©Journal of Sports Science and Medicine (2010) **9**, 459-463
http://www.jssm.org

Research article

Validity of a commercial linear encoder to estimate bench press 1 RM from the force-velocity relationship

Laurent Bosquet [1, 2, 3] ✉, Jeremy Porta-Benache [1] and Jérôme Blais [2]
[1] Faculty of Sport Sciences, University of Poitiers, Poitiers, France, [2] Department of Kinesiology, University of Montreal, Montreal, Canada, [3] Sport Experts association, Poitiers, France

Abstract
The aim of this study was to assess the validity and accuracy of a commercial linear encoder (Musclelab, Ergotest, Norway) to estimate Bench press 1 repetition maximum (1RM) from the force – velocity relationship. Twenty seven physical education students and teachers (5 women and 22 men) with a heterogeneous history of strength training participated in this study. They performed a 1 RM test and a force – velocity test using a Bench press lifting task in a random order. Mean 1 RM was 61.8 ± 15.3 kg (range: 34 to 100 kg), while 1 RM estimated by the Musclelab's software from the force-velocity relationship was 56.4 ± 14.0 kg (range: 33 to 91 kg). Actual and estimated 1 RM were very highly correlated (r = 0.93, p<0.001) but largely different (Bias: 5.4 ± 5.7 kg, p < 0.001, ES = 1.37). The 95% limits of agreement were ±11.2 kg, which represented ±18% of actual 1 RM. It was concluded that 1 RM estimated from the force-velocity relationship was a good measure for monitoring training induced adaptations, but also that it was not accurate enough to prescribe training intensities. Additional studies are required to determine whether accuracy is affected by age, sex or initial level.

Key words: Muscle strength diagnosis, performance prediction, innovative technology.

Introduction

The ability to develop high levels of force to accelerate or decelerate a limb or an external load of constant mass, usually defined as isoinertial strength (Abernethy and Jürimäe, 1996), is a major determinant of performance in many sports. It is therefore not surprising to observe that the development of maximal isoinertial strength is given a high priority in conditioning programs (Baechle and Earle, 2008). Optimal strength development requires not only a sound understanding of the mechanisms underlying maximal isoinertial strength and a repertoire of strategies to enhance these underlying factors, but also valid and reliable tests and measures to assess this specific component of physical fitness.

Concentric one repetition maximum (1 RM), which represents the maximum load that can be moved through a positive range of motion (i.e. against gravity), has been used for many years to test this specific component of physical fitness (Logan et al., 2000). Reliability of 1 RM has been shown to be very high (r ≥ 0.90) (Hoeger et al., 1990), thus making this measure a convenient tool to monitor training induced adaptations, but also to prescribe training intensities or assist talent identification.

However, for some populations, training status, age or pre-existing medical conditions may be contraindications to the safe completion of 1 RM testing (Reynolds et al., 2006). Predictive equations have thus been developed to estimate 1 RM from submaximal testing, including the maximum number of repetitions that can be performed at a given absolute (Mayhew et al., 2002) or relative load (Hoeger et al., 1990), or the heaviest load that can be lifted for a predetermined number of repetitions (Reynolds et al., 2006). The limit with this approach is that the relationship between 1 RM and submaximal performance is influenced by a number of factors, including age, sex, training status, velocity of movement or muscle group (Hatfield et al., 2006; Hoeger et al., 1990). Validity of these equations is therefore limited to the characteristics of the population used to develop them.

Another possibility to estimate concentric maximal force from submaximal testing consists of extrapolating it from the force – velocity relationship. The typical test consists of performing short maximal sprints (about 6 s) on a bicycle ergometer against increasing braking forces. Velocity ($m\cdot min^{-1}$) is obtained by multiplying cadence ($revolutions\cdot min^{-1}$) by the length of the flywheel ($m.revolution^{-1}$). Sargeant et al. (1981) reported a linear negative relationship between force and velocity in cycling (r = -0.979), and the intercept of the linear regression curve with the force axis has been occasionally used to assess maximal possibilities of elite athletes (Vandewalle et al., 1987). Since this intercept is theoretically equivalent to the maximal isometric force that can be developed in a cycling task, it can be assumed that concentric maximal force borders on this value.

