SESNZ
SPORT & EXERCISE SCIENCE
NEW ZEALAND

*The Journal of Sport and Exercise Science, Vol. 4, Issue 2, 100-105 (2020)*

www.sesnz.org.nz

JSES
ISSN: 2703-240X

# Validity and reliability of the Beast™ sensor to measure movement velocity during the back squat exercise

Florencio T. Vallejo[1 *], Loh Tze Chien[2], Kim Hébert-Losier[3], Martyn Beaven[3]

[1]*Fusion Sport Pty Ltd, Australia*
[2]*National Sports Institute of Malaysia, Malaysia*
[3]*Te Huataki Waiora School of Health, University of Waikato, New Zealand*

ARTICLE INFO

*Received: 24.04.2020*
*Accepted: 07.09.2020*
*Online: 02.10.2020*

*Keywords:*
*Velocity-based training*
*Wearables sensors*
*Accelerometer*

ABSTRACT

*The purpose of this study was to analyze the validity and reliability of the BEAST™ wearable device to measure movement velocity during the back squat exercise. Eleven national-level female field-hockey players (age: 18.4 ± 1.7 y; back squat 1-RM: 92.7 ± 14.1 kg; height: 158.4 ± 4.6 cm; weight: 54.5 ± 5.5 kg) performed 3 repetitions of the back squat exercise with four loads on a power rack. Movement velocity for each repetition was simultaneously recorded using a linear position transducer (LPT) and the BEAST™ sensor. Results showed excellent agreement between the LPT and the BEAST™ for mean movement velocity and power, with intra-class correlation coefficient (ICC) values of 0.966 and 0.957, respectively; however, a systematic bias was observed with the BEAST™ sensor compared to the LPT device with greater mean velocity (+0.098 m·s-1, $p < 0.001$, 14.3%) and power (+51.8 W, $p < 0.001$, 21.9%). For repetitions at a given workload, mean velocity and power measures were highly reproducible for both the BEAST™ (velocity: ICC = 0.935, CV = 7.4%, power: ICC = 0.962, CV = 8.4%) and the LPT (velocity: ICC = 0.929, CV = 8.7%; power: ICC = 0.923, CV = 10.2%). The results support the use of the BEAST™ as a reliable low-cost wearable device to track velocity and power outputs during back squat training. Comparisons between data from the BEAST™ sensor and the LPT device should be made with caution due to the significant systematic bias observed. Wearable devices, such as the one used in this study, have valuable practical applications for athletes, strength and conditioning coaches, and sport scientists attempting to optimize training via feedback or monitor adaptations resultant from the manipulation of training micro-cycles and periodised plans.*

## 1. Introduction

Resistance training is a fundamental part of an athlete's conditioning program with clear benefits on health (Shaw, Shaw, & Brown, 2015) and performance (Crewther, Cronin, & Keogh, 2005; Harries, Lubans, & Callister, 2012). Prescribing the proper training intensity to optimize gains requires adequate assessment of muscle strength, which is typically quantified using direct measurements of 1-repetition maximum (Baechle & Earle, 2008) or estimated using predictive equations (LeSuer, McCormick, Mayhew, Wasserstein, & Arnold, 1997). Both methods have limitations as they can be time-consuming and have the potential to expose individuals to an increased injury risk, particularly for inexperienced athletes with little to no experience in lifting relatively heavy loads (Hooper et al., 2014; Sánchez-Medina & González-Badillo, 2011). Furthermore, 1-RM values can change after only a few training sessions (González-Badillo & Sánchez-Medina, 2010). Therefore, there is a cogent argument for conducting strength assessments frequently to ensure that the optimal training intensities are prescribed across a range of muscle groups and exercises. Although recurring assessments of 1-RM over a short period of time for individual sport athletes may be feasible, doing so with team sport athletes is a challenge given

*Corresponding Author: Florencio T. Vallejo, Fusion Sport Pty Ltd., Australia, florencio.tenllado@fusionsport.com

the number of athletes involved and their differing functional abilities.

