever mechanical power results are to be used effectively, they should be obtained directly with the use of a force platform or a kinematic analysis system. Jump height results should be reported, analyzed, and interpreted only as vertical jump performance.

Practical implications

- Jump height is a poor predictor of leg power.
- Mechanical power should be measured directly with validated methods and instruments.
- Power and other performance prediction equations in exercise science should always be evaluated using our within-subject analysis model, since they will mostly be applied to monitoring changes in individual athletes.

Conflict of interest: No conflicts of interest, financial or otherwise, are declared by the authors. The authors have no financial or other interest in the testing equipment or its distribution. All authors declare that the results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

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A-Financing, **B-**Study design, **C-**Data collection, **D-**Statistical analysis and interpretation of results, **E-**Manuscript preparation.

6. References

Aragón-Vargas, L.F. (2000). Evaluation of Four Vertical Jump Tests: Methodology, Reliability, Validity and Accuracy. *Measurement in Physical Education and Exercise Science*, *4*(4), 215–228. https://doi.org/10.1207/S15327841MPEE0404_2

Aragón-Vargas, L. F., & González-Lutz, M. I. (2023a). Dataset for experiment 1 of A novel validation approach shows new, solid reasons why vertical jump height should not be used to predict leg power. *Pensar en Movimiento: Revista de Ciencias del Ejercicio y la Salud, 21*(2). https://doi.org/10.15517/pensarmov.v21i2.56206

Aragón-Vargas, L. F., & González-Lutz, M. I. (2023b). Dataset for experiment 2 of A novel validation approach shows new, solid reasons why vertical jump height should not be used to predict leg power. *Pensar en Movimiento: Revista de Ciencias del Ejercicio y la Salud, 21*(2). https://doi.org/10.15517/pensarmov.v21i2.56208

Aragón-Vargas, L.F., & Gross, M.M. (1997a). Kinesiological factors in vertical jump performance: Differences among individuals. *Journal of Applied Biomechanics*, *13*(1), 24–44. https://doi.org/10.1123/jab.13.1.24

Aragón-Vargas, L.F., & Gross, M.M. (1997b). Kinesiological factors in vertical jump performance: Differences within individuals. *Journal of Applied Biomechanics*, *13*(1), 45–65. https://doi.org/10.1123/jab.13.1.45

Bar-Or, O. (1987). The Wingate anaerobic test. An update on methodology, reliability and validity. *Sports Medicine*, *4*(6), 381–394. https://doi.org/10.2165/00007256-198704060-00001

Barquero, J. F., & Salazar, W. (2020). Efecto agudo de los entrenamientos de fuerza, velocidad, pliometría y velocidad contra resistencia en la carrera de velocidad . *Pensar en Movimiento: Revista de Ciencias del Ejercicio y la Salud*, *18*(2), e40315. https://doi.org/10.15517/pensarmov.v18i2.40315

Bosco, C., Luhtanen, P., & Komi, P.V. (1983). A simple method for measurement of mechanical power in jumping. *European Journal of Applied Physiology and Occupational Physiology*, *50*(2), 273–282. https://doi.org/10.1007/BF00422166

Canavan, P. K., & Vescovi, J. D. (2004). Evaluation of Power Prediction Equations: Peak Vertical Jumping Power in Women. *Medicine & Science in Sports & Exercise*, *36*(9), 1589–1593. https://doi.org/10.1249/01.MSS.0000139802.96395.ac

Del Coso, J. D., & Mora-Rodríguez, R. (2006). Validity of cycling peak power as measured by a short-sprint test versus the Wingate anaerobic test. *Applied Physiology, Nutrition, and Metabolism = Physiologie Appliquee, Nutrition Et Metabolisme*, *31*(3), 186–189. https://doi.org/10.1139/h05-026

Harman, E., Rosenstein, M., Frykman, P., Rosenstein, R., & Kraemer, W. (1991). *Estimation of Human Power Output from Vertical Jump*. https://www.semanticscholar.org/paper/Estimation-of-Human-Power-Output-from-Vertical-Jump-Harman-Rosenstein/47eeda520e5a2595392064a2faaf93909323751e

Hatze, H. (1998). Validity and Reliability of Methods for Testing Vertical Jumping Performance. *Journal of Applied Biomechanics*, *14*(2), 127–140. https://doi.org/10.1123/jab.14.2.127

Jiménez-Reyes, P., Samozino, P., Pareja-Blanco, F., Conceição, F., Cuadrado-Peñafiel, V., González-Badillo, J. J., & Morin, J.-B. (2017). Validity of a Simple Method for Measuring Force-Velocity-Power Profile in Countermovement Jump. *International Journal of Sports Physiology and Performance*, *12*(1), 36–43. https://doi.org/10.1123/ijspp.2015-0484

Kirkendall, D. R., Gruber, J. J., & Johnson, R. E. (1987). *Measurement and evaluation for physical educators.* Human Kinetics. https://library.olympics.com/Default/doc/SYRACUSE/67952/measurement-and-evaluation-for-physical-educators-don-r-kirkendall-joseph-j-gruber-robert-e-johnson

Lara-Sánchez, A. J., Zagalaz, M. L., Berdejo-del-Fresno, D., & Martínez-López, E. J. (2011). Jump Peak Power Assessment Through Power Prediction Equations in Different Samples. *The Journal of Strength & Conditioning Research*, *25*(7), 1957–1962. https://doi.org/10.1519/JSC.0b013e3181e06ef8

Mann, T. (2011). Mean response disregards the importance of individual variation. *South African Journal of Sports Medicine*, *23*(1), 30. https://doi.org/10.17159/2078-516X/2011/v23i1a532

Mann, T. N., Lamberts, R. P., & Lambert, M. I. (2014). High responders and low responders: Factors associated with individual variation in response to standardized training. *Sports Medicine*, *44*(8), 1113–1124. https://doi.org/10.1007/s40279-014-0197-3

Morin, J.-B., Jiménez-Reyes, P., Brughelli, M., & Samozino, P. (2019). When Jump Height is not a Good Indicator of Lower Limb Maximal Power Output: Theoretical Demonstration, Experimental Evidence and Practical Solutions. *Sports Medicine*, *49*(7), 999–1006. https://doi.org/10.1007/s40279-019-01073-1

Rodríguez Zárate, N. M., Argothy Bucheli, R. E., Acero Jáuregui, J. A., Gómez Salazar, L., Menzel, H., & Cohen, D. D. (2018). *Lineamiento de política pública en ciencias del deporte en Biomecánica*. Coldeportes. https://acortar.link/Y8dpff

Samozino, P., Morin, J.-B., Hintzy, F., & Belli, A. (2008). A simple method for measuring force, velocity and power output during squat jump. *Journal of Biomechanics*, *41*(14), 2940–2945. https://doi.org/10.1016/j.jbiomech.2008.07.028

Sayers, S. P., Harackiewicz, D. V., Harman, E. A., Frykman, P. N., & Rosenstein, M. T. (1999). Cross-validation of three jump power equations. *Medicine & Science in Sports & Exercise*, *31*(4), 572–577. https://doi.org/10.1097/00005768-199904000-00013.

Tessier, J.-F., Basset, F.-A., Simoneau, M., & Teasdale, N. (2013). Lower-Limb Power cannot be Estimated Accurately from Vertical Jump Tests. *Journal of Human Kinetics*, *38*(2013), 5–13. https://doi.org/10.2478/hukin-2013-0040

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