The transposition of this approach to classical lifting tasks such as the Bench press is limited by the difficulty to obtain an accurate measure of the velocity of the bar. Ergotest (Norway) developed a commercial linear encoder that enables access to this information, as well as an algorithm to estimate 1 RM from the force – velocity relationship. This measure could prove to be very interesting for strength diagnosis (Wilson and Murphy, 1996) if its accuracy was confirmed. The aim of this study was therefore to assess the validity and accuracy of a commercial linear encoder (Musclelab, Ergotest, Norway) to estimate Bench press 1 RM from the force – velocity relationship.

Methods

Following a thorough briefing all participants signed a

Received: 22 February 2010 / Accepted: 13 July 2010 / Published (online): 01 September 2010

written statement of informed consent. They completed a Bench press 1 RM test and a Bench press force – velocity test in a random order. Both tests were separated by at least 48 hours and were performed in a 10 – day period. To avoid any residual fatigue induced by recent training, participants were asked to refrain from strenuous exercise the day before the tests. They were also asked to arrive fully hydrated to the laboratory, at least three hours after their last meal. No attempt was made to control the content of this meal.

Participants

Twenty seven physical education students or teachers (5 women and 22 men) participated in this study. They had a heterogeneous history of strength training, but all of them were recreationally active (they exercised at least two times a week). Their age, stature and body mass were 29 ± 10 years, 1.77 ± 0.07 m and 71 ± 12 kg, respectively. The protocol was reviewed and approved by the Research Ethics Board in Health Sciences of the University of Montreal (Canada) and has been conducted in accordance with recognized ethical standards and national/international laws.

Procedures

Exercise testing

Bench press one repetition maximum test

The Bench press 1 RM test was performed on a Smith Machine allowing only vertical movements (Atlantis, Laval, Quebec, Canada). Participants laid supine on a bench with arms fully extended. When cued, they lowered the bar to the chest and had to stay motionless for four seconds before pressing to full extension without assistance (Wilson et al., 1991). Load incrementation was determined according to the procedure proposed by Tagesson and Kvist (Tagesson and Kvist, 2007). Briefly, participants rated the difficulty of each load on a 7-point Likert scale, 30 seconds after the completion of the movement. Load incrementation was then adjusted to this subjective assessment, according to the procedure described in Table 1. Three minutes of passive recovery were given between each attempt (Beelen et al., 1995), and load was increased until task failure. The heaviest load that could be lifted with proper technique was considered as the 1 RM (in kg).

Table 1. Relationship between the rating of perceived exertion for one trial and the load incrementation for the next trial.

Ratings of Perceived Exertion	Load incrementation (kg)
Vey, very light	10
Very light	10
Fairly light	5
Somewhat hard	5
Hard	2
Very hard	2
Very, very hard	1

Bench press force-velocity test

The force-velocity test was performed on the same Smith Machine as the Bench press 1 RM test (Atlantis, Laval, Quebec, Canada). When cued, participants lowered the bar to the chest and had to stay motionless for four seconds before pressing to full extension as fast as possible, and without assistance (Wilson et al., 1991). Participants were allowed to release the bar when possible (i.e. at light loads). Two consecutive trials were performed per load, with the best reading recorded for further analyses. Three minutes of passive recovery were given between each load (Beelen et al., 1995). Initial load was set at 10 kg, and increased by 5 kg every trial. The test was finished when power decreased during at least two consecutive loads. Velocity was recorded by linking a shuttle to the end part of the bar locked to an infrared sensor (Musclelab, Ergotest, Norway). The accuracy of this electronic device reached the 10 µs time resolution with an optical transducer interruption each 3 mm of displacement. Bosco et al. (1995) reported that the maximal measurement error of velocity due to the system was less than 0.9% in any single case. Relative reliability, which represents the degree to which individuals maintain their position in a sample with repeated day-to-day measurements , is very high (r = 0.97), while absolute reliability, which represents the degree to which day-to-day repeated measurements vary for individuals, is very acceptable in both laboratory and field settings (coefficient of variation = 2.3%) (Bosco et al., 1995). Average velocity was calculated through the whole range of motion utilized to perform a complete repetition (from the chest to the full extension), and multiplied by the resistance (in N) to obtain average power (in W). The highest power reached during the test was considered as peak power (P_{peak}, in W). One repetition maximum (in kg) was estimated by the software (Musclelab, Ergotest, Norway) from the force – velocity relationship according to an algorithm that is not provided by the manufacturer.

