Common Measurement Methods Are Used to Verify the Effectiveness of Lower Limb Explosive Power

Sihang Zeng
College of Physical Education and Health, Guangxi Normal University, Guilin, Guangxi, China

Abstract: The purpose of this paper is to explore the correlation between several common explosive force measurement methods—standing long jump, Wingate anaerobic power bicycle, anaerobic power step (Margaria-kalamen), and reactive power index test—and lower limb explosiveness, to determine which measurement method can more cost-effectively measure lower limb explosive power. Methods: Sixteen students (aged 21.6 ± 1.2 years old) majoring in physical training in school were selected by literature method, experimental method and mathematical statistics method, and the explosive force performance of athletes under different exercise loads was measured by reducing the load range of vertical jump test by reducing the load range of vertical jump test, to obtain the maximum power peak of lower limbs and accurately measure the explosive force of the human body. Then, the correlation analysis with several common explosiveness tests of subjects was carried out to lay a foundation for evaluating the effectiveness of human explosiveness indicators. The results showed a significant correlation between the reactive strength index (RSI) and Wingate anaerobic power bicycle and lower limb explosive power, with correlation coefficients of 0.882, 0.826, and 0.694, respectively. Conclusion: There is a high correlation between the explosive power of the lower limbs and the standing long jump, the reaction strength index, and the measurement methods of the power bicycle, which can be used as an effective method to evaluate the explosive power of the lower limbs.

Keywords: Lower Limb Explosiveness; Standing Long Jump; Wingate; Margaria-Kalamen Anaerobic Power Steps; Reaction Power Index

1. Introduction

Explosive power is a kind of ability, and the characteristics of explosive power expression are different under different external loads. As the most common method for evaluating explosive power, vertical jumping is widely used in athlete selection and evaluation [1]. The strongest explosiveness is the greatest reserve and expression of this ability. The strongest explosive power of the lower limbs can only be fully expressed under a certain load, and in order to find the best load, it is necessary to find the maximum power of the lower limb vertical jump.

At present, there are three representative theories at home and abroad on the question of the nature of explosive power. The first is the "maximum acceleration view" [1] of Bühler in Germany. This theory is a good explanation for the explosive power of speed (e.g., throwing), which is aimed at gaining maximum speed, but it does not explain the power of explosive events (e.g., weightlifting). The second is the "rapid power view" of Professor Tian Maijiu, a famous scholar in China [3]. He emphasized the temporal variation gradient of power (i.e., the explosive force index), but the large temporal gradient of power change does not reflect the explosive force, because the explosive force index only reflects the gradient change of the power curve, and cannot reflect the absolute magnitude of the explosive force and the functional force, which shows that there is a logical error in interpreting the concept of explosive power from the perspective of fast power. The third is the "maximum power view" of Deng Shuxun, a famous scholar in China [4]. He studied explosive force from the perspective of energy, and believed that explosive force is the output of muscles in a contracted state, but this view ignores that the effect of explosive force on the body is achieved by doing work, and the magnitude of work does not depend only on strength, but also on the duration of action. Based on the current training and testing methods of athletes, there are various methods of human explosive power testing, which can effectively evaluate human explosive power, but the current testing methods have different limitations [5], among which the determination and quantification of key factors are the key factors restricting human explosive power. This study proposes that the manifestations of explosive power are all special action effects (reaching the fastest or maximum power) in a short period of time, and the specific action effects refer to the accumulation of time. At the same time, the generation of explosive power is a process of action, and its effect is reflected by the average value of energy, and the essence of explosive power is the peak average power.

Existing studies have proved that the gravitational potential energy of the body is converted into its own kinetic energy in the standing long jump pre-swing, which improves the explosive power of the take-off jump [6]. The reaction strength index is based on the theory that vertical jumps can reflect the neuromuscular condition of athletes [7]. The anaerobic power test can analyze the strength of athletes' upper limbs, which can provide data reference for targeted training and reasonable formulation of periodic training plans, and comprehensively improve the exercise ability and performance of long-distance mobilization [8]. Maximal anaerobic power-explosive power tests were performed on male sprinters and long jumpers using Margaria, and the results showed that the ATP-CP energy supply system is an important component of anaerobic capacity and constitutes anaerobic intensity [9].