Over the past few years, there is a growing scientific and practical interest in the use of movement velocity for assessing and monitoring resistance training. González-Badillo and Sánchez-Medina (2010) demonstrated the existence of an “inextricable relationship” between the relative load and mean velocity. This relationship allows maximal strength assessment using the mean concentric velocity of movement without the need to perform a 1-RM test once the minimal velocity threshold for a specific resistance exercise is identified. In the past, movement velocity has been tracked using Linear Position Transducers (LPT). These devices typically involve a central processing unit that is attached to the resistance training equipment (such as a barbell) via a retractable measuring cable to yield the displacement, velocity, and acceleration of an object with respect to time. The literature regarding the use of position transducer technology in strength and conditioning practice has been reported previously (Harris, Cronin, Taylor, Boris, & Sheppard, 2010), and validity and reliability with respect to force plates (O’Donnell, Tavares, McMaster, Chambers, & Driller, 2018) and an isoinertial dynamometer (Garnacho-Castaño, López-Lastra, & Maté-Muñoz, 2015) has also been reported.

Unfortunately, LPT are costly (over $3,200 NZD) and not affordable for most strength and conditioning specialists, especially those dealing with teams where multiple units would be required. However, in recent years, devices equipped with an accelerometer have been validated against LPT for measuring bar velocity by integrating the acceleration data with respect to time (Balsalobre-Fernandez, Kuzdub, Poveda-Ortiz, & Campo-Vecino, 2016; Balsalobre-Fernandez et al., 2017; Banyard, Nosaka, & Haff, 2017; Comstock et al., 2011). In a training environment, such devices are often attached to the barbell or affixed directly to the weight plates to collect movement data in real-time. The BEAST™ sensor (Beast Technologies, Brescia, Italy) is a device specifically designed to be worn on the wrist to track velocity (m·s-1) and power (W), and provide real-time data through a smartphone application, that costs ~$420 NZD. The sensor weighs 38 g with dimensions of 20 x 19 x 40 mm. However, despite the increasing popularity of the BEAST™ technology in strength and conditioning, the validity and reliability of the device have not been reported in team sport athletes with minimal resistance training history.

## 2. Methods

This study aimed to analyze the validity and reliability of the BEAST™ sensor to measure bar movement velocity and power during the commonly prescribed back squat exercise, using a LPT as reference for comparison.

### *2.1. Participants*

Eleven female field-hockey players ([mean ± standard deviation] age: 18.4 ± 1.7 y, height: 158.4 ± 4.6 cm, body mass: 54.5 ± 5.5 kg, back squat 1-RM: 92.7 ± 14.1 kg or 1.7 ± 0.3 kg/kgBM, resistance training history 1.2 ± 1.0 y) from the Malaysian national women’s development squad performed 3 repetitions of the back squat exercise on a power rack with four different loads. Movement velocity for each of the total 132 repetitions (i.e., 11 players x 3 repetitions x 4 loads) was simultaneously recorded using the CHRONOJUMP™ linear position transducer (CHRONOJUMP™, Barcelona, Spain) and the BEAST™ sensor. The players were informed of the risks and benefits of participation in the study and provided informed consent to participate. Ethical approval was attained from the institutional ethics committee of the National Sports Institute.

### *2.2. Procedures*

The back squat test was performed in a gymnasium using a squat rack, a 20 kg barbell, and free weights. The test procedure started with a standard warm up involving 5-min of cycling on a stationary bike, 5-min of dynamic stretching, 10 repetitions of bodyweight squats, and 10 repetitions of the back squat exercise with the unloaded 20 kg barbell. The players then rested for five minutes. After the warm up, each athlete completed three repetitions of the back squat to parallel with the unloaded to standardize the squat depth with a 5 s rest between repetitions. The athletes were instructed to maintain a shoulder width stance, and to perform the concentric phase of the back squat movement as fast as possible. The process was repeated with four absolute submaximal loads: 20, 30, 40, and 60 kg, with 5 min passive rest between sets. The players did not perform any heavy training the day prior to the test, and were informed to attend the test session well rested, hydrated, and in a non-fasted state. All testing was conducted by the team’s physiologist in a single testing session.

### *2.3. Apparatus*

The BEAST™ sensor unit consists of a 3-axis accelerometer, 3-axis gyroscope, and 3-axis magnetometer with an acquisition frequency of 50 Hz. The BEAST™ sensor was placed on the dorsal aspect of the player's left wrist, approximately 2 cm proximal to joint line, and connected to an android-based smartphone Samsung™ S6 (Samsung Electronics Co. Ltd, Seoul, South Korea) via Bluetooth 4.0 LE running the BEAST™ application for android (version 1.9.11).

