

Original Research

Validity and reliability of the My Lift app in determining 1RM for deadlift and back squat exercises

Onat Cetin¹, Ozkan Isik^{2,3*}¹ Faculty of Sport Sciences, Yalova University, Yalova, Turkey² Faculty of Sport Sciences, Balıkesir University, Balıkesir, Turkey³ Directorate of Sports Sciences Application and Research Center, Balıkesir University, Balıkesir, Turkey* Correspondence: (Ozkan Isik) ozkanisik86@hotmail.com  <https://orcid.org/0000-0003-2561-1695>

Received: 02/01/2021; Accepted: 31/05/2021; Published: 30/06/2021

Abstract: Smartphone technologies are seen as a rapidly developing field of research in physical activity research. However, it is important to use smartphone applications that have proven validity and reliability in performance measurement. This study aimed to determine the validity and reliability of the My Lift mobile app used for the determining estimated 1RM for conventional deadlift and barbell back squat exercises. 10 male weightlifters (\bar{X}_{age} : 17.50 ± 1.27 years) voluntarily participated in the study. For the conventional deadlift and barbell back squat movements of the weightlifters, My Lift app measurements were obtained during the 1RM test simultaneously with sub-maximal loads (75-85% 1RM). Results obtained from My Lift app and actual 1RM were compared with Bland-Altman plots. The My Lift app provided high reliability interclass correlation coefficient for conventional deadlift and barbell back squat (ICC = 0.99). The results were highly correlated obtained from My Lift app and the actual 1RM test (determination coefficient for conventional deadlift: $R^2 = 0.99$; barbell back squat: $R^2 = 0.99$). When compared with the actual 1RM test, My Lift app that used to determine estimated 1RM is a very valid and reliable tool. The My Lift app can be used by athletes and coaches as a practical and valid measurement tool for determining 1RM using sub-maximal loads.

Keywords: 1RM, mobile app, athletic performance, weightlifting.

1. Introduction

As it causes increases in muscle strength, muscle hypertrophy, power output, and local muscle endurance, resistance training is used as an effective method to increase athletic performance (Kraemer & Ratamess, 2004). The ultimate aim of any

resistance training program to optimize athletic performance should be to achieve the greatest strength increase (Mann, Thyfault, Ivey, & Sayers, 2010). But, objectively quantifying and monitoring the actual training load of athletes for maximizing performance, has been an essential problem for professional practitioners and researchers



(González-Badillo & Sánchez-Medina, 2010). For decades, the traditional approach to improving muscle performance criteria such as muscle strength and strength has been to train at various percentages of one-repetition maximum (1RM) strength, to change the training volume and frequency (Mann, Ivey, & Sayers, 2015). To measure 1RM strength, the athlete must perform the maximum lift with a load that can only be moved once (Robertson et al., 2008). However, individual stressors (sports, daily and social) cause daily fluctuations in the ability to move an external resistance and this affects the daily stability of the 1RM strength level (Fry & Kraemer, 1997). Moreover, the necessity to test all movements in the training program and the lack of time and practice for large groups (teams) causes some disadvantages for the 1RM test (Loturco et al., 2013). Therefore, when considering the extreme effort and disadvantages of the 1RM test, different strategies have emerged to estimate the 1RM strength level indirectly and with less effort (Kravitz, Akalan, Nowicki, & Kinzey, 2003).

In recent years, software applications for portable devices such as wearable units, smartphones, and tablets, which have become popular in the field of sports and exercise science, offer innovative solutions to methods used by coaches and athletes for performance measurement (Thompson, 2017). Mobile software applications that offer alternative methods in terms of cost, time, and place for practitioners and athletes have been developed to collect physiological, kinanthropometric, and performance-related data (Peart, Balsalobre-Fernández, & Shaw, 2019). Although various alternatives are used to estimate 1RM, measuring the bar velocity was reported as the most accurate methodology due to the strong ($R^2 > 0.97$) relationship between the load in %1RM and the speed at which each load is lifted (Chapman et al., 2019; Muñoz-López et al., 2017). Previous researches indicate a good correlation between the mean displacement velocity of a load equivalent to body weight and 1RM and it is possible to determine an exercise-specific %1RM by measuring

movement velocity (Bazuelo-Ruiz et al., 2015; Conceição et al., 2016).