Standing long jump, Wingate anaerobic power cycling, anaerobic power step (Margaria-kalamen), and reaction strength index are several methods to test the explosive power of the lower limbs, which are widely used in athlete selection and related special tests. In this paper, these common tests are selected, the relevant data are measured, and the correlation analysis is carried out with the peak average power of lower limb explosive power, and which test can more clearly reflect the test effect of lower limb explosive power, so as to further improve the economy and timeliness of lower limb explosive training evaluation.

2. Research Objects and Methods

2.1 Experimental Design and Ideas

Through the experimental expression and capture of the strongest explosive force, the experiment was carried out with a larger load range between 0 (self-weight not loaded) and 1RM load, so as to avoid missing the load point of the strongest explosive force, and at the same time take into account the characteristics of explosive force and the actual physical condition of the subject, and then roughly determine the load range where the strongest explosive force appears. Finally, the longitudinal jump load of 8 loads was selected to be tested with 20% 1RM, 30%1RM, 40%1RM, 45%1RM, 50%1RM, 55%1RM, 60%1RM, 65%1RM, and 8 loads of longitudinal jump on the experimental force table, so as to accurately capture the strongest explosive force, and record the corresponding kinematics, kinetics and other indicators, so as to accurately obtain the peak average power of the subjects and prepare for the subsequent research on explosive force measurement methods.

2.2 Research Subjects

In this study, a total of 16 male students were enrolled in the physical training program of the School of Physical Education and Health of Guangxi Normal University, who had excellent physical fitness and a certain foundation in strength training, and did not undergo high-intensity training before the experiment. The details are shown in **Table 1**.

Table 1. Basic Information of Experimental Subjects

Number of Subjects	Gender	Age (years)	Height (m)	Weight (kg)
16	Male	21.6 ± 1.2	1.73 ± 0.05	69.42 ± 6.49

2.3 Research Methods

2.3.1 Experimental Instruments and Software

3D motion capture system. Using the infrared motion capture system of Qualisys in Sweden and 8 high-speed infrared cameras (and the corresponding infrared reflective Marker ball (14mm diameter), the system is mainly used to collect the biomechanical characteristics of the subject's vertical jump for different tasks.

AMTI Force Plates. One three-dimensional force plate (L×W×H: 1800×400 ×82.55 mm, USA, model: 2m) produced by AMTI Company was used for kinetic data acquisition in this study, and the force plate was built with a GEN5 amplifier. Kistler force plates. QTM processing software. The original kinematic signal is preprocessed (Marker point naming, smoothing, noise reduction, patching, etc.) by using the built-in QTM signal acquisition and processing software of Qualisys in Sweden. Visual3D analysis software. The kinematic data captured by the QTM system and the kinetic data collected by the AMTI force plate were processed and the inverse dynamics were calculated and analyzed by Visual3D gait analysis software (V3D, C-Motion, USA). Isokinetic devices. High-speed camera, gymnasium-specific pole, new standard weight barbell plate, isokinetic tester, Swedish Monark894E power bicycle, Monark power meter, Monark 894E power bicycle with anaerobic power test software, steps, 40cm height jump box, electronic induction device that can measure contact time: force table contact pad; Rubber ropes with different elastic strengths, sports shorts, fascia guns, special relaxation pads, experimental results record sheets, etc. Two assistants and a recorder are also required. (2) Experimental process A. Precautionary measures before the test: On the day before the start of the test, tell the subjects not to do high-intensity activities, not to drink, not to stay up late, and to test about one hour after meals. Pre-experiment data record: After the subject arrives at the laboratory, the participant's name, date of birth, weight, etc. are registered, and the informed consent form is read out. After determining that there are no problems, the muscles are activated, ready for the formal experiment. Pre-experiment warm-up activities: small steps, hip turns, 20 vertical jumps, leg raises between marches, gladiator walking, greatest stretch, nerve-activated sprints. After the warm-up, put on your sports shorts, tidy up your appearance, and prepare for the next experiment. B. Collect static data signals. First of all, calibrate the force tester platform and the surrounding environment, and calibrate the parameters. At the same time, according to the Qualisys test guidelines, the upper and lower limbs were marked and pasted on the corresponding parts of the subjects (a total of 36 stickers). The subject then stands with their legs apart, hands crossed over their shoulders, and faces the HD camera for 5 seconds until the Mark data collection is complete. C. Collect dynamic data signals. After the static modeling was completed, the 8 reflection points on the two feet, the medial and outer sides of the knees, were removed. Before the start of each formal trial, participants do some pre-training until they have a full understanding of the process and practical operation of the trial.