A CHRONOJUMP™ Bosco-system Linear Position Transducer (CHRONOJUMP™, Barcelona, Spain), which had previously been demonstrated to be valid (ICC range 0.925 to 0.988) and reliable in assessing average velocity (mean bias 0.018%) and average power (mean bias 0.024%) (Vivancos et al., 2014) when compared to the T-Force system (Ergotech, Murcia, Spain), was considered the criterion in this study. The LPT was placed in an inverted position on top of the squat rack and the retractable cable was attached to the left extremity of the barbell. Bar velocity was measured using the LPT at a sample rate of 1000 Hz and the data was smoothed using nonlinear spline adaptive filtering. The LPT was connected via USB to a laptop running

Windows 7 Professional and the CHRONOJUMP™ Software (version 1.5.6). For each back squat repetition, the mean velocity (m·s-1) and power (W) values were extracted from the BEAST™ sensor (in the Z direction) and LPT device, and recorded for further analysis.

### 2.4. Statistical Approach

Descriptive statistics (mean, standard deviation (SD), and range values) were calculated for the total sum of the four submaximal loads (20, 30, 40 & 60 kg). Normality of distribution was assessed using z-scores for skewness and kurtosis before performing further statistical analyses (Kim, 2013). As the data were normally distributed, parametric tests were used. The within-subject reliability of measures was assessed using intra-class correlation coefficients (ICC) with 95% confidence intervals [upper, lower].

The relative reproducibility of measures was considered poor, good, and excellent when the corresponding ICC values were < 0.4, 0.4 – 0.75, and > 0.75 (Shrout & Fleiss, 1979). The absolute reliability was quantified using the coefficient of variation (CV) as outlined by Hopkins (Hopkins, 2000), and deemed adequate when < 10% (Harper, Morin, Carling, & Kiely, 2020; Rogers et al., 2019).

The concurrent validity of mean velocity and power measures from the BEAST™ and LPT was also quantified using ICC with 95% confidence intervals [upper, lower], and the qualitative thresholds describe above. Independent paired t-tests and Bland-Altman plots with mean differences (± 1.96 SD) were employed to identify any potential systematic bias between recording devices. All statistical analyses were performed using Statistical Package for the Social Sciences (SPSS) version 21.0 (IBM Corporation; Armonk, New York, USA) unless stated otherwise. The level of significance was set at $p \leq 0.05$.

## 3. Results

### 3.1. Reliability

Descriptive and reliability statistics for mean velocity and power of the BEAST™ sensor and LPT device are presented in Table 1. Mean velocity was measured at 20 kg (BEAST™ sensor: 0.95 $m·s^{-1}$ / LPT: 0.84 $m·s^{-1}$), 30 kg (0.77 / 0.67 $m·s^{-1}$), 40 kg (0.73 / 0.65 $m·s^{-1}$), 60 kg (0.66 / 0.53 $m·s^{-1}$). Mean power was calculated at 20 kg (BEAST™ sensor: 201 W / LPT: 168 W), 30 kg (246 / 203 W), 40 kg (308 / 266 W), 60 kg (415 / 318 W). Note that the current data set only enables an estimation of the concurrent error within the testing session, as opposed to a true within-subject variation.

Table 1: Descriptive and within-subject reliability statistics for mean velocity and power values from BEAST™ sensor and LPT device.

| Parameter | Mean ± SD | ICC [upper, lower] | CV (%) |
|---|---|---|---|
| BEAST™ mean velocity ($m·s^{-1}$) | 0.765 ± 0.148 | 0.935 | 7.4 |
| Trial 1 | 0.737 ± 0.154 | [0.872, 0.968] | |
| Trial 2 | 0.762 ± 0.154 | | |
| Trial 3 | 0.798 ± 0.133 | | |
| LPT mean velocity ($m·s^{-1}$) | 0.668 ± 0.149 | 0.929 | 10.0 |
| Trial 1 | 0.638 ± 0.150 | [0.863, 0.965] | |
| Trial 2 | 0.674 ± 0.152 | | |
| Trial 3 | 0.690 ± 0.143 | | |
| BEAST™ mean power (W) | 287.4 ± 88.6 | 0.962 | 8.4 |
| Trial 1 | 275.4 ± 83.3 | [0.927, 0.981] | |
| Trial 2 | 291.5 ± 94.7 | | |
| Trial 3 | 295.0 ± 87.8 | | |
| LPT mean power (W) | 235.5 ± 70.7 | 0.923 | 12.3 |
| Trial 1 | 223.2 ± 64.6 | [0.856, 0.961] | |
| Trial 2 | 242.9 ± 76.3 | | |
| Trial 3 | 239.6 ± 70.3 | | |

Values are mean ± standard deviation (SD), intra-class correlation coefficient (ICC) with 95% confidence limits [upper, lower], and coefficient of variation (CV).

