Estimated lower limb mechanical muscular power during vertical jumps by contact mat and bosco’s equation: a correlation and agreement cross-sectional study

ABSTRACT
The mechanical muscular power (MMP) can be estimated by different methods and because that, it could lead to misinterpretation. This study investigated the correlation and agreement between lower limb MMP in a vertical jumping estimated by two on-field evaluation tools to sports performance, being a contact mat (MMP\text{contact_mat}) and estimated by the Bosco’s equation.
Fifty-two athletes participated in the study. The maximum continuous vertical jumps test was used for 60s on a contact mat to determine the MMP. The test was applied just once. The MMP\textsubscript{contact_mat} was provided by the software Multisprintfull\textsuperscript{®} and the MMP\textsubscript{Bosco's equation} was calculated by the Bosco’s equation. The correlation was determined by the Pearson test and the agreement by the Bland Altman test. The mean values of MMP\textsubscript{contact_mat} and MMP\textsubscript{Bosco's equation}, both in W$\cdot$kg$^{-1}$, were respectively 4.5±0.5 and 15.4±3.7. Measures were correlated, $r = 0.72$; $p < 0.001$, but not concordant. A bias of 10.82 was found with $T (51) = 23.23$; $p < 0.001$, this bias being correlated with the means of the measurements. We concluded that although MMP measures were correlated, they did not agree with each other. The MMP\textsubscript{contact_mat} was also underestimated about MMP\textsubscript{Bosco's equation} and the bias increased in proportion to the increase in MMP production.

**Keywords:** muscle strength, athletic performance, plyometric exercise, kinetics, muscle contraction.

**RESUMO**
O presente estudo investigou a correlação e concordância entre a potência muscular mecânica (PMM) dos membros inferiores em saltos verticais estimada por dois instrumentos de avaliação do desempenho desportivo no terreno, sendo um tapete de contacto (PMM\textsubscript{contact_mat}) e estimada pela equação de Bosco (PMM equação de Bosco). Para a determinação do MMP foi utilizado o teste de saltos verticais máximos contínuos para 60s em tapete de contacto. O teste foi aplicado apenas uma vez. O MMP\textsubscript{contact_mat} foi fornecido pelo software Multisprintfull\textsuperscript{®} e o MMP\textsubscript{Bosco's equation} foi calculado pela equação de Bosco. A correlação foi determinada pelo teste de Pearson e a concordância pelo teste de Bland Altman. Os valores médios de MMP\textsubscript{contact_mat} e MMP\textsubscript{Bosco's equation}, ambos em W$\cdot$kg$^{-1}$, foram respectivamente 4,5±0,5 e 15,4±3,7. As medidas foram correlacionadas, $r = 0,72$; $p < 0,001$, mas não concordantes. Foi encontrado um viés de 10,82 com $T (51) = 23,23$; $p < 0,001$, sendo esse viés correlacionado com as médias das medidas. Concluímos que, embora as medidas de MMP estivessem correlacionadas, elas não eram concordantes entre si. O MMP\textsubscript{contact_mat} também foi subestimado em relação à equação de MMP\textsubscript{Bosco} e o viés aumentou proporcionalmente ao aumento da produção de MMP.

**Palavras-chave:** força muscular, desempenho atlético, exercício pliométrico, cinética, contração muscular.

**1 INTRODUCTION**
Mechanical muscular power (MMP) production is the amount of mechanical work produced by a unit of time (Kobal et al., 2017; Rodríguez-Rosell et al., 2017). The MMP is influenced by force-velocity relationship and by interrelated neuromuscular factors, both potentially modifiable by a systematized physical training program (Cormie et al., 2011a, 2011b; Dal Pupo et al., 2012; Storniolo et al., 2012). Determining MMP involved in sports gestures is
applicable for quantifying performance in sports and to identify adaptations produced by the training (Kobal et al., 2017; Rodríguez-Rosell et al., 2017).