My Lift (the previous name was Power Lift) is a smartphone app based on high-speed video recording and Newtonian physics to measure barbell velocity and to estimate 1RM according to the barbell velocity at/with specific loads (Balsalobre-Fernández, Marchante, Muñoz-López, & Jiménez, 2018). In the studies examining the validity and reliability of such devices and mobile applications, the estimated 1RM data obtained from these devices and apps are compared with the actual 1RM data obtained from the 1RM test protocols recommended by the formal strength and conditioning associations (e.g. ACSM and NSCA). Balsalobre-Fernández et al (2017; 2018) analyzed the validity and reliability of the Power Lift app for the measurement of mean velocity on different resistance training exercises (bench press, full squat, and hip thrust). The app was found to be highly valid ($r = 0.97-0.98$, $SEE = 0.03-0.05 \text{ m}\cdot\text{s}^{-1}$) and reliable ($ICC > 0.9$) in comparison with a linear transducer and a wearable device. On the contrary, Martínez-Cava et. al., (2020) investigated the inter- and intra-device agreement of four new devices including the My Lift app marketed for barbell velocity measurement for bench press and full squat exercises. My Lift app was reported to be ill-advisable for VBT due to its large measurement errors when tracking lifts $> 0.30 \text{ m/s}$. The researchers have stated that the load-velocity relationship may differ depending on the type of exercise and the implementation of the exercise (Helms et al., 2017; García-Ramos et al., 2018). For example, squat exercises can vary depending on the place where the barbell is located (back or front squat) the squatting depth (full or parallel squat), the feet position (sumo squat) (Coratella et al., 2021).

While previous studies have investigated the My Lift app for measuring bench press, full squat, and hip thrust; to the authors' knowledge, no other studies have assessed the reliability and validity of additional resistance training exercises. To strengthen the generalizations on this

subject, further studies that investigate different exercises (e.g. deadlift) and exercises variants (e.g. parallel back squat) are required. Therefore, this study aimed to determine the validity and reliability of the My Lift app used for the determine estimated 1RM load for conventional deadlift and barbell back squat (parallel) exercises. We hypothesized that the My Lift app would show high concurrent validity and reliability when estimating actual 1RM for conventional deadlift and barbell back squat exercises.

2. Materials and Methods

Subjects — Ten young male weightlifters (\bar{X}_{age} : 17.50 \pm 1.27 years; \bar{X}_{height} : 168.60 \pm 8.76 cm; $\bar{X}_{\text{bodyweight}}$: 70.10 \pm 13.88) participated in this study voluntarily. All participants were trained, competitive athletes, and familiar with the 1RM testing protocols. Testing protocols were explained and written and signed informed consent was obtained from all subjects and the parents of participants under the age of 18 before starting the study. The data of this research were collected within the weightlifters' own 1RM training period. The study protocol complied with the Declaration of Helsinki for Human Experimentation.

Experimental design — According to their training program, all participants performed two 1RM trials (for reliability) for each exercise separated by 48 hours (total 4 days). Barbell back squat measurements were performed on the first two trials and conventional deadlift measurements on the second two trials. My Lift measurements were also performed with submaximal loads (%75, %85 of 1RM) during the implementation of the 1RM protocol of both exercises. The participants did not do any sports exercises for at least 48 hours before the first trial, except for daily life activities. Between trials, they had a passive rest for 48 hours. End of the trials, the estimated 1RM values of the My Lift app were compared with actual 1RM values.