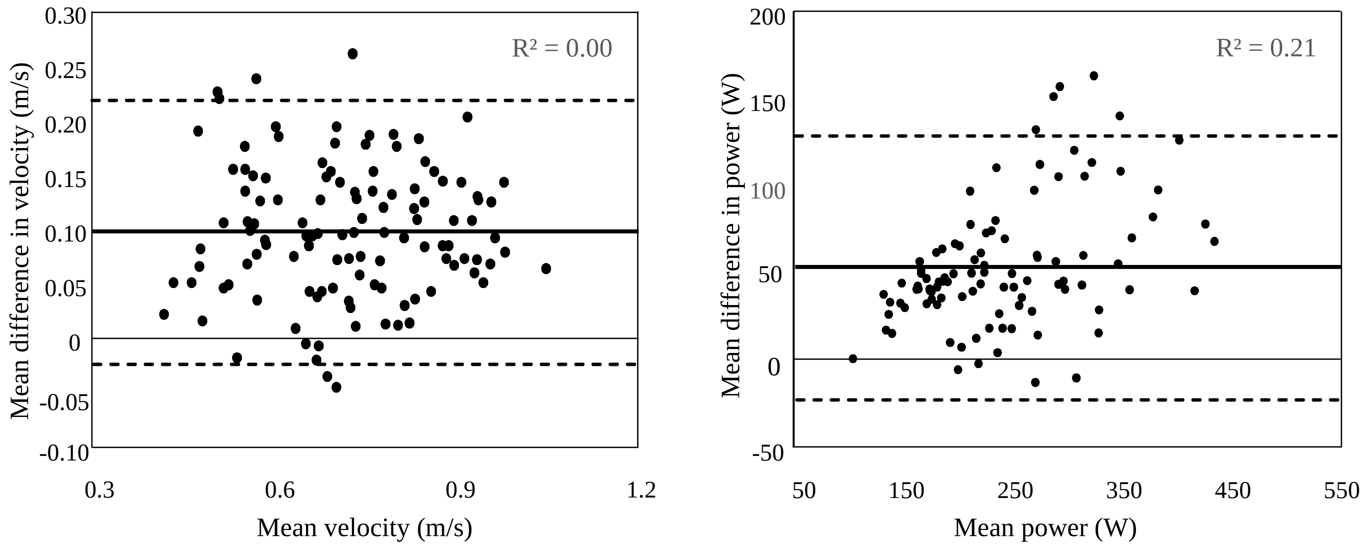


Figure 1: Bland-Altman plots between BEAST™ and LPT metrics, A: mean velocity; B: mean power
The central line represents the systematic bias between instruments (positive values mean higher velocity obtained with the BEAST™, while negative values mean higher velocity obtained with the LPT), while the upper and lower dotted lines represent ±1.96 SD.

*3.2. Validity*

There was an excellent agreement (ICC = 0.966 [range 0.943 to 0.982]) between the mean velocity measured by the LPT and the BEAST™ sensor. However, there was a systematic bias between the mean velocity from the two devices ($p < 0.001$), with the BEAST™ sensor providing values 14.3% higher than the LPT device (0.098 m·s$^{-1}$ [0.058 to 0.137], refer Figure 1A). Similarly, there was an excellent agreement (ICC = 0.931 [0.873 to 0.965]) between mean power measured by the LPT and the BEAST™. However, there was a systematic bias between the two devices ($p < 0.001$), with the BEAST™ sensor providing values 21.9% higher than the LPT (51.8 W [30.7 to 73.0], Figure 1B).

## 4. Discussion

This study determined that the BEAST™ sensor is a reliable tool to measure mean movement velocity and power during the back squat exercise when compared to a validated LPT device. Both systems exhibited excellent relative reliability (ICC > 0.75) while the BEAST™ sensor actually outperformed the LPT in terms of absolute reliability (CV) for velocity and power measures. The absolute reliability is similar to the 5.0 ± 4.1% CV reported for the PUSH™ wearable device (Balsalobre-Fernandez et al., 2016). A very large correlation and excellent agreement was found between the BEAST™ sensor and the LPT for both mean velocity and power data collected during the back squat exercise. The resultant smallest worthwhile effect derived from the between-subject standard deviation is 19 W and 0.03 m·s-1 for the BEAST™ sensor, with values of 16 W and 0.03 m·s-1 for the LPT.