Statistical analysis

Standard statistical methods were used for the calculation of means and standard deviations. Normal Gaussian distribution of the data was verified by the Shapiro-Wilk test, and homoscedascticity by a modified Levene Test. Both sets of data met these underlying hypotheses. A student t-test for dependent samples was used to test the null hypothesis that 1 RM estimated from the force – velocity relationship was not different from actual 1 RM. The magnitude of the difference was assessed by the Effect Size (ES), calculated according to the following equation:

$$ES = \frac{\dfrac{M_2 - M_1}{SD_{pooled}}}{\sqrt{(1-r)}}$$

where ES is the effect size, M_1 and M_2 are the mean of actual and estimated 1RM, r is the product moment correlation of the two sets of data, and SD_{pooled} is the pooled standard deviation, calculated as follows:

$$SD_{pooled} = \sqrt{\frac{\left(S_1^2 \times (n_1 - 1)\right) + \left(S_2^2 \times (n_2 - 1)\right)}{(n_1 + n_2 - 2)}}$$

where S_1^2 and S_2^2 are the variance of actual and estimated 1 RM, and n is the number of participants.

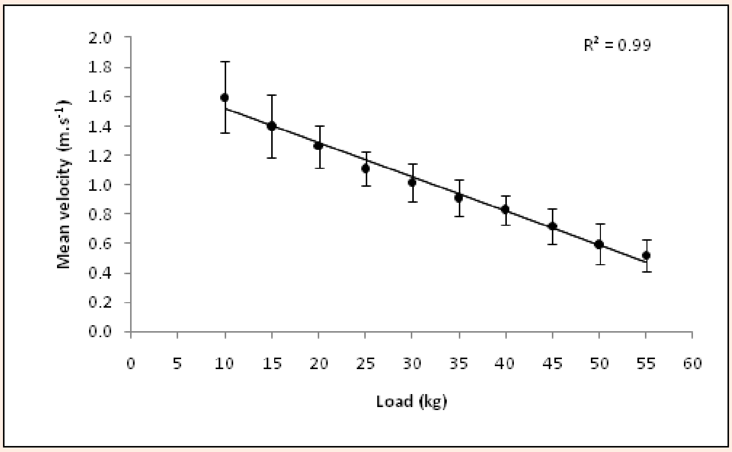

Figure 1. Relationship between load and mean velocity during a bench press task performed on a Smith Machine.

The magnitude of the difference was considered either small ($0.2 < ES \leq 0.5$), moderate ($0.5 < ES \leq 0.8$), or large ($ES > 0.8$) (Cohen, 1988). *A posteriori* power analysis indicated that 27 participants per group would result in a 99% chance of obtaining statistical significance at the 0.05 level for the 1.37 effect size observed in this study. Pearson product moment correlation was used to evaluate the association between the two measures of 1 RM. We considered a correlation over 0.90 as very high, between 0.70 and 0.89 as high and between 0.50 and 0.69 as moderate (Munro, 1997). The 95% limits of agreement were calculated according the method of Bland and Altman (Bland and Altman, 1986). Statistical significance level was set at $p < 0.05$. All calculations were made with Statistica 6.0 (Statsoft, Tulsa, USA).

Results

The number of trials required to detect 1 RM was 4 ± 1 (range: 3 to 6). Mean 1 RM was 61.8 ± 15.3 kg (range: 34 to 100 kg). The number of trials required to obtain the force – velocity relationship was 10 ± 2 (range: 5 to 14). The average curve of participants who were able to perform at least 10 trials (n =19) is presented in Figure 1. Mean P_{peak} of the overall sample was 265 ± 59 W (range: 86 to 407 W) and was reached at 48 ± 9% of actual 1 RM (range: 35 to 65%). Mean 1 RM estimated from the force velocity relationship by the Musclelab's software was 56.4 ± 14.0 kg (range: 33 to 91 kg). Actual and estimated 1 RM were very highly correlated (Figure 2; r = 0.93, $p < 0.001$) but largely different (Bias: 5.4±5.7 kg, $p < 0.001$, ES = 1.37). The 95% limits of agreement were ±11.2 kg (i.e. ± 18% of actual 1 RM), thus suggesting that the difference between actual and estimated 1 RM will lie between these limits in 95 of 100 new individuals performing these tests. The linear regression equation of the relationship between actual and estimated 1 RM (Figure 2) was:

$$y = 1.02x + 4.25$$

where x and y represent estimated and actual 1 RM (kg), respectively. Adjusted coefficient of determination was 0.98 and the standard error of estimate (SEE) was 5.83 kg.