1RM assessment — The maximal strength of the participants was measured with the 1RM test, which consists of the maximum load that an individual can lift during exercise. The 1RM test was applied following the test protocol determined by the American College of Sports Medicine (ACSM) (Thompson, 2017). Before each 1RM assessment standardized warm-up consist of 8 minutes of jogging, 5 minutes of lower extremity mobility exercises, and 3 reps of the deadlift and the squat with 20 kg barbell was done. After warming up, participants performed 5-10 reps at loads corresponding to ~ %50 of 1RM. Following a 1-min rest, athletes performed 3-5 reps at loads between %60 and %85 of 1RM. After a 3-minutes rest, the load was adjusted to find the maximum equivalent load of a repeat ranging from 3 to 5 trials. The maximum load was recorded in kg as the load used in the last part of the exercise and not repeated more than once by the participant.

Methodology — *Estimation of 1RM with My Lift app* — My Lift app (v.9.1.3; © 2016-19 Carlos Balsalobre-Fernández) can estimate 1RM by recording the velocity of exercise and using scientifically verified algorithms with high-speed video recording on iPhone and iPad devices. The application designed to calculate the bar velocity (in m/s) between the 2 video frames using the Newton equation. Besides velocity measurement, it is also used to estimate 1RM using force (load) and velocity relationship (Balsalobre-Fernández et al., 2018). According to the "Full test" instructions of the app, My Lift app needs 2 submaximal loads to calculate the estimated 1RM. 2 lifts of the participants in the loads corresponding to %75 and %85 of the 1RM were recorded with iPad Pro 11. (Apple, USA) at a distance of 1.5 m. My Lift estimated 1RM data was obtained by marking the starting and ending frames of the exercises and then loading range of motion (cm) of the exercises and the lifted loads (kg) to the application. The measurements were repeated each trial day for both exercises.

Range of motion measurement – To determine the mean velocity of the bar displacement, the range of motion of the exercise must be loaded to the application in cm. Therefore, during warm-up, a metric tape placed vertically to the ground was used to determine the starting and ending points of the exercises.

Statistical analyses – MedCalc software was used to compare the data obtained for estimated and actual conventional deadlift and barbell back squat 1RM. Mean and standard deviation values were given as descriptive statistics. Paired samples t-test and Bland-Altman graphics were used to evaluate whether the two methods gave different results. The reliability analysis was tested with interclass correlation coefficients. The significance level was determined as $p < 0.05$.

3. Results

No significant differences for the conventional deadlift were seen between trials 1 and 2 of actual 1RM (129.05 ± 35.74 ; 129.10 ± 35.70) and estimated 1RM (128.90 ± 35.89 ; 128.48 ± 35.28) using My Lift app. Similarly, no significant differences for the barbell back squat were seen between trials 1 and 2 of actual 1RM (137.80 ± 41.97 ; 138.20 ± 41.90) and estimated 1RM (136.60 ± 42.14 ;

137.26 ± 42.80) using My Lift app. Interclass correlation coefficients of the conventional deadlift and barbell back squat for the 1RM were found as .99. Magnitudes of the relationships between actual and estimated 1RM were interpreted using Pearson correlation coefficients, described as trivial (0.0–0.1), low (0.1–0.3), moderate (0.3–0.5), high (0.5–0.7), very high (0.7–0.9), or practically perfect (0.9–1.0) (Jidovtseff, Harris, Crielaard, & Cronin, 2011). According to this classification, our reliability results show that in practically perfect for both movement patterns.

There was no statistically significant difference between estimated and actual conventional deadlift ($\bar{X}_{\text{estimated}} \pm \text{S.D.} = 129.10 \pm 35.70$; $\bar{X}_{\text{actual}} \pm \text{S.D.} = 128.48 \pm 35.28$; $p = 0,248$) and barbell back squat ($\bar{X}_{\text{estimated}} \pm \text{S.D.} = 137.26 \pm 42.80$; $\bar{X}_{\text{actual}} \pm \text{S.D.} = 137.90 \pm 41.94$; $p = 0,201$) 1RM. Moreover, the determination coefficient between two different measurement methods were determined as $R^2 = 0.99$ for the conventional deadlift (Figure 1) and barbell back squat (Figure 2).

