PRINCIPAL SCIENTIFIC VALIDATIONS

Myotest Accelerometer System

- Validating two systems for estimating force and power - London, UK
- Validity of the Myotest in measuring force and power - Connecticut, USA
- Myotest performs construct validity and reliability - Connecticut, USA
- Validity of Myotest during a vertical jump test - Dijon, FR
- Effects of plyometric training using a portable self coaching system - Kyoto, JP

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Validating Two Systems for Estimating Force and Power

Abstract

This study examined the validity of 2 kinematic systems for estimating force and power during squat jumps. 12 weight-trained males each performed single repetition squat jumps with a 20-kg, 40-kg, 60-kg and 80-kg load on a Kistler portable force plate. A commercial linear position transducer (Gymaware [GYM]) and accelerometer (Myotest® [MYO]) were attached to the bar to assess concentric peak force (PF) and peak power (PP). Across all loads tested, the GYM and MYO estimates of PF and PP were moderately to strongly correlated ($r=0.59–0.87$) with the force plate measurements ($r=0.66–0.97$), respectively. The mean PF and PP values were not significantly different between the 2 kinematic systems and the force plate, but the estimates did produce some systematic bias and relatively large random errors, especially with the 20-kg load (PF bias $>170$N, PP bias $>335$N, PP error $>878$W). Some proportional bias was also identified. In summary, the estimation of PF and PP by a linear position transducer and accelerometer showed moderate to strong relative validity and equivalent absolute validity, but these estimates are limited by the presence of bias and large random errors.

Introduction

The accurate and reliable assessment of force and power are fundamental to sports testing, training and rehabilitation. Force can be described as the ability of muscle/s to produce tension, whereas power is the expression of force at a given velocity [7]. The direct acquisition of this kinetic data requires a force plate or platform, which is not always a practical and cost-effective option, and generally limited to lab-based assessments [8,22]. Thus, kinematic systems (e.g., linear position transducers, accelerometers) are becoming increasingly popular as tools for estimating the force and power outputs with exercise. Linear transducers use a tethered cord (attached to a person or equipment) to extract time-displacement data and from this, movement velocities and subsequent accelerations are calculated. Through the process of differentiation, this kinematic data can be used to estimate forces and power when the mass of the load and/or subject moved are factored in [8,9]. Some commercially available linear transducers can also offer additional features such as real-time feedback, wireless transmission and/or online support services. Valid estimates of force and/or power ($r=0.86–1.00$) have been reported during the performance of isoinertial exercise using a single linear transducer system [8,9]. Accelerometers can also be used to estimate force and power via the differentiation of acceleration and mass data [16,20]. Due to their small size, portability and ease of use, these devices can be attached to a wide range of equipment or even directly to a person during sporting and normal everyday activities, thereby offering greater versatility than linear transducers. Tri-axial accelerometers also have the potential for assessing human movement in 3 different planes, especially when coupled with other devices (e.g., gyroscope, magnetometer). The validity ($r=0.85–0.99$) of accelerometers for calculating force, velocity and power during isoinertial exercise has been confirmed [4,16,20]. Despite their relative validity, the performance estimates from linear transducers or accelerometers can still differ from criterion values [5,6,15,16,20]. This highlights the need to address both the relative and absolute validity of
a given measurement system. Little research has also described the criterion and concurrent validity of both instruments during a dynamic exercise relevant to sport (e.g., loaded squat jumps) and in a trained population. Finally, little research has additionally described the presence of bias within the estimated performance values. Addressing these issues would allow researchers and practitioners to make informed decisions about the use of each kinematic system in different constructs.

This study assessed the validity of 2 commercially available kinematic systems, a linear position transducer and accelerometer, for estimating peak force (PF) and peak power (PP) during squat jumps in weight-trained males. We hypothesized that each system would exhibit relative validity (i.e., strong correlations), but their absolute validity (i.e., mean values) would differ from a criterion force plate. We also addressed the presence of systematic and proportional bias in the performance estimates.

**Methods**

**Participants**

12 healthy males were recruited with a mean (± SD) age, height and body mass of 28.8 ± 6.8 years, 181.1 ± 8.4 cm and 86.8 ± 9.2 kg, respectively. The criteria for study inclusion were: a weight-training background, being able to squat 1.5 times their body mass and no injuries or conditions that would prevent them from safely undertaking the testing procedures. Each participant read and signed an informed consent form and filled out a health questionnaire. The Human Subject Ethics Committee of Swansea University provided ethical approval. This study was performed in accordance with the ethical standards of the International Journal of Sports Medicine [12].

**Testing procedures**

The testing procedures involved the simultaneous assessment of squat jump force and power using 2 kinematic (linear transducer, accelerometer) systems and a kinetic (force plate) system. Before testing, subjects performed a light warm-up comprising of dynamic bodyweight exercise and stretching. Next, 2× single repetition squats were performed with a 20-kg, 40-kg, 60-kg and 80-kg load (including the 20-kg bar mass) with 2 min rest separating each trial. The squats were performed using a standard technique [5, 6]. Subjects began in a standing position, feet shoulder width apart, with the loaded bar placed on the shoulders and upper back. Subjects then slowly descended to a self-selected depth, keeping the head up and back straight, before extending upwards to the start position. Fast concentric movements were performed with subjects attempting to leave the ground with each lift. For safety reasons, subjects were instructed to extend up onto the toes when lifting the 80-kg load, but to maintain ground contact at all times.

Subjects performed their squats directly on top of a Kistler portable force plate (Type 92866AA, Kistler Instruments Ltd, Farnborough), which was used to collect ground reaction force (GRF) data. The force plate was positioned in the centre of the squat rack and stabilized using a solid wooden base that was also flush with the force plate surface. A commercial linear position transducer (Gymaware [GYM], Kinetic Performance Technology, Australia) was also tested, consisting of a linear encoder unit which relays information (via infrared signals) to a hand-held unit. The connection cable was attached to the right side of the bar with the encoder placed directly under, and perpendicular to, the bar movements. A light weight (<200 g) commercial tri-axial accelerometer (Myotest® [MYO] – Myotest Inc, Switzerland) was attached to the bar using a custom-built plastic clip. The device was placed near the centre of the bar, between the shoulder and thumb of the right hand, and kept vertical for each lifting movement. ▶ Fig. 1 shows the attachment for the 2 kinematic devices to the squatting bar.