The vertical jump as a predictor of MMP is described in the literature (Bosco et al., 1983; Rodrigues & Marins, 2011; Rodríguez-Rosell et al., 2017; van Hooren & Zolotarjova, 2017). The performance in vertical jump tests correlates significantly and positively with some variables, such as mechanical - musculotendinous stiffness and maximum rate of torque production (Driss et al., 2015); metabolic - peak power and mean power obtained by Wingate test (Nikolaidis et al., 2016); and physiological - muscle fiber type (Bosco et al., 1983b; Bosco & Komi, 1979). One of the most used information obtained on the vertical jump test to predict MMP is the jump height (Moura et al., 2015). The relationship between jump height and MMP is explained by classical physics concepts, especially by Newtonian’s laws of motion (Enoka, 2000).

Physically, the momentum is the amount of body movement, and it can be expressed mathematically as the product of the body mass by the velocity. During jump body mass is invariable, then jump height is determined by the velocity modules at the instant the body loses contact with the ground (take-off). After take-off, according to Newton’s third law, the action-reaction law, no force can be exerted to accelerate the body in the flight phase. Therefore, the greater the force applied at take-off the height reached in the flight phase will be greater (Bosco et al., 1983; Enoka, 2000).

Performance in jumping tests contributes not only to monitoring training evolution but also helps professionals responsible for the athletes’ training and rehabilitation programs to make a decision (Bertor et al., 2017; Rodrigues & Marins, 2011). However, different methodologies (Dal Pupo et al., 2012; van Hooren & Zolotarjova, 2017) as well as the different tools used in these tests (Moura et al., 2015) lead to confusion in the interpretation of the results.

Different tools used to assess MMP can always not be used interchangeably. While devices like force platforms consider the ground reaction forces to calculate the jump height, contact mats, popular and practical equipment, use just the flight time to measure jump height (Buckthorpe et al., 2012). Although it has different commercial models contact mat, the flight time is measured similarly by photosensitive cells or by photogrammetric systems connected to a timer (Borges Junior et al., 2010). Differences in methods to achieve the values of jump height could be a source of bias in MMP estimations. Therefore, verifying the validity and reliability of
information obtained from jumping tests has been a concern among researchers (Ferreira et al., 2008; Rodrigues & Marins, 2011).

In the 1980s, researchers proposed an evaluation method of the lower limbs’ MMP, known as Bosco’s test. In this protocol, the subject must perform successive vertical jumps with the highest effort possible, during 60s without stopping (maximum and continuous vertical jumping test), on a contact mat. Then, an equation was created using variables provided by this test to estimate the lower limb’s MMP (Bosco’s Equation) (Bosco et al., 1983). The mean MMP over the 60s reflects the endurance of fast force and expresses the neuromuscular system ability to delay the onset of the fatigue process (Hespanhol et al., 2007).

The mean MMP provided by Bosco’s test was previously compared to the mean MMP obtained by a force platform. Considering that the force platform is a gold standard for MMP assessment, the authors concluded that Bosco’s Equation is a useful and convenient tool for MMP measurements (Storniolo et al., 2012). Although the force platform is the most reliable method to determine MMP, its use is restricted to laboratory settings which are difficult for most athletes to access. Taking this into account, more accessible tools, such as the contact mat, are being increasingly used in jumping tests (Ferreira et al., 2008).