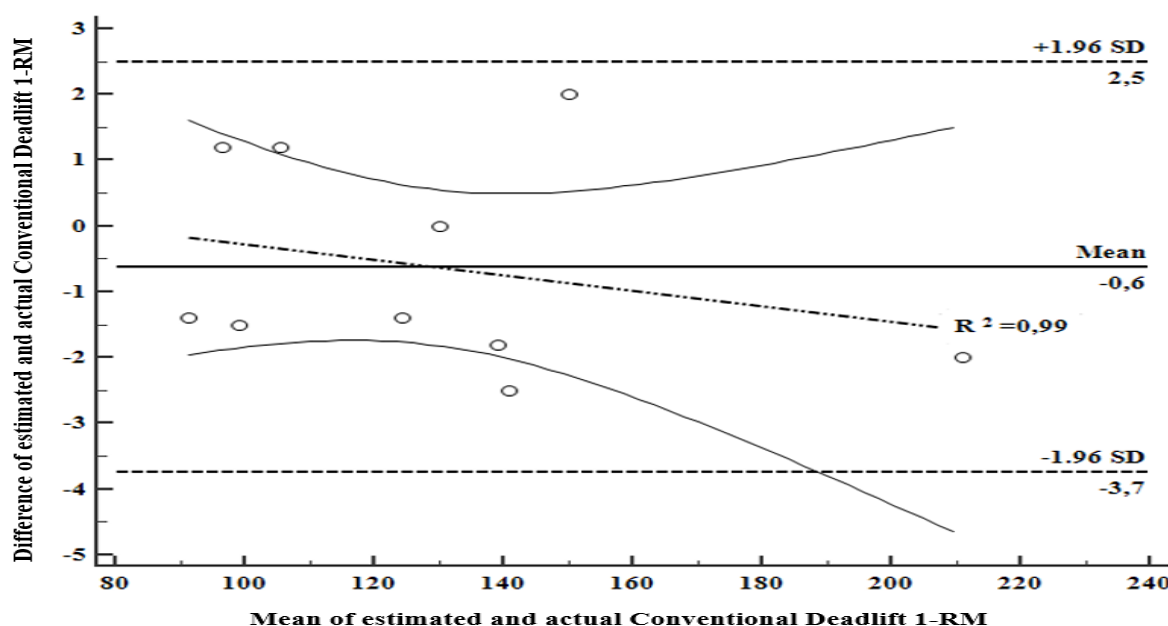


Figure 1. Bland-Altman plots for estimated and actual conventional deadlift 1RM

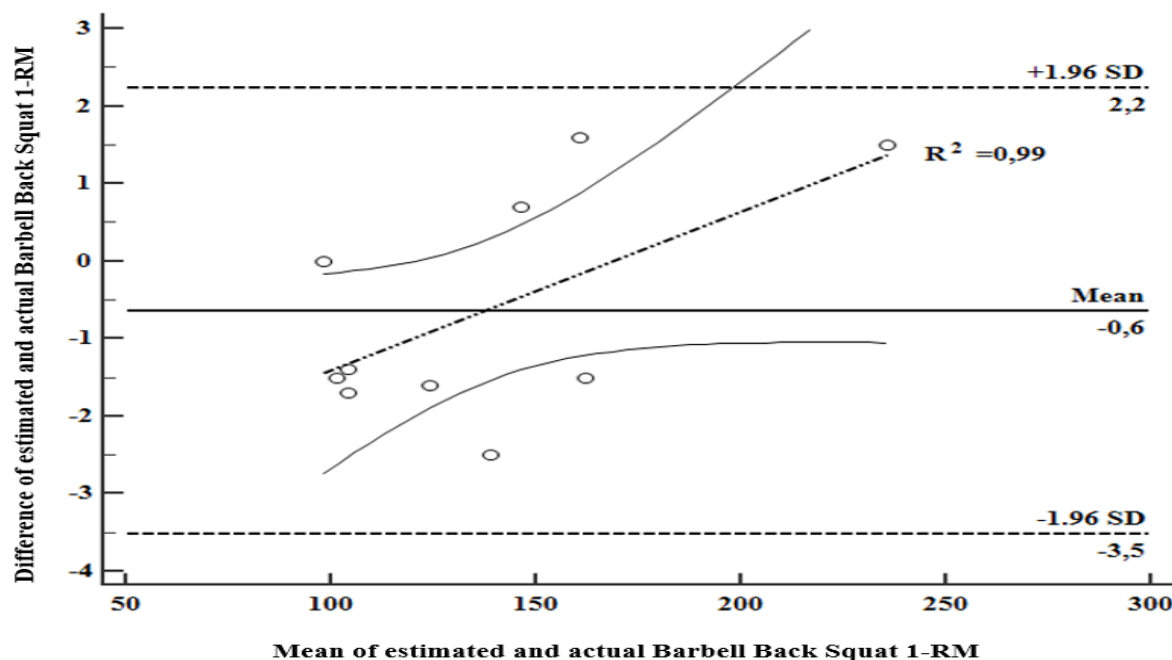


Figure 2. Bland-Altman plots for estimated and actual barbell back squat 1RM

4. Discussion

The purpose of the present study was to test the validity and reliability of the My Lift app used to determine estimated 1RM for conventional deadlift and barbell back squat exercises. The main findings of the study have shown that the app was found to be a highly valid and reliable tool for the estimation of 1RM for deadlift and barbell back squat exercises. No significant differences for the barbell back squat and conventional deadlift were seen between trials 1 and 2 of actual 1RM. My Lift produced a high level of reliability in these two exercises. The data reinforced by Bland-Altman plots (Figures 1 and 2) showed a high correlation between the values obtained with the app vs. the actual 1RM test. These findings suggest that even though the less repeated and submaximal loads are used, the app can accurately estimate 1RM.

The inventor and the researcher of the My Lift app analyzed the validity and reliability of the measurement of barbell velocity in different resistance training exercises (bench press, full squat, and hip thrust). The results indicate that My Lift the app was highly valid, reliable, and accurate for the measurement of barbell velocity and estimation of 1RM (Balsalobre-Fernández et