**Data analysis**

Data from the force plate were sampled at a rate of 1000 Hz for all jumps and the platform’s calibration was confirmed pre and post testing. The vertical component of GRF, as each subject performed their squat jumps, was used in conjunction with their body weight to determine instantaneous velocity and displacement of the subject’s centre of gravity (CG) [13]. Instantaneous power was determined as follows:

\[
\text{Power (W) = vertical GRF (N) × vertical velocity of CG (m.s}^{-1}\)\]

In order to determine the velocity of the subject’s CG numerical integration was performed using Simpson’s rule with intervals equal to the sample width. Prior to the calculation of the strip area, the subject’s body weight was subtracted from the GRF values. The area of the strip then represented the impulse for that time interval. Using the relationship that impulse equals change in momentum; the strip area was divided by the subject’s mass to determine the CG change in velocity, which was then added to the CG’s previous velocity to produce a new velocity for that time interval. The CG velocity was taken to be zero prior to the initiation of the jump and specifically at the point identified as the start of the jump. This point was defined as the time when the subject’s GRF exceeded the mean ± 5 standard deviations from the values obtained in the second (stationary body weight measuring) phase immediately prior to the command to jump [21]. The determination of power or velocity requires the force time history to be integrated and this has the effect of attenuating any noise present in the original signal [23], although this process is apparently sensitive to drift and the choice of integration constants [11]. In regards to the physical equipment, all screened cables and earth connections were checked for integ-
rity, and the testing location was chosen to reduce potential sources of mechanical or electrical interference. The GYM displacement data were time-stamped with a 1 millisecond resolution and then down-sampled to 50 Hz for analysis using a customized software programme. The sampled data were not filtered [9]. Instantaneous bar velocity was calculated for each time interval as bar displacement over change in time. Acceleration was determined from the change in velocity over the change in time for consecutive data points. Instantaneous force was then determined by multiplying system mass (i.e., external load and body mass) and acceleration, and instantaneous power by multiplying force and velocity, as follows:

\[
\text{Force (N)} = \text{system mass (kg)} \times \text{vertical acceleration of the bar (m.s}^{-2}) \加上 \text{acceleration due to gravity (m.s}^{-2})
\]

\[
\text{Power (W)} = \text{vertical force (N)} \times \text{vertical bar velocity (m.s}^{-1})
\]

The MYO data were down-sampled to 500 Hz and low-pass filtered (4th order, Butterworth) with a cut-off frequency of 10 Hz using a customized computer programme (Labview 8.0, National Instruments, USA). The acceleration data were multiplied by the combined mass of the external load and each subject to determine instantaneous forces, as follows:

\[
\text{Force (N)} = (\text{system mass [kg]} \times \text{vertical acceleration of the bar [m.s}^{-2}]) + (\text{system mass [kg]} \times \text{acceleration due to gravity [m.s}^{-2}])
\]

Acceleration data were multiplied by the time interval between data points to yield instantaneous velocity and instantaneous power was calculated as described above. Pilot testing in trained males revealed reliable estimates of force (coefficients of variation = 2.5% and 2.6%) and power (3.0% and 3.3%) from the GYM and MYO systems, respectively.

### Statistical analyses

Concentric PF and PP for each load were the main outcome variables. The relative validity of each kinematic system was assessed using least squares linear regression [18]. Absolute validity was assessed using repeated measures analysis of variance and Tukey post hoc comparisons, where appropriate. Bland-Altman plots were used to detect the presence of systematic bias ± random error, after plotting the mean of 2 systems against the system differences [1, 3]. Paired t-tests were used to detect any systematic bias between the system means. Proportional bias was also noted (\(r = 0.07 – 0.62\)), but only the MYO estimate of PF (60-kg) reached statistical significance (\(r = 0.62, P < 0.05\)), as seen in \(\text{Fig. 4}\).

### Results

Across all 4 loads, the estimates of PF and PP from the 2 kinematic systems were not significantly different from the measured force plate data (\(\text{Fig. 2, 3}\)). As seen in \(\text{Table 1}\), the PF values from the GYM and MYO systems were significantly correlated (\(P < 0.05 – 0.001\)) with corresponding force plate measurements (\(r = 0.59 – 0.87\) and \(r = 0.87 – 0.97\), respectively). The GYM and MYO estimates of PP were also significantly correlated to the force plate data (\(r = 0.62 – 0.82\) and \(r = 0.66 – 0.90\), respectively) (\(\text{Table 2}\)).

### Discussion

The PF and PP estimates from the GYM and MYO systems were moderately to strongly correlated with the corresponding force plate data across each load. These results are supported by pre-
error bars indicating the minimum and maximum values, respectively. The mean PF and PP values from the kinematic systems were found to be equivalent to the force plate system. However, further examination revealed systematic bias and relatively large random errors in the estimated values, especially with the 20-kg load (PF bias >170N, PF error >335N, PP bias >400W, PP error >878W). Other research have also identified different force and/or power values (v. criterion data) derived from accelerometers [16,20] and a single linear position transducer [5,6,15]. One likely reason lies in movement disparities between the centre of mass (measured by the force plate) and bar movement (measured by the kinematic systems) during the squat jumps, particularly when lighter loads are moved. Indeed, methods that rely solely on kinematic data cannot account for body movement that occurs independently of the bar [6]. Bar movements in the horizontal plane could provide another source of error, especially during free-weight exercises. Further problems lie in the differentiation of accelerations and velocities which can magnify any errors in data acquisition [23] and subsequent curve estimations, along with the varied sampling frequencies for each device in this study (50Hz, 500Hz and 1000Hz).

The exercise tested in this study requires some consideration. Experimental studies have demonstrated that different testing methods, involving one or more kinematic and/or kinetic systems, can strongly influence the force and power outputs obtained during squat jumps [5,6,15,17]. A review of these methods and calculations has highlighted several problems when assessing this exercise [10]. For example, assumptions that the human body works as a single rigid system and that the bar velocity is equivalent to that of the entire system [10]. It is also assumed that acceleration occurs uniformly between exercises and individuals. The need to exclude the mass of the shanks and feet, due to their static positioning prior to the jump squat takeoff, the effects of free-weight exercises and instructions given to participants are other considerations [10]. Given these issues, the best method/s for characterizing squat jump performance has yet to be defined.