It should be noted that a systematic bias was observed, whereby readings were larger from the BEAST™ sensor than the LPT in the squat movement pattern (mean velocity: 0.098 m·s-1; mean power: 51.8 W). Therefore, data from the BEAST™ sensor cannot be used interchangeably with a LPT without accounting for the systematic bias demonstrated herein. Specifically, this brings in to question the validity of the BEAST™ sensor when compared to the LPT. The observed bias is consistent with previous work that showed a 0.11 m·s-1 difference between an accelerometer-based technology and a LPT (Balsalobre-Fernandez et al., 2016). Noteworthy is that the Bland-Altman Figures suggest a more or less consistent absolute bias across the velocities observed ($R^2 = 0.00$); however, there was a tendency for a greater absolute mean difference between technologies as power output increased ($R^2 = 0.21$). We acknowledge that the use of a force platform may have provided a superior criterion measure for power data; however, the direct measurement of displacement and time establishes an LPT as an ideal criterion for movement velocity.

The cost of the BEAST™ sensor (~$420 NZD) along with the BEAST™ smartphone application has important implications for strength and conditioning coaches. The sensor allows assessment of strength and power capabilities, monitoring resistance training in real-time, and tracking changes in squat performance over time in a reliable manner. The BEAST™ sensor's online platform provides a summary of the training sessions, including relevant information such as a session's total volume, average intensity, and average power; data that coaches can use to effectively monitor training load. In addition, all resistance exercises performed during a training session are recorded, and data from the best repetition for each exercise are highlighted. This feature facilitates the monitoring of 1-RM changes over time given that changes in lifting velocities at a given load correlate with an athlete's strength capacity (González-Badillo & Sánchez-Medina, 2010). Further, the ability to assess 1-RM using previously established load-velocity relationships, also has the advantage of eliminating the need for dedicated strength testing sessions. In addition, the sensor can and provide strength and conditioning practitioners with a dynamic indication of the training status of an athlete.

The provision of real-time objective performance measures during training and testing of athletes has shown to be effective in eliciting higher performance outputs and desirable adaptations than in non-feedback conditions (Randell, Cronin, Keogh, Gill, & Pedersen, 2011). Although previously such training methods were mostly only accessible in elite sporting environments or research facilities, the ease-of-use and affordability of sensors and smartphone applications such as the BEAST™ is permitting a wider use of sensor technology across performance levels. Wearable sensors combined with smartphone applications are an easy-to-use and affordable system, eliciting a paradigm shift in the way strength and conditioning coaches and sport scientists approach resistance training and monitoring.

The data demonstrate that the BEAST™ sensor is a reliable tool to assess the lower-limb neuromuscular capacity of well-trained athletes performing a parallel back squat. As a result, exercise prescription, monitoring, and feedback can be enhanced. The reduced requirement for dedicated assessment sessions and the ability to dynamically monitor changes in neuromuscular capacity provides valuable information for practitioners, with respect to manipulation of periodised plans, training micro-cycles, and individual session goals.

## Conflict of Interest

The authors declare no conflict of interests.

## Acknowledgment

The authors wish to thank the participants and coaching staff from the National Sports Institute of Malaysia for their willingness and participation.

## References

Baechle, T. R., & Earle, R. W. (2008). Essentials of Strength Training and Conditioning (3rd ed.). Champaign, IL: Human Kinetics.

Balsalobre-Fernandez, C., Kuzdub, M., Poveda-Ortiz, P., & Campo-Vecino, J. D. (2016). Validity and reliability of the PushTM wearable device to measure movement velocity during the back squat exercise. *Journal of Strength and Conditioning Research, 30*(7), 1968-1974.

Balsalobre-Fernandez, C., Marchante, D., Baz-Valle, E., Alonso-Molero, I., Jimenez, S. L., & Munoz-Lopez, M. (2017). Analysis of wearable and smartphone-based technologies for the measurement of barbell velocity in different resistance training exercises. *Frontiers in Physiology, 8*, 649. 10.3389/fphys.2017.00649

Banyard, H. G., Nosaka, K., & Haff, G. G. (2017). Reliability and validity of the load-velocity relationship to predict the 1RM back squat. *Journal of Strength and Conditioning Research, 31*(7), 1897-1904.