al., 2017). The same researcher compared the My Lift app with a linear transducer and the app was found to be highly valid ($r = 0.964$) and reliable ($ICC = 0.965$) on bench press exercise (Balsalobre-Fernández et al., 2018). Similarly, Pérez-Castilla et al. (2019) reported Power Lift app (My Lift) as a reliable ($ICC = 0.70$, $CV = 3.97\%$) and valid ($r = 0.994$) device to obtain accurate velocity measurements for restricted linear movements. Thompson et al. (2020) investigated the inter-day and intra-device reliability, and criterion validity of six devices for measuring barbell velocity in the free-weight back squat and power clean exercises. The authors found that the My Lift app's validity ($r \geq 0.88$) was similar to the linear position transducers (LPT) which were accepted as gold standard equipment ($r = 0.902$). Martínez-Cava et al. (2020) investigated the inter-and intra-device agreement of four new devices and their results showed that the My Lift app was the least reliable tool compared to the other available devices. But Courel-Ibáñez et al. (2019) suggested that when analyzing the validity outcomes of a device such as bar velocity, Pearson's correlation coefficients might not be appropriate. The researchers also have examined the validity and reliability of estimation methods of 1RM

using different equations like multi-point or two-point methods. But they finally reported that the direct assessment of the 1RM demonstrates the greatest between-day reliability and accuracy (García-Ramos et al., 2019). The studies highlighted above examined the mobile apps' reliability and validity by comparing them with other devices but the present study was based on comparing them with actual 1RM.