Although only the MYO estimate of PF exhibited significant proportional bias (i.e., heteroscedastic error), some of the non-significant results also tended to suggest the presence of heteroscedasticity, based on the criteria of R²>0.1 [2]. These results are not uncommon for the measurement of variables in sports medicine and sports science [19]. The issue of proportional bias can be partly resolved by the log transformation of data [3], as we found (data not shown). It is important to note that measurement bias can also be detected using linear regression models [14,18], but their discussion is beyond the scope of this paper. Irrespective of the statistical method used, one must still decide on acceptable levels of bias associated with a given instrument and the subsequent applications in sport. Taken together with other information (e.g. size, portability, ease of use, cost effectiveness), these results can assist researchers and practitioners in making informed decisions about the use of each kinematic system within a specific construct.

**Table 1** Peak force (PF) results vs. the force plate data.

<table>
<thead>
<tr>
<th></th>
<th>20-kg</th>
<th>40-kg</th>
<th>60-kg</th>
<th>80-kg</th>
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<tbody>
<tr>
<td>GYM</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>correlations</td>
<td>0.59*</td>
<td>0.83**</td>
<td>0.87**</td>
<td>0.87**</td>
</tr>
<tr>
<td>systematic bias (N)</td>
<td>+202a</td>
<td>+108a</td>
<td>+39</td>
<td>+57</td>
</tr>
<tr>
<td>random error (N)</td>
<td>±579</td>
<td>±255</td>
<td>±255</td>
<td>±414</td>
</tr>
<tr>
<td>proportional bias</td>
<td>0.29</td>
<td>0.19</td>
<td>0.29</td>
<td>0.13</td>
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<tr>
<td>MYO</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>correlations</td>
<td>0.87**</td>
<td>0.89**</td>
<td>0.95**</td>
<td>0.97**</td>
</tr>
<tr>
<td>systematic bias (N)</td>
<td>+171a</td>
<td>+73</td>
<td>+32</td>
<td>+7</td>
</tr>
<tr>
<td>random error (N)</td>
<td>±336</td>
<td>±256</td>
<td>±196</td>
<td>±219</td>
</tr>
<tr>
<td>proportional bias</td>
<td>0.41</td>
<td>0.51</td>
<td>0.62*</td>
<td>0.21</td>
</tr>
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</table>

*a* Significant r-values P<0.05; ** Significant r-values P≤0.001

*Significance difference between the system means P<0.05*
One of the study limitations is the small number of subjects assessed (n=12), which can influence the interpretation of Bland-Altman plots [1] and the statistical power of our findings. Given the limited number of data points, it was also difficult to assess the uniformity (or lack thereof) of the random error across each of the measured variables. A review of gas analysis systems proposed that 40 subjects are needed for validation purposes [1], which could serve as a good starting point for research in this area. As a delimitation, the current study focused on the kinetic responses of the propulsive (i.e., lifting the load) phase of the squat jumps, not the deceleration (i.e., lowering the load) phase, and the population tested were weight-trained males.

In conclusion, the estimation of squat jump PF and PP (in the concentric phase) by a commercial linear position transducer and accelerometer both showed moderate to strong relative validity and equivalent absolute validity. However, the PF and PP estimates from the 2 kinematic systems are limited by the presence of systematic and proportional bias, along with relatively large random errors, which can affect their use within sport.

Acknowledgements

The authors acknowledge Mr. Scott Damman (Myotest, USA) for providing the MYO system. None of the authors have received any payment or other financial support related to this work. This project was partly funded by the Engineering and Physical Sciences Research Council (EPSRC) UK, as part of the Elite Sport Performance Research in Training with Pervasive Sensing (ESPSTR) programme (EP/H009744/1).

References
19 Nevill AM, Atkinson G. Assessing agreement between measurements recorded on a ratio scale in sports medicine and sports science. Br J Sport Med 1997; 31: 314–318
EFFECTS OF PLYOMETRIC TRAINING USING A PORTABLE SELF-COACHING SYSTEM ON RUNNING PERFORMANCE AND BIOMECHANICAL VARIABLES IN JUMP EXERCISES

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The ability of muscles and tendons to store and release elastic energy have been considered to be more important factors than previously thought to achieve a higher level of performance during distance running. However, few training studies have directly evaluated the effect of plyometric training on improving running performance. PURPOSE: To elucidate the effects of body weight plyometric training, integrated into an 8 week run training program, on running performance, running economy, and biomechanical variables in jump exercises. METHODS: Twenty subjects were randomly assigned into two groups and performed running training 2 to 3 times per week for 8 weeks. RUN group (n = 12) performed only running based training, consisting of 30 – 60 minutes of jogging and running. EXP group (n = 8) performed running training along with strength and power training, which consisted of basic strength exercises and body weight plyometrics. The EXP group was prescribed training information directly from a self-coaching system, which is a portable electronic system utilizing tri-axial accelerometer technology. Group results were measured pre and post using the 5-km distance running time, running velocity at OBLA, reactive leg strength (evaluated by index of flight time divided by contact time), peak power average of 10 reactive jumps, and counter movement jump height. RESULTS: Total average time spent for actual running throughout the training period in EXP group was significantly (p < 0.05) shorter than RUN group, (800 ± 28.3 and 593 ± 33.1 minutes for RUN and EXP group respectively). Both training group significantly (p < 0.05) improved the 5-km running time and running velocity at OBLA. Reactive leg strength (evaluated by index of flight time divided by contact time), peak power average of 10 reactive jumps, and counter movement jump height. RESULTS: Total average time spent for actual running throughout the training period in EXP group was significantly (p < 0.05) shorter than RUN group, (800 ± 28.3 and 593 ± 33.1 minutes for RUN and EXP group respectively). Both training group significantly (p < 0.05) improved the 5-km running time and running velocity at OBLA. However, there was no statistically significant (p > 0.05) difference between the groups. Only the EXP group significantly (p < 0.01) improved the reactive leg strength, peak power in the reactive jumps, and counter movement jump height.