2.3.2 Lower extremity explosiveness test

Therefore, to prevent the loading point of the maximum explosive force from being missed, and taking into account the physical condition of the subject and the speed pattern of the explosive force, we will perform 8 tests on the subject's vertical jump load at 20%-65%1 RM to obtain the maximum load range of the maximum explosive force, to accurately obtain the peak average power of the subject.

(1) Test content: The experimental force plate multi-joint longitudinal jump adopts 20% 1RM, 30% 1RM, 40% 1RM, 45% 1RM, 50% 1RM, 55% 1RM, 60% 1RM, and 65% 1RM loads.

(2) Action requirements: When preparing, keep your feet shoulder-width apart and your toes slightly outward. Avoid knee buckle or valgus, lean your torso slightly forward, don't arch your back or collapse your waist, your head is neutral in your body, and your eyes are looking ahead. After squatting to a certain angle (self-selected angle), the hips, knees, and ankles exert force, and jump up hard, the jump height is not required, and the toes can leave the ground. When you land, your toes hit the ground first, then transition to the full ball of your foot, and your knees are slightly bent to avoid excessive pressure.

(3) Test process: The athlete adopts a unified warm-up action, and jumps vertically from the waist in the form of vertical jumping on the spot, and the load increase is based on the jump height until the toes just jump off the ground. At this time, the load is 1RM, and the vertical jump of 1RM is generally measured within 4 times to avoid fatigue. The 1RM vertical jump refers to the vertical vertical jump under the condition of squatting on the back of the neck and carrying the weight barbell, using the toes off the ground as the jumping standard during the most vigorous jump, and the weight when the toes can just leave the ground as the 1RM weight.

(4) Test requirements

When the experimenter hears the command to "prepare", the subject puts the barbell on his shoulder, and then stands on the force plate to prepare for the position. After hearing the "start" command, the subject steps into the dynamometer, remains upright for 2 seconds, and then performs an explosive vertical jump with maximum force, then completes the movement naturally and remains upright.

When the "stop" command is given, the subject leaves the dynamometer platform and the barbell returns to its initial position. During this procedure, once the subject carries the bar, the protective person at the rear or both ends performs the protective action at the same time. Especially when the subject makes explosive movements and reaches the apex, the protection officer should seize the opportunity to protect and actively reach out to lift the barbell bar to help the subject cushion and reduce the impact force. At the same time, pay attention to the safety of personnel and avoid stepping into the force plate, which will affect the accuracy of experimental data.

After the action is over, the test subject will re-examine the motion trajectory image to determine the validity of the experiment. When performing jumping exercises, the spine is subjected to a large load, so only one valid data is taken for each vertical jump test.

2.3.3 Standing long jump test

According to the National Student Physical Health Standards (revised in 2016), the standing long jump test will be conducted. According to the list of subjects, each person has three test opportunities, and the best score of the three is taken as the data for this test.

2.3.4 Wingate anaerobic power bike test

(1) Test content

Subjects are required to complete the anaerobic power test experiment for 30 seconds to the maximum extent possible on an anaerobic power bicycle.

(2) Test method

After the subject fully understands the test method and requirements, let the subject do 3~5 minutes of adaptive pedaling, and the subject can carry out the formal experiment after fully adapting to the experimental instrument.

During the formal experiment, the subject raised his hand to sign up, and after the tester made a record, the subject rode on his own and prepared for bicycle debugging, and when he heard the tester give the "start" command, the subject immediately went all out to ride the bicycle without weight.

When maximum speed is reached, subjects are required to continue full pedaling for 30s seconds at a load of 0.075kg/kg body weight. During the test, the tester kept clapping and shouting to encourage the subject so that the subject could complete the anaerobic power test experiment for 30 seconds at maximum capacity.