Seo et al. (2012) stated that it is important to perform validity and reliability measurements on different muscle groups due to the widespread use of 1RM tests. Therefore, the present research aimed to measure validity and reliability in different resistance exercises and athlete types. Besides, in our study, weightlifters, whose athletic performances are highly associated with the 1RM, were used as the sample group. This sample group and exercise selection are thought to strengthen the level of validity and reliability in addition to past researches.

Smartphone technologies are seen as a rapidly developing field of research in physical activity research. Moreover, as smartphone technologies become more accessible and acceptable as physical activity measurement and response tools, this trend will continue in the future (Bort-Roig, 2014). According to a systematic review, the My Lift app suggested being the most often used mobile app for assessing the strength status of humans (Silva et al., 2021). When the current researches are examined, there are relevant studies that have analyzed the validity and reliability of smartphone apps using high-speed video analysis for the measurement of several variables related to physical performance such as vertical jump (Balsalobre-Fernández, Glaister, & Lockey, 2015; Gallardo-Fuentes et al., 2016) and sprinting (Romero-Franco, et al., 2017). Also, in these studies where smartphone applications were examined, the level of validity and reliability supporting this study's results have been reported. When resistance training programs are considered, autoregulation, which is a form of nonlinear resistance training periodization, aims for the

athletes to create the training program at their own pace of development, according to daily strength and performance level (Siff, 2000). Velocity-based training (VBT) has been a topic for resistance training programs. In this type of training program where the daily 1RM level is essential, determined using sub-maximal loads and valid and reliable estimated 1RM data, the My Lift app can provide athletes convenience in terms of time and effort.

Conclusions

Measuring 1RM strength level in a practical, valid, and reliable manner is an important criterion for establishing resistance training programs and monitoring the physical responses of the athlete to these training sessions. The results of this study show that the My Lift app is a valid and reliable tool for estimating 1RM in conventional deadlift and barbell back squat exercises. To better understand the effectiveness of mobile applications using the measurement of force and power levels, different resistance exercises, different sample groups, and researches with different applications are needed.

Acknowledgment

The researchers thank Assoc. Prof. Ilkay DOGAN for his contribution to the statistical analysis of the data using MedCalc. Also, we would like to thank the Sakarya Weightlifting Club athletes and trainers who supported us in this research.

Funding

This research received no external funding.

Conflicts of Interest

The authors declare no conflict of interest.

References

- Balsalobre-Fernández C., Glaister M., & Lockey R. A. (2015). The validity and reliability of an iPhone app for measuring vertical jump performance. *Journal of Sports Sciences*, 33(15), 1574-1579. doi: 10.1080/02640414.2014.996184