### TABLE. XXX.

<table>
<thead>
<tr>
<th></th>
<th>2.4 kph</th>
<th>4.0 kph</th>
<th>5.6 kph</th>
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<tr>
<td><strong>VO₂ (ml·kg⁻¹·min⁻¹)</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>MT</td>
<td>10.7 ± 2.0</td>
<td>13.8 ± 2.3</td>
<td>19.2 ± 3.9</td>
</tr>
<tr>
<td>CT</td>
<td>13.6 ± 1.6*</td>
<td>19.5 ± 2.3*</td>
<td>26.1 ± 2.7*</td>
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<tr>
<td><strong>HR (bpm)</strong></td>
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<td></td>
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<tr>
<td>MT</td>
<td>81 ± 8</td>
<td>88 ± 7</td>
<td>101 ± 8</td>
</tr>
<tr>
<td>CT</td>
<td>90 ± 9*</td>
<td>104 ± 10*</td>
<td>120 ± 10*</td>
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<tr>
<td><strong>RPE (0-10)</strong></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>MT</td>
<td>0.5 ± 0.7</td>
<td>0.8 ± 0.8</td>
<td>1.7 ± 1.1</td>
</tr>
<tr>
<td>CT</td>
<td>0.6 ± 0.9</td>
<td>1.3 ± 1.2*</td>
<td>2.0 ± 1.4</td>
</tr>
<tr>
<td><strong>StO₂ (%)</strong></td>
<td></td>
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<tr>
<td>MT</td>
<td>78 ± 13</td>
<td>79 ± 12</td>
<td>77 ± 12</td>
</tr>
<tr>
<td>CT</td>
<td>73 ± 17</td>
<td>74 ± 17*</td>
<td>73 ± 15*</td>
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</table>

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CONCLUSIONS: The strength and plyometric training integrated into the 8 week running program improved running performance and running economy to the same extent as the running only training, but with approximately 25% less running volume than the running only training. The increase of reactive leg strength and power appear to transfer into improved running economy more effectively, versus running only training.

PRACTICAL APPLICATIONS: Training with the portable self-coaching system used in this study appear to improve running performance more effectively than traditional running only training, and prevent injuries or overtraining syndrome often associated with run only training, while also building a foundation for subsequent training and development of running performance. ACKNOWLEDGMENT: This investigation was supported by Myotest, SA and New Balance Japan, Inc.
Validity of the Myotest® in Measuring Force and Power Production in the Squat and Bench Press

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1Human Performance Laboratory, Department of Kinesiology, University of Connecticut, Storrs, Connecticut; 2Department of Exercise Sciences and Sport Studies, Springfield College, Springfield, Massachusetts; 3Division of Geriatric Medicine, Center for Aging, University of Connecticut Health Center, Farmington, Connecticut; 4Department of Kinesiology, University of Rhode Island, Kingston, Rhode Island; and 5Department of Kinesiology, Health Promotion and Recreation, University of North Texas, Denton, Texas

ABSTRACT
Comstock, BA, Solomon-Hill, G, Flanagan, SD, Earp, JE, Luk, H-Y, Dobbins, KA, Dunn-Lewis, C, Fragala, MS, Ho, J-Y, Hatfield, DL, Vingren, JL, Denegar, CR, Volek, JS, Kupchak, BR, Maresh, CR, and Kraemer, WJ. Validity of the myotest® in measuring force and power production in the squat and bench press. J Strength Cond Res 25(8): 2293–2297, 2011—The purpose of this study was to verify the concurrent validity of a bar-mounted Myotest® instrument in measuring the force and power production in the squat and bench press exercises when compared to the gold standard of a computerized linear transducer and force platform system. Fifty-four men (bench press: 39–171 kg; squat: 75–221 kg) and 43 women (bench press: 18–80 kg; squat: 30–115 kg) (age range 18–30 years) performed a 1 repetition maximum (1RM) strength test in bench press and squat exercises. Power testing consisted of the jump squat and the bench throw at 30% of each subject’s 1RM. During each measurement, both the Myotest® instrument and the Celesco linear transducer of the directly interfaced BMS system (Ballistic Measurement System [BMS] Innervations Inc, Fitness Technology force plate, Skye, South Australia, Australia) were mounted to the weight bar. A strong, positive correlation (r) between the Myotest® and BMS systems and a high correlation of determination (R²) was demonstrated for bench throw force (r = 0.95, p < 0.05) (R² = 0.92); bench throw power (r = 0.96, p < 0.05) (R² = 0.93); squat jump force (r = 0.98, p < 0.05) (R² = 0.97); and squat jump power (r = 0.91, p < 0.05) (R² = 0.82). In conclusion, when fixed on the bar in the vertical axis, the Myotest is a valid field instrument for measuring force and power in commonly used exercise movements.

KEY WORDS strength testing, power testing, technology, concurrent validity, construct validity, testing reliability

INTRODUCTION
Monitoring of force and power during a workout can be important to determine the quality of a workout. With the increased use of flexible nonlinear periodization techniques, understanding if the quality is there for a power workout is key in making the determination whether to continue or not (16,24). In addition, understanding the peak force and power production in an exercise can help characterize the workout beyond just weight on the bar (10). Practical monitoring such workout characteristics in a weight room setting requires a field instrument that can be easily used and cost effective for use at multiple training stations with groups of athletes.

Over the past 15 years, field and weight room instruments allowing greater visualization of physical performance have become popular and are now used by strength and conditioning professionals (3,5,11,15,25). As training session evaluations become more sophisticated, a host of such technological interfaces will be needed to help strength and conditioning professionals visualize workout performances or track training progress. From such data, modifications in the exercise prescriptions can be made in real time during a workout or be used to evaluate the training progression and subsequent exercise prescriptions for the upcoming workouts (16,22,24). Thus, performance evaluation is therefore an...
important component of strength and conditioning success and performance outcomes for a range of populations from athletes to health and fitness enthusiasts.

A host of techniques and instruments have been developed to measure performance, including contract mats, accelerometers, and force platforms. According to Nigg and Herzog (21), a force platform paired with a linear transducer is still considered to be the gold standard for direct performance evaluations. However, the cost of this equipment, its size, and its experimental requirements has limited its application beyond the laboratory to this point in time (10). However, such laboratory systems are important in the determination of the validity of different instruments to provide similar measures of performance in field and weight room conditions. The need for multiple instruments to be used in the weight room or on the courts and athletic fields has driven sport scientists and industry to develop more economical and portable instruments for such uses (5,10,11,15,19,23,25).