Considering that the same variable can be assessed by different methods, an agreement between the results obtained is necessary. Thus, the propose of this study was to investigate the correlation and agreement between lower limb MMP in a vertical jumping estimated by two on-field evaluation tools to sports performance, being a contact mat (MMP\textsubscript{contact\_mat}), and estimated by the Bosco’s equation (MMP\textsubscript{Bosco\_s\_equation}). Although none of the two on-field evaluation tools are considered the gold standard, we considered the MMP\textsubscript{Bosco\_s\_equation} as the reference since there is a previous study that observed that the muscle power coming from the Bosco’s equation presented a correlation value of R=0.82 in relation to that obtained by equation derived from the fundamental laws of physics using the force platform; and the difference between the means of the MMP\textsubscript{Bosco\_s\_equation} and the one whose calculation was based on the ground reaction force data were all within the confidence intervals were between the confidence limits imposed by the Bland and Altman test (Storniolo et al., 2012). We hypothesized that MMP values, obtained by both methods, would be correlated and in agreement with each other.
2 METHODS

2.1 EXPERIMENTAL APPROACH TO THE PROBLEM

This paper was a correlation and agreement cross-sectional study and the MMP was the variable of the study, it is determined by estimation.

2.2 PARTICIPANTS

The institutional ethics committees approved the study previously, and the number report is 118/2012. We provided informed consent by the participants and their legal guardians. The authors have no conflicts of interest to disclose.

Fifty-two indoor soccer or volleyball athletes, both sexes and age between 14 and 29 years old (29 male and 23 female; 17.3±2.8 years; 174.6±7.8 cm; 68.6±11.9 kg) were recruited via personal invitation.

The inclusion criterion was to had been training systematically for at least one year. The exclusion criteria were: a history of acute neuromuscular or skeletal injuries in the last six months; a history of chronic neuromuscular or skeletal injuries; a history of systemic diseases.

2.3 METHODOLOGICAL PROCEDURES

The data collection was done in only one approach at a school clinic of a higher education institution. All participants received information about how to perform the test and watched a demonstration of the movement. For the test, it was used to countermovement jump type. The volunteers underwent a warm-up for three minutes, on a stationary bicycle with low intensity, before the jumping test.

2.3.1 Maximum vertical jumping test

After familiarization and warm-up, the participants positioned themselves on the 50x60cm size contact mat (Jumptest®, Hidrofit LTDA, Belo Horizonte, Brazil), connected to a laptop computer (Itautec Infoway, Intel Core i3 370M 2.40 GHz, 8.00 GB RAM), with approximately 90º of knee flexion, keeping their hands at the waist. It was requested the performance of the highest number of vertical jumps in maximum intensity for 60s uninterrupted. During the test, they received verbal motivation to maintain the maximum effort and the correct positioning (Bosco et al., 1983a; Bosco et al., 1983). Each participant executed only one attempt.
2.4 DATA PROCESSING

2.4.1 Calculation of the MMP by the software of the contact mat (MMP\textsubscript{contact_mat})

The contact mat was composed of two conductive surfaces that respond to small pressure changes. After the feet had lost contact with the mat, in the aerial phase of the jump, a timer in the software Multisprintfull® (Hidrofit LTDA, Belo Horizonte, Brazil) was triggered and kept timing until the volunteer’s feet touch the mat again when the timing stopped. The duration of the aerial phase was called flight time. At the end of the test, the software automatically calculated the MMP\textsubscript{contact_mat}.

Multisprintfull® software took into account the flight time to calculate the jump height, as (equation 1) (Couto et al., 2012; Ferreira et al., 2008):

\[ h = g \cdot t^2 \cdot 8^{-1} \]  \hspace{1cm} (1)

Where:

\[ h = \text{jump height (m)}; \ g = \text{acceleration of gravity (9.81 m} \cdot \text{s}^{-2}); \ t = \text{flight time (s)}. \]

The software calculated the MMP\textsubscript{contact_mat} for every single jump performed on the mat (PMM\textsubscript{Single}) and expressed it in watts (W), by the following equation 2:

\[ \text{MMP}_{\text{Single}} = m \cdot g \cdot \frac{h}{t} \]  \hspace{1cm} (2)

Where:

\[ \text{MMP}_{\text{Single}} = \text{muscular mechanical power (W), obtained by the contact mat for each single jump; m = body mass (kg); g = acceleration of gravity (9.81 m} \cdot \text{s}^{-2}); h = \text{jump height (m); t = flight time (s)}. \]