- Balsalobre-Fernández C., Marchante D., Baz-Valle E., Alonso-Molero I., Jiménez S. L., & Muñoz-López 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. doi: 10.3389/fphys.2017.00649
- Balsalobre-Fernández C., Marchante D., Muñoz-López M., & Jiménez S. L. (2018). Validity and reliability of a novel iPhone app for the measurement of barbell velocity and 1RM on the bench-press exercise. *Journal of Sports Sciences*, 36(1), 64-70. doi:10.1080/02640414.2017.1280610
- Bazuelo-Ruiz B., Padial P., García-Ramos A., Morales-Artacho A. J., Miranda M. T., & Feriche B. (2015). Predicting maximal dynamic strength from the load-velocity relationship in squat exercise. *The Journal of Strength & Conditioning Research*, 29(7), 1999-2005. doi: 10.1519/JSC.0000000000000821
- Bort-Roig J., Gilson N. D., Puig-Ribera A., Contreras R. S., & Trost S. G. (2014). Measuring and influencing physical activity with smartphone technology: a systematic review. *Sports Medicine*, 44(5), 671-686. doi:10.1007/s40279-014-0142-5
- Chapman M., Larumbe-Zabala E., Goss-Sampson M., Colpus M., Triplett N. T., & Naclerio F. (2019) Perceptual, Mechanical, and Electromyographic Responses to Different Relative Loads in the Parallel Squat. *The Journal of Strength & Conditioning Research*, 33(1), 8-16. doi: 10.1519/JSC.0000000000001867
- Conceição F., Fernandes J., Lewis M., González-Badillo J. J., & Jimenez-Reyes P. (2016). Movement velocity as a measure of exercise intensity in three lower limb exercises. *Journal of Sports Sciences*, 34(12):1099-1106. doi:10.1080/02640414.2015.1090010
- Coratella, G., Tornatore, G., Caccavale, F., Longo, S., Esposito, F., & Cè, E. (2021). The Activation of Gluteal, Thigh, and Lower Back Muscles in Different Squat Variations Performed by Competitive Bodybuilders: Implications for Resistance Training. *International Journal of Environmental Research and Public Health*, 18(2), 772. doi: 10.3390/ijerph18020772
- Courel-Ibáñez, J., Martínez-Cava, A., Morán-Navarro, R., Escribano-Peñas, P., Chavarren-Cabrero, J., González-Badillo, J. J., & Pallarés, J. G. (2019). Reproducibility and repeatability of five different technologies for bar velocity measurement in resistance training. *Annals of Biomedical Engineering*, 47(7), 1523-1538. doi: 10.1007/s10439-019-02265-6
- Fry A. C., & Kraemer W. J. (1997). Resistance exercise overtraining and overreaching. *Sports Medicine*, 23(2), 106-29. doi:10.2165/00007256-199723020-00004
- Gallardo-Fuentes F., Gallardo-Fuentes J., Ramírez-Campillo R., Balsalobre-Fernández C., Martínez C., Caniuqueo A., et al. (2016). Intersession and intrasession reliability and validity of the My Jump app for measuring different jump actions in trained male and female athletes. *The Journal of Strength & Conditioning Research*, 30(7), 2049-2056. doi: 10.1519/JSC.0000000000001304
- García-Ramos, A., Pestaña-Melero, F. L., Pérez-Castilla, A., Rojas, F. J., & Haff, G. G. (2018). Differences in the load-velocity profile between 4 bench-press variants. *International journal of sports physiology and performance*, 13(3), 326-331. doi: 10.1123/ijsp.2017-0158
- García-Ramos, A., Barboza-González, P., Ulloa-Díaz, D., Rodríguez-Perea, A., Martínez-García, D., Guede-Rojas, F., ... & Weakley, J. (2019). Reliability and validity of different methods of estimating the one-repetition maximum during the free-weight prone bench pull exercise. *Journal of sports sciences*, 37(19), 2205-2212. doi: 10.1080/02640414.2019.1626071
- 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: 347-352. doi: 10.1055/s-0030-1248333