In this study, we tested the validity of Myotest® Performance Measuring System (Myotest® SA) when clipped to the bar to measure peak force and power in 2 of the most common exercises used in the weight room, the squat and bench press. Therefore, the primary purpose of this investigation was to conduct a concurrent validity analysis of a bar-mounted Myotest® System in measuring peak force and power production as compared to a gold standard measurement system.

**METHODS**

**Experimental Approach to the Problem**

This study was aimed at the determination of concurrent validity to evaluate a portable field type testing instrument. A secondary purpose was to determine the test–retest reliability of the measures. Our approach was to simultaneously measure force and power with a gold standard laboratory setup and the experimental instrument. We chose the bench press and the squat exercises because they are standard exercises used in most resistance training programs (2). To evaluate peak force, we examined the 1 repetition maximum (1RM) and to evaluate peak power we examined it during the performance of a bench throw and squat jump at 30% of 1RM. Our approach also was to recruit men and women with a wide variety of exercise training backgrounds and performance capabilities to produce the needed wide distribution of scores for analysis (26). We also examined the test–retest reliability of the measures with a subset of the subject population performing the same tests on different days (14).

**Subjects**

Each of the subjects was informed of all benefits and risks and of the investigation and then signed an institutionally approved informed consent document before all testing. All experimental protocols were approved by the University of Connecticut’s Institutional Review Board for use of human subjects. All testing was done at the University of Connecticut’s Human Performance Laboratory using the same equipment. Fifty-four men and 43 women volunteered for this study. We had a wide range of capabilities in the 1RM strength in the bench press and the squat exercises. In the men (height, 182.9 ± 10.1 cm; body mass, 872 ± 14.2 kg; age, 24.2 ± 4.2 years) we saw lifts in the bench press ranging from 39 to 171 kg and in the squat ranging from 75 to 221 kg. In the women (height, 167.1 ± 10.1 cm; body mass, 65.1 ± 12.2 kg; age, 23.2 ± 4.2 years), we saw lifts in the bench press ranging from bench press of 18 to 80 kg and in the squat a range of 30–115 kg. In Table 1, the basic strength characteristics of our subjects are presented.

Power testing consisted of the jump squat and the bench throw at 30% of each subject’s 1RM. As noted in our Experimental Approach to the Problem, we recruited subjects with a wide span of performance capabilities owing to their different styles of training ranging from untrained to recreationally trained to highly weight trained individuals. We tested a larger number of subjects to enhance our statistical power and the stability of the coefficients in the regression analyses (14,26). In selecting a heterogeneous group, our investigation sought to better characterize a statistically robust normal curve (14).

**Procedures**

Subjects were familiarized with the testing protocols and allowed to practice the tests to eliminate any neurological learning effects (12). In addition, subjects were hydrated, screened by a registered dietician, had proper amount of sleep, and were ready for all testing. Test–retest reliability data were also collected. The Myotest® instrument was clipped onto the inside portion of the Olympic bar just and for the squat just outside of outside of the shoulder by about 3 cm and outside of the grip in the bench press. The exercise setup was

<table>
<thead>
<tr>
<th>Table 1. Mean ± SD and range of 1 repetition maximum strength capabilities in the 2 tested exercises.</th>
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</thead>
<tbody>
<tr>
<td><strong>Bench press (kg)</strong></td>
</tr>
<tr>
<td>Men (n = 54)</td>
</tr>
<tr>
<td>Women (n = 43)</td>
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</tbody>
</table>
simultaneously interfaced with the computerized hardware and software associated with our Ballistic Measurement System (BMS) system on a Smith machine (Innervations, Inc., Australia, Fitness Technology force plate, Skye, South Australia, Australia), which included a Celesco linear transducer (Chatsworth, CA, USA) measuring at 200 Hz (20). The Myotest® and the BMS simultaneous collected performance data during each of the repetitions. Before this investigation, our laboratory observed that the action of unracking a weight bar from the Smith machine created a change from the Myotest’s® reference axis that influenced results (unpublished data). To ensure that the Myotest® was limited to 1 axis of movement, data collection for the Myotest was initiated only after the bar was unracked for each set. Subjects waited for 1 second after the Myotest® data collection started before commencing each movement. At the cessation of each movement, subjects waited an additional second before the Myotest® data collection was stopped. Subjects were then permitted to rerack the weight bar. The Myotest® was maintained in a vertical position (perpendicular to the floor) for all attempts. All instruments used were calibrated before each testing session. Peak power and force for each movement was obtained for the concentric portion of the movement.

Performance Tests
The 1RM strength tests were completed for both the bench press and squat exercises according to previously described methods (17,18). The bar was unracked, and the starting positions for data collection were in the standing position for the squat and the extended arm position for the bench press. The BMS system and Myotest® commenced data collection after the bar was unracked to the standing (squat) or extended arms (bench press) position and both the eccentric and concentric movements were recorded (17). The Myotest® was stopped once the bar returned to the top position but before racking the bar. The linear transducer was individually set to recognize the bottom point of each exercise (i.e., of the bench press at the chest for the bench press and at the parallel position of the femur with the floor for the squat).

Bench throws and squat jumps were performed to examine the power analysis of the Myotest® instrument. For power testing, we used a load of 30% of the 1RM bench and 1RM squat, respectively (17). Again, data collection started after the subject unracked the bar with either the arms fully extended for the bench throw or the subject standing for the start of the squat jump. Subjects performed a bench throw or squat jump and returned the bar to the starting position. Each exercise movement was repeated for 3 consecutive explosive repetitions with the highest value used for analysis from the same repetition. Data collection stopped when the subject ended the last repetition and was ready to rack the bar. The linear transducer was set to recognize the release point of the bar for the bench throw and the take-off point of the squat jump.

Statistical Analyses
Regression analysis was used to determine pairwise relationships between the Myotest® instrument and the direct online measurement systems (14). All assumptions for linear statistics were met and statistical power was ≥0.89. Because of familiarization with all testing, the reliability of the measures demonstrated intraclass correlation coefficients (ICCs) of $R \geq 0.96$ for all tests for men and women. The ICCs were assessed for each measure to determine test–retest reliability of the measurements (1). Significance in this study was set at $p \leq 0.05$.