Comstock, B. A., Solomon-Hill, G., Flanagan, S. D., Earp, J. E., Luk, H. Y., Dobbins, K. A., . . . Kraemer, W. J. (2011). Validity of the Myotest® in measuring force and power production in the squat and bench press. *Journal of Strength and Conditioning Research, 25*(8), 2293-2297.

Crewther, B., Cronin, J., & Keogh, J. (2005). Possible stimuli for strength and power adaptation: acute mechanical responses. *Sports Medicine, 35*(11), 967-989.

Garnacho-Castaño, M. V., López-Lastra, S., & Maté-Muñoz, J. L. (2015). Reliability and validity assessment of a linear position transducer. *Journal of Sports Science & Medicine, 14*(1), 128-136.

González-Badillo, J. J., & Sánchez-Medina, L. (2010). Movement velocity as a measure of loading intensity in resistance training. International *Journal of Sports Medicine, 31*(5), 347-352.

Harper, D. J., Morin, J. B., Carling, C., & Kiely, J. (2020). Measuring maximal horizontal deceleration ability using radar technology: reliability and sensitivity of kinematic and kinetic variables. *Sports Biomechanics*, 1-17. 10.1080/14763141.2020.1792968

Harries, S. K., Lubans, D. R., & Callister, R. (2012). Resistance training to improve power and sports performance in adolescent athletes: a systematic review and meta-analysis. *Journal of Science and Medicine in Sport, 15*(6), 532-540.

Harris, N. K., Cronin, J., Taylor, K., Boris, J., & Sheppard, J. (2010). Understanding position transducer technology for strength and conditioning practitioners. *Strength and Conditioning Journal, 32*(4), 66-79.

Hooper, D. R., Szivak, T. K., Comstock, B. A., Dunn-Lewis, C., Apicella, J. M., Kelly, N. A., . . . Kraemer, W. J. (2014). Effects of fatigue from resistance training on barbell back squat biomechanics. *Journal of Strength & Conditioning Research, 28*(4), 1127-1134.

Hopkins, W. G. (2000). Measures of reliability in sports medicine and science. *Sports Medicine, 30*(1), 1-15.

Kim, H. Y. (2013). Statistical notes for clinical researchers: assessing normal distribution (2) using skewness and kurtosis. *Restorative Dentistry & Endodontics, 38*(1), 52-54.

LeSuer, D. A., McCormick, J. H., Mayhew, J. L., Wasserstein, R. L., & Arnold, M. D. (1997). The accuracy of prediction equations for estimating 1-RM performance in the bench press, squat, and deadlift. *Journal of Strength and Conditioning Research, 11*(4), 211-213.

O'Donnell, S., Tavares, F., McMaster, D. T., Chambers, S., & Driller, M. (2018). The validity and reliability of the GymAware linear position transducer for measuring counter-movement jump performance in female athletes. *Measurement in Physical Education and Exercise Science, 22*(1), 101-107.

Randell, A. D., Cronin, J. B., Keogh, J. W., Gill, N. D., & Pedersen, M. C. (2011). Effect of instantaneous performance feedback during 6 weeks of velocity-based resistance training on sport-specific performance tests. *Journal of Strength and Conditioning Research*, *25*(1), 87-93.

Rogers, S. A., Hassmén, P., Hunter, A. M., Alcock, A., Crewe, S. T., Strauts, J. A., . . . Weissensteiner, J. R. (2019). The Validity and reliability of the MyJump2 application to assess vertical jumps in trained junior athletes. *Measurement in Physical Education and Exercise Science, 23*(1), 69-77.

Sánchez-Medina, L., & González-Badillo, J. J. (2011). Velocity loss as an indicator of neuromuscular fatigue during resistance training. *Medicine and Science in Sports and Exercise, 43*(9), 1725-1734.

Shaw, B. S., Shaw, I., & Brown, G. A. (2015). Resistance exercise is medicine: Strength training in health promotion and rehabilitation. International *Journal of Therapy and Rehabilitation*, *22*(8), 385-389.

Shrout, P. E., & Fleiss, J. L. (1979). Intraclass correlations: uses in assessing rater reliability. *Psychological Bulletin*, *86*(2), 420-428.

Vivancos, A., Zambudio, A., Ramírez, F., Del Águila, A., Castrillón, F., & Pardo, P. (2014). Reliability and validity of a linear position transducer for strength assessment. *British Journal of Sports Medicine, 48*(Suppl 3), A5.