(3) Testing requirements

The subject's buttocks are not to leave the seat during the experiment. When the subject hears the "end" command, the subject needs to continue to perform a relaxing pedal for 3~5 minutes instead of immediate braking to prevent injury and relieve the fatigue of the lower limb muscles. After getting off the bus, the subjects used yoga mats and foam rollers to massage and relax the muscles of the lower limbs according to the guidance of the testers to relieve muscle fatigue.

2.3.5 Anaerobic power step (Margaria-kalamen) test

(1) Test content

The subject ran up at least 10 steps of steps or stairs (about 1.05 meters in height) at the fastest speed to determine the time required to climb the steps.

(2) Test method

Measure the height of the first step with a tape measure or measuring rod to calculate the height of the third to ninth steps.

b. Install the infrared start switch on the third step, and install the end switch on the ninth step.

c. The tester weighs himself, warms up, and practices running once to climb three steps before the test.

During the d-test, the tester runs about six meters away from the steps, and climbs the ninth step in the shortest amount of time after crossing three steps each time.

e Records the time taken by the tester from the third step to the ninth step as measured by the infrared timing system, accurate to 0.001s.

Repeat the test twice, with an interval of 2-3 min between each test.

(3) Testing requirements

Power (kgm/s) = Weight (kg) × Vertical distance from level 3 to level 9 (m) / Time from level 3 to level 9 (s)

2.3.6 Reaction strength index test

(1) Test content

The test athletes were tested at a height of 40 cm, and the best results of 3 jumps were taken and recorded.

(2) Test method

A test athlete stands on the jump box, at least 0.2m away from the front of the force test.

bAfter hearing the tester's command, the test athlete places his hands on his hips, then steps off the box with one foot, and immediately jumps as high as possible after touching the mat, while minimizing the time of contact with the ground. After landing, step out of the force test, and the experiment is over.

c. Obtain the jump height and ground contact time according to the instrument device, and obtain the reaction force index by dividing the jump height by the ground contact time.

(3) Testing requirements

Subjects should be instructed not to jump or actively jump, and the take-off, landing, and jumping posture should be consistent for each test. Subjects can repeat the test by jumping from different heights to obtain a series of contractile responses from the subject. At the same time, pay attention to whether the descent action is normal and whether the data transformation is reasonable; otherwise, the data will not be recorded.

2.4 Data Processing and Analysis

The lower limb explosive force test mainly obtains the raw data through Visual 3D software, and the raw data is calculated by the trapezoidal numerical integration method to calculate the power value of the explosive force, which is achieved by finding the area enclosed by the curve and the x-axis, and then dividing the area by time. In this study, a special program was written in the Python language to process data. This program uses the trapz method in the numpy library to implement the trapezoidal integration method, uses the matplotlib library to plot the linear interpolation method to draw the result curve, and uses the PySimple GUI library to construct the data input and output interfaces. Figure 1 shows the specific data processing process of the program.

The standing long jump, Wingate anaerobic power bicycle, anaerobic power step (Margaria-kalamen), and reaction power index experiments were measured by instruments, and different data were sorted out and recorded using relevant data processing software.

The Shapiro-Wilk test is used to assess the normality of outcome measures. Descriptive statistics were performed for all subject statistics and outcome measures. Since the data of each variable is normally distributed, parametric statistics are used for analysis. The Pearson correlation test was used to observe the correlation between the standing long jump, Wingate anaerobic power bicycle, anaerobic power step (Margaria-kalamen), response strength index, and lower limb explosive power expression. SPSS 26.0 software was used for statistical analysis, and the difference was statistically significant, $p<0.05$.

3. Results

In this study, it was found that among 16 subjects, the peak average power of lower limb explosive power was tested with data from several common measurement methods, and all of them met a normal distribution, as shown in the **Table 2** below.