RESULTS
Table 2 presents the results of the regression analysis and the $R^2$ representing the amount of shared variance of the 2 variables accounted for in the regression analysis. The highest amount of shared variance was observed for the relationship of the maximal force during the 1RM in both the bench press and squat exercises. Relationships for power in the bench throw were also quite high. However, squat jump power was lower for each of the individual sex partition groups compared to the combined group. Nevertheless, each of the individual correlations would be considered high because they were $>0.7$ (1,14).

DISCUSSION
With improved technology now available for use in the field of strength and conditioning to evaluate force and power, validation of different types of instruments with gold standard laboratory technology can play an important role in enhancing its use. Recent studies have attested to this important need

### Table 2. $R^2$ correlations of Myotest with laboratory gold standard measurements.*

<table>
<thead>
<tr>
<th></th>
<th>Bench press force (1RM)</th>
<th>Bench throw peak power (30% of 1RM)</th>
<th>Squat force (1RM)</th>
<th>Squat jump peak power (30% of 1RM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men ($n = 54$)</td>
<td>0.97</td>
<td>0.98</td>
<td>0.97</td>
<td>0.66</td>
</tr>
<tr>
<td>Women ($n = 43$)</td>
<td>0.93</td>
<td>0.88</td>
<td>0.73</td>
<td>0.56</td>
</tr>
<tr>
<td>Combined</td>
<td>0.92</td>
<td>0.92</td>
<td>0.97</td>
<td>0.82</td>
</tr>
</tbody>
</table>

*1RM = 1 repetition maximum.
Concurrent Validity of Myotest Instrument

in the literature (4–6,10). Although reliability may be highly dependent upon each individual group’s capabilities for adequate control, concurrent validity of new technology with “gold standard” methodologies is needed for understanding its potential use. In this study, the primary finding was that the Myotest® instrument demonstrated high concurrent validity when compared to the laboratory-based instrumentation.

Reliability of a particular measure is dependent upon the controls and familiarization used by the investigative group or strength and conditioning staff. Therefore, although a test may be reliable in 1 group’s hands, it may not necessarily be the same in another’s. Reliability measures are really more important for the investigative group performing the tests because no guarantees can be made that others will be able to perform the tests at the same level of repeatability as demonstrated in a specific study. However, without high reliability within a study of validity, the findings may be moot. Reliability of the measures is related to the controls implemented in a testing protocol and must be detailed in the procedures for others to use. In this study, the reliability of the Myotest® instrument demonstrated exceptionally high test–retest reliability of $R \geq 0.96$ in both men and women. This reliability was in part related to the controls for exercise technique, time of day, and nutritional controls (17).

The concurrent validity of the bench press and squat maximal forces was very high for men and women. The women demonstrated a very high bench press force validity yet in the squat, although still considered high, the validity was lower in magnitude. The overall differential between the maximal lifts may be because of the past experience with the squat technique using a Smith machine. Differences in the bar movement and technique might have differentially influenced the measurement systems over the range of motion. We can speculate that this might be because of the bar position during the lift and possible forward rotation of the bar in the movement even when using a maximal weight and this may have impacted accelerometry compared to BMS calculations in the women. In the squat, the overall validity was apparently statistically smoothed out with the inclusion of both sexes (1).

The majority of the exercises used to assess performance (squat, vertical jump) produce body movement in the frontal or sagittal plane. This introduces a challenge for the collection of data on the vertical axis. Extraneous horizontal displacement of measurement devices from the vertical axis may disrupt the accuracy of velocity and vertical displacement. It has been demonstrated that in the traditional bar-mounted linear transducer, a change in horizontal displacement of a weight bar by $10^\circ$ may result in overestimations of vertical velocity by 1.54% (8). Similarly, the excessive horizontal movement of the body during various movements may result in invalid measurements from an accelerometer mounted to the hips or other parts of the body. Further, oscillations of body tissue during a movement may influence the results of a body-mounted device. In this study, instrument placement was the bar and only subject to rotational effects.

In the power production for the bench press in both men and women, $R^2$’s were very high (0.98 and 0.86 for men and women, respectively, again with smoothing effect with the total sample population). This may again have been because of the lack of significant bar rotation in this movement with hands on the bar with little perturbation to alter the grip-to-bar relationship during the lifts. In the bench throw, the bar is released at the height of the acceleratory arm movement on a fixed vertical axis (17,20). The prior familiarization is vital to allow for experience in this explosive test in a fixed vertical plane on the Smith machine. The reliability also interacts to produce the absolute magnitude similarities in velocity calculations in the measurement systems. Although differences are well established between free weight and Smith machine resistance exercise modalities, instrument positioning and horizontal excursions from the vertical and bar rotational movements appear to be the major concerns for comparative accuracy between the different measurement systems (9).

In the squat jump power, a similar phenomenon of bar rotation might have existed because concurrent validity $R^2$ was 0.66 and 0.56 for men and women, respectively. With a larger degree of freedom in the bar movement with arm to grip use in the jump, rotational movement of the bar may again have altered the relationship between the 2 measurement systems. Again with combined data from men and women, a statistical smoothing effect on the entire regression curve was evident with the combined distributions. With the use of the Smith machine, horizontal movements of the bar away from the vertical vector was eliminated thus pointing to the role of bar rotation over the range of motion as being a potential measurement complexity. Nevertheless, the concurrent validity of the Myotest® instrument would be considered high. This combined with the reliability makes the instrument a viable field testing modality when more expensive computerized systems are not available.

Previous investigations into the validity of accelerometers demonstrated limitations in velocity measures when mounted to the body. Casartelli et al. (7) evaluated the validity of the Myotest® (mounted at the hip on an elastic belt) to the Optojump for various jump-related tasks. Although the Optojump exhibited strong concurrent validity and good test–retest reliability with a force platform, it underestimates vertical jump height by approximately 1 cm (13). A high concurrent validity in Myotest® flight time was seen in squat jump (0.98), countermovement jump (0.98), and rebound jump (0.98) in their investigation; however, the Myotest® showed a low concurrent validity for velocity in 3 of the jumps.