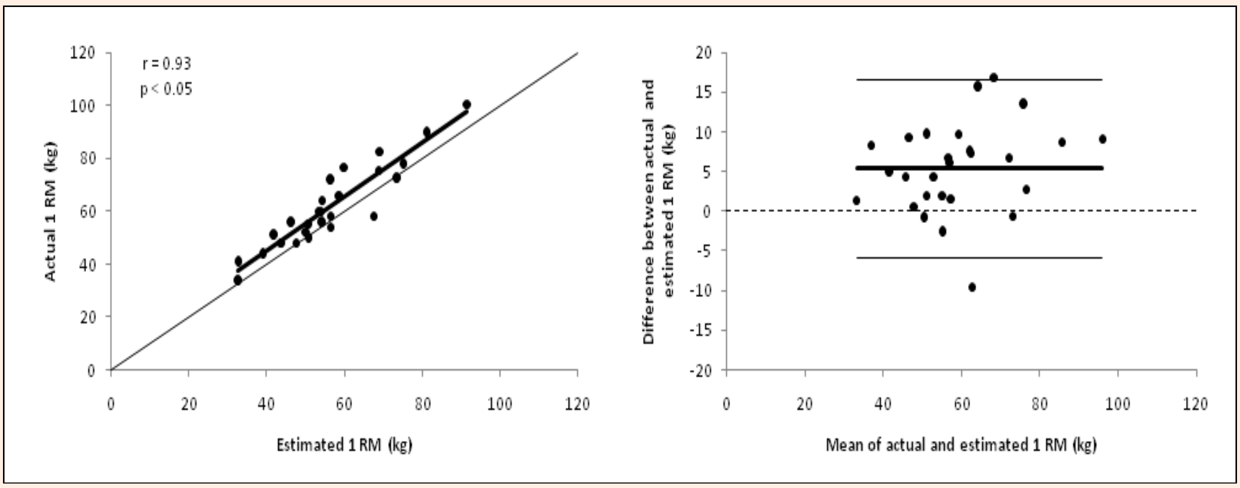

Figure 2. Left panel: association between actual and estimated bench press 1 RM. The dashed line is the line of identity. Right panel: Bland and Altman plots for the comparison between actual and estimated bench press 1 RM. Thick line is the bias, thin lines are the 95% limits of agreement and dashed line is the null bias.

Discussion

The aim of this study was to assess the validity and accuracy of a commercial linear encoder (Musclelab, Ergotest, Norway) to estimate Bench press 1 RM from the force – velocity relationship. Our main finding was the high validity of this estimation, together with a questionable accuracy. Interestingly, the correlation and 95% limits of agreement computed in our study compare very well with data published in two recent reports.

Mayhew et al. (2008) assessed the validity and accuracy of prediction equations that have been developed to estimate Bench press 1 RM from submaximal performance. They reported a very high heterogeneity between methods that was partly explained by the number of repetitions to fatigue used for the predictions (from 2 to 30). A subgroup analysis was therefore performed with equations using no more than 10 RM. A very high validity ($0.91 < ICC < 0.93$) was reported by the authors. Accuracy of predictions, as estimated by the 95% limits of agreement computed from data presented in table 4 by Mayhew et al. (2008) ranged from ±14 to ±21% of actual 1 RM (27.8 9±4.8 kg).

Jidovtseff et al. (2010) examined the relationship between Bench press 1 RM and maximal isometric force estimated from the Bench press force – velocity profile. They reported a very high correlation between actual and predicted Bench press 1 RM ($r = 0.98$), thus confirming the validity of this approach. They did not provide any statistics about the presence of a possible bias between actual and predicted 1 RM, but accuracy of prediction, as estimated by the 95% limits of agreement computed from data presented in the text by Jidovtseff et al. (2010) was ±13.7% of actual 1 RM (60 ± 19 kg).