Then, a mean value representing MMP\textsubscript{contact_mat} was calculated as the average of all MMP\textsubscript{Single} obtained during the 60s in which the jumps were performed, normalized by the volunteer’s body mass, and expressed by W·kg\textsuperscript{-1}. 
2.4.2 Calculation of the MMP by the Bosco’s Equation (MMP\textsubscript{Bosco\_equation})

The MMP\textsubscript{Bosco\_equation} for a continuous maximal vertical jump in 60s was calculated by the Bosco’s Equation as proposed in the literature (equation 3) (Storniolo et al., 2012):

\[
MMP_{\text{Bosco\_equation}} = g^2 \cdot T_f \cdot 60/4n(60 - T_f) \tag{3}
\]

Where:

\begin{itemize}
  \item \(MMP_{\text{Bosco\_equation}}\) = muscular mechanical power estimated by the Bosco’s Equation (W\cdot kg\textsuperscript{-1});
  \item \(g\) = acceleration of gravity (9.81 m\cdot s\textsuperscript{-2});
  \item \(T_f\) = sum of the flight time of all single jumps (s);
  \item \(n\) = total number of jumps during the test.
\end{itemize}

The flight time data and the number of jumps used in this equation were provided by Multisprintfull® software.

2.5 STATISTICAL ANALYSIS

The normality of the data was analyzed by the Shapiro-Wilk test. Descriptive statistics were presented as means and standard deviations. Correlations were obtained by the Pearson correlation test. Also, the intraclass correlation coefficient (ICC) was calculated and the correlation strength was evaluated by the following criterion: 0-0.25 very low or none, 0.26-0.49 low, 0.50-0.69 moderate, 0.70-0.89 high, and 0.90-1.00 very high. The agreement was analyzed by the Bland Altman test (Hirakata & Camey, 2009).

Statistical analyses were performed using the Statistical Software for Social Sciences (IBM 15.0, SPSS inc., Chicago, IL, USA) with an a priori level of significance of 0.05.

3 RESULTS

The mean values of \(MMP_{\text{contact\_mat}}\) and \(MMP_{\text{Bosco\_equation}}\), both in W\cdot kg\textsuperscript{-1}, were: 4.5 ± 0.5 and 15.4 ± 3.7, respectively. It was observed a high correlation (\(r = 0.72\); \(p <0.001\)) between \(MMP_{\text{contact\_mat}}\) and \(MMP_{\text{Bosco\_equation}}\) (Figure 1).
Figure 1 - Correlation between the mean mechanical power estimates of maximum continuous jumps for 60s obtained by the mat (MMP\textsubscript{contact_mat}) and by the Bosco’s equation (MMP\textsubscript{Bosco’s_equation}).

There was no agreement between MMP\textsubscript{contact_mat} and MMP\textsubscript{Bosco’s_equation}. A bias of 10.82 was found with $T(51) = 23.23$ ($p < 0.001$) and 95% confidence interval from 9.89 to 11.76 and 95% agreement limits from 4.23 to 17.41. It is noted that the bias, seen on the y-axis of the graph (Figure 2), increases as the mean values common to both methods, viewed on the x-axis of the graph, become higher.
4 DISCUSSION

This study aimed to verify the correlation and the agreement between two distinct evaluation methods of MMP by maximal vertical jump tests. Our hypothesis that both methods would be correlated and in agreement with each other was partially confirmed. Despite the high correlation between MMP values, there was no agreement between them.

It has been noted that as the mean values of the MMP_{contact_mat} become higher, the bias also increases. These findings suggest that the greater the capacity to produce MMP, the greater the error between the methods with the MMP calculated by the contact mat software being underestimated concerning the Bosco’s equation.