To help maintain the measurement instrument in the vertical axis, a linear transducer is often attached to the weight bar of a Smith machine. This technique also eliminates the sagittal movement of the barbell during the test, but bar rotational effects can still be possible due to grip on the bar, as well as individual shoulder and bar position. The current
investigation supported our hypothesis in demonstrating that fixing the Myotest® eg; to the bar of a smith machine provided valid experimental results. Although small changes in athletic performance may not produce statistical significance, such changes may be meaningful to coaches and athletes. It is therefore vital to understand the reliability and validity of measurement tools, especially when newly developed (1). When fixed to a single plane, the Myotest® instrument demonstrated high validity in testing strength and power. In addition, the Myotest® instrument demonstrated high concurrent validity scores in measuring strength and power in men and women of various strength fitness capabilities.

PRACTICAL APPLICATIONS

The Myotest® instrument demonstrates a very high degree of concurrent validity along with reliability as a field testing instrument. The relative changes to track any type of training program will be sensitive to a <5% of treatment effect. Placement of the Myotest® instrument seems to be a vital consideration when using a barbell or when rotational effects or horizontal deviation are in play. Thus, care in the placement of the instrument is a vital consideration (e.g., clip onto the nonmoving collar of the Olympic bar and predetermine the amount of displacement from the vertical axis for free weights or jumps which should be <10% for the instrument vertical tracking changes) for matching the magnitude of each system’s measurement output, yet the data are still highly associated even when bar rotational effects are experienced when using a Smith machine. However, coaches and athletes must take care to maintain a fixed vertical axis and limited bar rotational to ensure accurate results. The use of this instrument is appropriate to evaluate changes in power and force production for the bench press and squat exercises.

ACKNOWLEDGMENTS

The authors would like to thank the many dedicated subjects that made this study possible. The findings of this study do not imply endorsement by the National Strength and Conditioning Association. This study was funded in part by a grant from Myotest Inc, Royal Oak, MI, United States.

REFERENCES

With the importance of field and laboratory assessments of workouts and training programs, it is vital that testing instruments are available that are both valid and reliable in their measurements. Myotest Inc. is dedicated to a line of research to provide independent laboratory evaluations of its instrumentations. Investigators in the Human Performance Laboratory at the University of Connecticut are conducting the research on the “Myotest” instruments performance to determine its “construct validity” using simultaneous data collection to compare the typically used “golden standard” force plate and transducer data acquisition systems. **Examples of a two data sets on some of the technology comparisons** that are being made can be seen in Figures 1 and 2 showing how they compare with gold standard measures. In addition, the test-retest reliability is being determined under different time frames. The Myotest testing instrument is designed to provide quantitative assessment of power, force, velocity, displacement, and other measures of physical performance. Traditionally, the high costs, impracticality, and technical demand of “gold standard” devices have negatively impacted their use. Myotest, a wireless hand-held device weighing a few ounces, is less costly than traditional performance assessment devices. It appears to possess the potential to make a substantial impact in its fields of use. The Myotest device would improve quantitative assessment in clinical, research, and applied practices, if the precision and accuracy of measurement corresponds to “golden standard” devices. To test the primary role of the Myotest device, data was simultaneously recorded using the gold standard of performance measurement, a force plate technology and linear transducers, along with the Myotest device. Once complete, 150 subjects representing a broad spectrum of ability will have performed batteries of

![Figure 1. Regression analysis Myotest with force plate](image)
performance tests designed to test of capabilities of the Myotest unit in a range of functional uses (including high intensity force and power exercises). While the research is still under way (with expanded testing) our preliminary abstract on this study shows that the construct validity is very high. Thus, Myotest device possesses measurement capability comparable to that of previously established gold standards. Tests designed to elicit measurements of power, force, and velocity from the Myotest device have all demonstrated results highly comparable to gold standards using force plate and transducer technology. The combination of an advanced accelerometer and advanced intrinsic mathematical modeling systems seems capable of allowing the Myotest device to precisely and accurately gauge physics-based indices of performance. Such measurements are important for assessing workouts and tracking conditioning programs progress.

Figure 2. Regression analysis Myotest with force plate technology.
Validity of Myotest® during a vertical jump test: Preliminary study

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Centre d'expertise de la performance (Performance expertise center) – Faculty of Sport Sciences – Dijon – France

Introduction
The vertical jump is a fundamental quality for athletes. The evaluation of this quality is thus essential when monitoring a person’s physical training. Several tests and evaluation systems can be deployed to assess this quality. The aim of this experiment was to check the validity of the Myotest® for measuring vertical jump tests. The experiment involves comparing two measuring systems to measure vertical movement during squat jumps (SJ) and a reactivity test.

Experimental procedure

Subjects. 30 subjects (6 girls and 24 boys), all of whom study physical education, took part in the study. Each subject was evaluated randomly by means of the two vertical displacement tests: The squat jump (SJ) and reactivity test.

Tests. The SJ allows measurement of “non-pliesometric” displacement and the ability to develop a great deal of strength within a very short space of time (explosiveness). This test consisted of the person jumping as high as possible with their hands on their hips from a half-squat position (i.e. 90° bending of the knees). This position was maintained for about 1s. The subjects were then instructed to extend the lower limbs as explosively as possible with the aim of performing a squat jump. Three attempts were made at this exercise. The best result was retained for analysis.

The reactivity test allows us to measure the calf muscle power. The subjects performed 6 vertical jumps (with as little bending of the knees as possible) with their arms as support. The idea was to achieve the least possible contact time for a maximum jump height. The test was only performed once.

The average height of the 6 jumps was calculated and then compared.

Equipment used. The jump heights were simultaneously recorded using two evaluation systems. The Myotest® (Myotest, Sion, Switzerland) system allows you to calculate the jump height using an accelerometer placed on the pelvis with integration calculations, allowing you to determine the sensor’s vertical displacement (i.e. jump height).
The jump height can also be determined by measuring the airborne time with an Ergojump (Globus Italia, Codogne, Italy) contact mat.

**Statistical analysis.** The values obtained from the two measurement systems are compared per test student. The correlations are then researched to establish the degree of association between the performances recorded by the two systems. A significance threshold of 0.05 was adopted for all of the statistical analyses.