Table 2. Results of Normality Test Analysis

Test	*n*	Mean	SD	Skewness	Kurtosis	Shapiro-Wilk (W)	*p*
Peak average power	16	1635.66	307.01	0.667	0.037	0.931	0.254
Standing long jump	16	2.70	0.131	0.667	0.037	0.919	0.163
Wingate cycle	16	543.51	117.31	-0.257	0.416	0.927	0.222
Margaria-Kalamen step	16	1593.95	164.03	0.697	0.642	0.976	0.923
RSI	16	1.642	0.43	0.950	0.220	0.902	0.088

The results of correlation analysis showed that there was no significant correlation between the peak average power of lower limb explosive power and the standing long jump test ($r=0.251$). The correlation with anaerobic power step (Margaria-kalamen) was significantly lower ($r=0.357$). There was a significant correlation between the peak average power of lower limb explosiveness and Wingate anaerobic power bicycle ($r=0.693$, $p<0.01$), which proved that the higher the power of Wingate anaerobic bicycle, the stronger the lower limb explosive power. There was a significant correlation between the peak average power of lower limb explosive power and the reactive power index (RSI) (r=0.826, p<0.01), that is, the higher the value of reactive power index, the higher the level of lower limb explosive power, indicating that the improvement of reactive power index could effectively enhance the explosive power of lower limb.

Table 3. Correlation Analysis Results

Test	Standing long jump	Wingate cycle	Margaria-Kalamen	RSI
Peak average power	0.882	0.693**	0.357	0.826**

4. Discussion

4.1 Analysis of Common Measurement Methods and Peak Average Power Characteristics of Lower Limb Explosive Force

In this study, a strong positive correlation was shown between the standing long jump and reaction power index (RSI) and the peak average power of the lower limb. This result is consistent with a previous study [10] [11], which also found a significant correlation between RSI and lower extremity explosiveness. The standing long jump, as a traditional, simple means to evaluate the explosiveness of the lower limbs, was fully confirmed in this study. However, although RSI is an effective tool for assessing lower extremity explosiveness, it does not fully reflect the complex biomechanical mechanisms of specific sports due to its limited popularity in athlete selection and testing, due to its expensive testing equipment [12]. This may be because the RSI mainly measures the ratio of jump height to ground contact time and fails to cover other important biomechanical parameters during exercise, such as joint angles, muscle activation patterns, etc. The correlation coefficient between the Wingate test and lower limb explosiveness was 0.694, indicating that the test is also an effective tool for assessing lower limb explosiveness. This finding is consistent with the findings of Watkins et al. [13], who found that the anaerobic power bike test can be used as a reliable method to assess the explosive power of the lower extremities. This is further confirmed by our findings and provides additional empirical support for the use of this test method. The failure of the anaerobic power step test to show a significant effect on lower extremity explosiveness may be related to the small sample size or to the fact that these test methods reflect more lower extremity strength and endurance [13] than explosiveness. This finding suggests that these tests should be used with caution when assessing lower extremity power, and that consideration should be given to combining them with other, more sensitive test tools.

4.2 Recommendations on the Use of Measurement Methods

Considering the impact of individual differences on explosive performance, future studies should also take into account factors such as athletes' age, gender, training years, and sport for a more individualized assessment. This study demonstrated the effectiveness of the standing long jump, RSI, and Wingate anaerobic power bike tests in assessing lower limb explosiveness through experimental data, while also pointing out the limitations of the anaerobic power step test. These findings have important implications for athlete selection, training, and competition, but also remind us of the need to consider the limitations of these test methods when applying them and to combine them with other assessment tools to obtain a more comprehensive assessment of athlete ability. Future studies should further explore the applicability of different test methods and consider the impact of individual differences on test results.

5. Conclusion

Through the analysis and interpretation of the experimental results, there is a strong correlation between the explosive power of the lower limb and the standing long jump, the reaction strength index, and the measurement method of power bicycle, which can be used as an effective method to evaluate the explosive power of the lower limb. Although the anaerobic power step test failed to measure the significant correlation of lower limb explosive power, it may be due to the factors of rough measurement details or a too small sample size. While the Reflex Force Index is a useful tool for assessing lower extremity explosiveness, it has limited relevance to specific sports and does not adequately explain the complex biomechanical principles behind it. Therefore, this index should not be used as a basis for measuring the explosiveness of special sports during training.

These findings have important guiding implications for athletes' training and evaluation, but also remind us of the need to consider their limitations when applying these test methods and combine them with other assessment tools to obtain a more comprehensive assessment of athlete ability.

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