The ICC is a measure of relative consistency and denotes the degree to which the subjects maintain their position in a sample with repetitive measures (Stålbom et al., 2007). It has been suggested that values above 0.70 have a high correlation. In the present study, the high value of ICC allows us to affirm that there is a correlation between the evaluated methods, that is, in general, the highest values obtained in one method, tend to be the highest values also in the other.
However, no agreement was observed between them, since the relationship established by the Bland Altman test was shown to be distributed outside the expected in the graphical analysis by a bias of 10.82 and a wide agreement interval. In the case of two methods that agree with each other, the bias should be at or very close to zero, since it reflects the difference between the measures obtained by both (Hirakata & Camey, 2009).

In a study that used the Bland and Altman concordance analysis between different jump height measurement tools, using contact mat, videometry, and the Abalakov belt, it is also observed that the measurements were correlated, but not concordant (Moura et al., 2015).

It is possible that the lack of agreement between the measurements obtained in the present study could be explained by the mathematical processing for the determination of the MMP_{contact_mat}. When observing the input data for the calculation of the MMP by the software Multisprintfull®, it is verified that eliminating the influence of the variables that do not change such as the body mass and the acceleration of gravity, the determination of the MMP is dependent on the height of the jump and the flight time. These variables are only counted during the period in which the subject is in the flight phase, without contact with the mat, since the contact of the feet with the mat stops the system (Couto et al., 2012; Ferreira et al., 2008).

One study that compared four jump height measure tools corroborate our findings once the authors of that study conclude that contact mat, comparative with force plate as the gold standard, did not provide valid measures of a vertical jump. Indeed, the height jump average was 11.7 cm lower than the measurement recorded using the criterion force plate. For the authors, the reason for that discrepancy was that the contact mat is not able to account for the center of mass rise before the take-off and, because this, the height jump is underestimated (Buckthorpe et al., 2012).

By contrast, Bosco's equation considers not only the mechanical work performed during the loss of ground contact, but also all the mechanical work carried out to propel the center of mass, during the contact phase, from the lowest position of the center of mass until the moment of loss of contact with the platform. Consequently, the jump height in Bosco's equation is the sum of both centers of mass dislocation at flight time as at contact time (Bosco et al., 1983). This way, the MMP_{Bosco's equation} is the sum of concentric and eccentric phase works.

As the processing of the Multisprintfull® software disregards these values, we believe that this is the reason why the MMP_{contact_mat} values were underestimated concerning the
MMP_{\text{Bosco's equation}} values. The eccentric phase plays an important role in MMP production because at this stage there is the stretching of the musculotendinous unit that returns to the system during the concentric phase, elastic energy which, together with the muscular mechanical work, potentiates the MMP production \cite{van17}.

Based on these concepts, we speculate that the increase in bias proportionally to increase in MMP averages is due not just to the Multisprintfull® software not taking account for the muscular mechanical work performed during the terrestrial phase, but also for disregarding the elastic energy generated during that phase. Considering that Bosco's equation considers the displacement of the body's center of mass both during the phase of foot contact with the ground and during the flight phase \cite{bosc83}, it potentially comes closer to reality when estimating MMP than the calculation provided by Multisprintfull® software, which considers only the flight phase \cite{couto12, ferreira08}.

The practical message of these results is that contact mat users who consider only the concentric phase for determining muscle mechanical power can use it for the control of their athletes' MMP since there was a good correlation between the two methods, but they should be aware that the MMP produced is underestimated by this method since it disregards the eccentric phase. The main limitation of this study was not having muscle power values obtained by methods considered the gold standard, although the calculation of muscle power proposed by Bosco, through a 60s test performed in vertical jumps, is validated when comparing the muscle power coming from the force platform data.

We concluded that, although the estimates for mean MMP of maximum jumps repeated continuously for 60s quantified by the contact mat and the Bosco’s Equation are correlated, they do not agree with each other. The MMP_{\text{contact mat}} was underestimated concerning the MMP_{\text{Bosco's equation}} and that the bias increases in proportion to the increase of MMP production.
REFERENCES