**Results**

The jump height comparison gained from the Myotest® and the Ergojump did not show any significant differences (see table 1). Nevertheless, the jump heights are slightly higher with the Myotest® when compared to those of the Ergojump. This difference was approx. 3 cm, meaning a relative average difference of 9.5%.

<table>
<thead>
<tr>
<th></th>
<th>Ergojump (cm)</th>
<th>Myotest® (cm)</th>
<th>Difference (cm)</th>
<th>Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Squat Jump</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>32.1</td>
<td>34.8</td>
<td>2.7</td>
<td>8.7</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>6.3</td>
<td>7.0</td>
<td>2.8</td>
<td>9.1</td>
</tr>
<tr>
<td><strong>Reactivity</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>31.5</td>
<td>34.6</td>
<td>3.0</td>
<td>10.7</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>5</td>
<td>7.2</td>
<td>3.3</td>
<td>12.5</td>
</tr>
</tbody>
</table>

*Table 1* Heights of the squat jump tests and reactivity measured with the Myotest® and Ergojump.

Relations between the jump heights measured with the Myotest® and Ergojump are shown in figure 1. Significant correlations were achieved for the SJ and reactivity test ($P < 0.001$).

![Figure 1](image)

*Figure 1 – Correlations between the jump heights of the Ergojump and Myotest® during the SJ (A, $r^2 = 0.84$, $P < 0.001$) and reactivity test (B, $r^2 = 0.87$, $P < 0.001$).*
Conclusion
The aim of this experiment was to check the validity of the Myotest® during vertical jump tests. The preliminary results show a significant correlation between this system and the Ergojump for both the SJ and the reactivity test. A difference of about 9% was recorded in favor of the Myotest®. This difference can be explained due to the measurement method and the calculation method used. The contact mat takes the airborne time into account whereas the Myotest® only measures the acceleration of the center of gravity during the ground contact phase. The Myotest® therefore appears to be an efficient tool for evaluating performance during the vertical jump test. However, complementary studies need to be carried out to round out this study. Such studies could include (i) a comparison of the Myotest® with other systems (e.g. force platform) using parameters such as take-off speed or power or (ii) a test involving the reproducibility of the measurements.
EFFECTS OF PLYOMETRIC TRAINING USING A PORTABLE SELF-COACHING SYSTEM ON RUNNING PERFORMANCE AND BIOMECHANICAL VARIABLES IN JUMP EXERCISES

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The ability of muscles and tendons to store and release elastic energy have been considered to be more important factors than previously thought to achieve a higher level of performance during distance running. However, few training studies have directly evaluated the effect of plyometric training on improving running performance. PURPOSE: To elucidate the effects of body weight plyometric training, integrated into an 8 week run training program, on running performance, running economy, and biomechanical variables in jump exercises. METHODS: Twenty subjects were randomly assigned into two groups and performed running training 2 to 3 times per week for 8 weeks. RUN group (n = 12) performed only running based training, consisting of 30 - 60 minutes of jogging and running. EXP group (n = 8) performed running training along with strength and power training, which consisted of basic strength exercises and body weight plyometrics. The EXP group was prescribed training information directly from a self-coaching system, which is a portable electronic system utilizing tri-axial accelerometer technology. Group results were measured pre and post using the 5-km distance running time, running velocity at OBLA, reactive leg strength (evaluated by index of flight time divided by contact time), peak power average of 10 reactive jumps, and counter movement jump height. RESULTS: Total average time spent for actual running throughout the training period in EXP group was significantly (p < 0.05) shorter than RUN group, (800 ± 28.3 and 593 ± 33.1 minutes for RUN and EXP group respectively). Both training group significantly (p < 0.05) improved the 5-km running time, running velocity at OBLA, reactive leg strength (evaluated by index of flight time divided by contact time), peak power average of 10 reactive jumps, and counter movement jump height. However, there was no statistically significant (p ≥ 0.05) difference between the groups. Only the EXP group significantly (p ≤ 0.01) improved the reactive leg strength, peak power in the reactive jumps, and counter movement jump height.

<table>
<thead>
<tr>
<th>Table. XXX.</th>
<th>2.4 kph</th>
<th>4.0 kph</th>
<th>5.6 kph</th>
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<tr>
<td>VO₂ (ml·kg⁻¹·min⁻¹)</td>
<td></td>
<td></td>
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<tr>
<td>MT</td>
<td>10.7 ± 2.0</td>
<td>13.8 ± 2.3</td>
<td>19.2 ± 3.9</td>
</tr>
<tr>
<td>CT</td>
<td>13.6 ± 1.6*</td>
<td>19.5 ± 2.3*</td>
<td>26.1 ± 2.7*</td>
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<td>HR (bpm)</td>
<td></td>
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<tr>
<td>MT</td>
<td>81 ± 8</td>
<td>88 ± 7</td>
<td>101 ± 8</td>
</tr>
<tr>
<td>CT</td>
<td>90 ± 9*</td>
<td>104 ± 10*</td>
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<td></td>
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<tr>
<td>MT</td>
<td>0.6 ± 0.7</td>
<td>0.8 ± 0.8</td>
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<tr>
<td>CT</td>
<td>0.6 ± 0.9</td>
<td>1.3 ± 1.2*</td>
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<tr>
<td>StO₂ (%)</td>
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<tr>
<td>MT</td>
<td>78 ± 13</td>
<td>79 ± 12</td>
<td>77 ± 12</td>
</tr>
<tr>
<td>CT</td>
<td>73 ± 17</td>
<td>74 ± 17*</td>
<td>73 ± 15*</td>
</tr>
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</table>
CONCLUSIONS: The strength and plyometric training integrated into the 8 week running program improved running performance and running economy to the same extent as the running only training, but with approximately 25% less running volume than the running only training. The increase of reactive leg strength and power appear to transfer into improved running economy more effectively, versus running only training.

PRACTICAL APPLICATIONS: Training with the portable self-coaching system used in this study appear to improve running performance more effectively than traditional running only training, and prevent injuries or overtraining syndrome often associated with run only training, while also building a foundation for subsequent training and development of running performance.

ACKNOWLEDGMENT: This investigation was supported by Myotest, SA and New Balance Japan, Inc.

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