The general approach which consists of estimating Bench press 1 RM from the force velocity relationship can therefore be considered as being as valid as other methods relying on submaximal performance. A question that remains opened is to determine whether accuracy of the Musclelab's predictions could be improved. Unfortunately, the algorithm developed by Ergotest (Norway) to estimate 1 RM from the force – velocity relationship is unknown. Several possibilities exist, including the force corresponding to a given velocity or to a given percentage of the x-intercept. It is also possible to consider the exclusion of data identified as possible outliers from the regression. However, it was beyond the scope of this study to test such possibilities, and sample size was not appropriate to develop multiple regression equations to estimate 1 RM from the parameters of the force – velocity relationship or other characteristics such as sex, age or initial level. The linear regression between actual and estimated 1 RM could have been used in this purpose, but the measurement error (SEE) was the same than that of direct estimations, and was no better than that reported by Jidovtseff et al. (2010).

Conclusions drawn from the present study are limited to a Bench press lifting task performed on a Smith Machine. It is not certain that our results, particularly those concerning accuracy, would have been the same with a non-guided Bench press lifting task. Moreover, specific data for other common lifting tasks such as the squat are required. We chose a heterogeneous population, including men and women, as well as novices and experts in strength training to cover the largest spectrum of individuals that may use this approach. It cannot be excluded that validity and most probably accuracy of 1 RM predictions are affected by these variables. However, sample size was not large enough to make the subgroup analyses that would have allowed to test this hypothesis.

Conclusion

The Musclelab (Ergotest, Norway) provides a valid estimation of Bench press 1 RM from the force – velocity relationship. Although this estimation compares with other methods using the performance in a ≤10 RM test, the moderate accuracy of this estimation limits its practical usefulness. Athletes and coaches should therefore consider this measure as a good one for monitoring training induced adaptations, since any increase in estimated 1 RM should reflect a real improvement of this component of muscle strength, but not for prescribing training intensities, the error of prediction being too large to determine precisely training loads. In a more general manner, this study illustrates the importance of using technology with discernment. It undoubtedly brings valuable information to athletes and coaches. This is particularly true for the Musclelab (Ergotest, Norway), since the control of velocity is a key component when the conditioning program is focused on maximal power. However, it should always be kept in mind that these equipments suffer some limits that may affect their practical use.

Acknowledgements

No funds were received for this work from any organizations and the authors have no conflicts of interest directly relevant to the content of this paper.

References

Abernethy, P. and Jürimäe, J. (1996) Cross-sectional and longitudinal uses of isoinertial, isometric, and isokinetic dynamometry. *Medicine and Science in Sports and Exercise* **28**, 1180-1187.

Baechle, T. and Earle, R. (2008) *Essentials of strength training and conditionning*, Human Kinetics, Champaign (Ill).

Beelen, A., Sargeant, A., Jones, D. and de Ruiter, C. (1995) Fatigue and recovery of voluntary and electrically elicited dynamic force in humans. *The Journal of physiology* **484 (Pt 1)**, 227-235.

Bland, J. and Altman, D. (1986) Statistical methods for assessing agreement between two methods of clinical measurement. *The Lancet* **8**, 307-310.

Bosco, C., Belli, A., Astrua, M., Tihanyi, J., Pozzo, R., Kellis, S., Tsarpela, O., Foti, C., Manno, R. and Tranquilli, C. (1995) A dynamometer for evaluation of dynamic muscle work. *European Journal of Applied Physiology* **70**, 379-386.

Cohen, J. (1988) *Statistical power analysis for the behavioral sciences*. 2nd ed, L. Erlbaum Associates, Hillsdale.

Hatfield, D., Kraemer, W., Spiering, B., Hakkinen, K., Volek, J., Shimano, T., Spreuwenberg, L., Silvestre, R., Vingren, J., Fragala, M., Gomez, A., Fleck, S., Newton, R. and Maresh, C. (2006) The impact of velocity of movement on performance factors in resistance exercise. *Journal of Strength and Conditioning Research* **20**, 760-766.

Hoeger, W., Hopkins, D., Barette, S. and Hale, D. (1990) Relationship between repetitions and selected percentages of one repetition

maximum: a comparison between untrained and trained males and females. *Journal of Applied Sports Science Research* **4**, 47-54.
Jidovtseff, B., Harris, N., Crielaard, J. and Cronin, J. (2010) Using the load-velocity relationship for 1 RM prediction. *Journal of Strength and Conditioning Research* **Epub ahead of print**, doi: 10.1519/JSC.0b013e3181b62c5f
Logan, P., Fornasiero, D., Abernethy, B. and Lynch, K. (2000) Protocols for the assessment of isoinertial strength. In: *Physiological tests for elite athletes.* ed: Australian Sports Commission ed. Champaign (Ill): Human Kinetics. 200-221.
Mayhew, J., Johnson, B., Lamonte, M., Lauber, D. and Kemmler, W. (2008) Accuracy of prediction equations for determining one repetition maximum bench press in women before and after resistance training. *Journal of Strength and Conditioning Research* **22**, 1570-1577.
Mayhew, J., Ware, J., Cannon, K., Corbett, S., Chapman, P., Bemben, M., Ward, T., Farris, B., Juraszek, J. and Slovak, J.P. (2002) Validation of the NFL-225 test for predicting 1-RM bench press performance in college football players. *The Journal of sports medicine and physical fitness* **42**, 304-308.
Munro, B. (1997) *Statistical methods for health care research. Third edition*, Lippincott, New York.
Reynolds, J., Gordon, T. and Robergs, R. (2006) Prediction of one repetition maximum strength from multiple repetition maximum testing and anthropometry. *Journal of Strength and Conditioning Research* **20**, 584-592.
Sargeant, A., Hoinville, E. and Young, A. (1981) Maximum leg force and power output during short-term dynamic exercise. *Journal of applied physiology: respiratory, environmental and exercise physiology* **51**, 1175-1182.
Tagesson, S. and Kvist, J. (2007) Intra- and interrater reliability of the establishment of one repetition maximum on squat and seated knee extension. *Journal of Strength and Conditioning Research* **21**, 801-807.
Vandewalle, H., Peres, G., Heller, J., Panel, J. and Monod, H. (1987) Force-velocity relationship and maximal power on a cycle ergometer. Correlation with the height of a vertical jump. *European Journal of Applied Physiology* **56**, 650-656.
Wilson, G., Elliott, B. and Wood, G. (1991) The effect on performance of imposing a delay during a stretch-shorten cycle movement. *Medicine and Science in Sports and Exercise* **23**, 364-370.
Wilson, G. and Murphy, A. (1996) Strength diagnosis: the use of test data to determine specific strength training. *Journal of Sports Sciences* **14**, 167-173.

Key points

- Some commercial devices allow to estimate 1 RM from the force-velocity relationship.
- These estimations are valid. However, their accuracy is not high enough to be of practical help for training intensity prescription.
- Day-to-day reliability of force and velocity measured by the linear encoder has been shown to be very high, but the specific reliability of 1 RM estimated from the force-velocity relationship has to be determined before concluding to the usefulness of this approach in the monitoring of training induced adaptations.

AUTHORS BIOGRAPHY

Laurent BOSQUET
Employment
Professor, Faculty of sport sciences, University of Poitiers (France), Associate professor, Department of kinesiology, University of Montreal (Canada)
Degree
PhD
Research interests
Exercise physiology, aerobic and anaerobic capacity, autonomic control of heart rate, overreaching.
E-mail: laurent.bosquet@univ-poitiers.fr

Jeremy PORTA-BENACHE
Employment
Student (Master degree), Faculty of sport sciences, University of Poitiers (France)
Degree
BSc
Research interests
Strength, power, repeated sprint ability.
E-mail: jeremy.porta-benache@etu.univ-poitiers.fr

Jerome BLAIS
Employment
Student (Master degree), Department of education sciences, University of Montreal (Canada)
Degree
BSc
Research interests
Strength, power.
E-mail: Jerome.blais@umontreal.ca

✉ **Laurent Bosquet**
Faculty of Sport Sciences, University of Poitiers, 4, allée Jean Monnet 86000 Poitiers, France