- Helms, E. R., Storey, A., Cross, M. R., Brown, S. R., Lenetsky, S., Ramsay, H., ... & Zourdos, M. C. (2017). RPE and velocity relationships for the back squat, bench press, and deadlift in powerlifters. *The Journal of Strength & Conditioning Research*, 31(2), 292-297. doi: 10.1519/JSC.0000000000001517
- Jidovtseff, B., Harris, N. K., Crielaard, J. M., & Cronin, J. B. (2011). Using the load-velocity relationship for 1RM prediction. *The Journal of Strength & Conditioning Research*, 25(1), 267-270. doi: 10.1519/JSC.0b013e3181b62c5f
- Kraemer, W. J., & Ratamess, N. A. (2004). Fundamentals of resistance training: progression and exercise prescription. *Medicine & science in sports & exercise*, 36(4), 674-688. doi: 10.1249/01.mss.0000121945.36635.61
- Kravitz L., Akalan C., Nowicki K., & Kinzey S. J. (2013). Prediction of 1 repetition maximum in high-school power lifters. *The Journal of Strength & Conditioning Research*, 17(1), 167-172. doi:10.1519/1533-4287(2003)017<0167: pormih>2.0.co;2.
- Loturco I., Ugrinowitsch C., Tricoli V., Pivetti B., & Roschel H. (2013). Different loading schemes in power training during the preseason promote similar performance improvements in Brazilian elite soccer players. *The Journal of Strength & Conditioning Research*, 27(7), 1791-1797. doi: 10.1519/JSC.0b013e3182772da6
- Mann J. B., Ivey P. A., & Sayers S. P. (2015). Velocity-based training in football. *Strength Conditioning Journal*, 37(6), 52-7. doi:10.1519/SSC.0000000000000177
- Mann J. B., Thyfault J. P., Ivey P. A., & Sayers S. P. (2010). The effect of autoregulatory progressive resistance exercise vs. linear periodization on strength improvement in college athletes. *The Journal of Strength & Conditioning Research*, 24(7), 1718-23. doi: 10.1519/JSC.0b013e3181def4a6
- Martínez-Cava, A., Hernández-Belmonte, A., Courel-Ibáñez, J., Morán-Navarro, R., González-Badillo, J. J., & Pallarés, J. G. (2020). Reliability of technologies to measure the barbell velocity: Implications for monitoring resistance training. *PLoS one*, 15(6), e0232465. doi: 10.1371/journal.pone.0232465
- Muñoz-López M., Marchante D., Cano-Ruiz M. A., Chicharro J. L., & Balsalobre-Fernández C. (2017). Load-, force-, and power-velocity relationships in the prone pull-up exercise. *International Journal of Sports Physiology and Performance*, 12(9), 1249-1255. doi:10.1123/ijspp.2016-0657
- Peart D. J., Balsalobre-Fernández C., Shaw M. P. (2019). Use of mobile applications to collect data in sport, health, and exercise science: a narrative review. *The Journal of Strength & Conditioning Research*, 33(4), 1167-77. doi: 10.1519/JSC.0000000000002344
- Pérez-Castilla, A., Piepoli, A., Delgado-García, G., Garrido-Blanca, G., & García-Ramos, A. (2019). Reliability and concurrent validity of seven commercially available devices for the assessment of movement velocity at different intensities during the bench press. *The Journal of Strength & Conditioning Research*, 33(5), 1258-1265. doi: 10.1519/JSC.0000000000003118
- Robertson R. J., Goss F. L., Aaron D. J., Gairola A., Kowallis R. A., Liu Y., et al. (2008). One repetition maximum prediction models for children using the OMNI RPE scale. *The Journal of Strength & Conditioning Research*, 22(1), 196-201. doi:10.1519/JSC.0b013e31815f6283
- Romero-Franco N., Jiménez-Reyes P., Castaño-Zambudio A., Capelo-Ramírez F., Rodríguez-Juan J.J., González-Hernández J, et al. (2017). Sprint performance and mechanical outputs computed with an iPhone app: Comparison with existing reference methods. *European Journal of Sport Science*, 17(4), 386-392. doi:10.1080/17461391.2016.1249031
- Seo D. I., Kim E., Fahs C. A., Rossow L., Young K., Ferguson S. L., et al. (2012). Reliability of the one-repetition maximum test based on muscle group and gender. *Journal of Sports Science and Medicine*, 11(2), 221-225. PMID: 24149193

- Siff, M. (2000). Strength and the muscular system. *Supertraining, 5th ed.* Denver: Supertraining Institute, 1-93.
- Silva, R., Rico-González, M., Lima, R., Akyildiz, Z., Pino-Ortega, J., & Clemente, F. M. (2021). Validity and Reliability of Mobile Applications for Assessing Strength, Power, Velocity, and Change-of-Direction: A Systematic Review. *Sensors, 21*(8), 2623. doi:10.3390/s21082623
- Thompson W. R. (2017). Worldwide survey of fitness trends for 2018. *ACSM's Health & Fitness Journal, 20*(6), 8-17. doi:10.1249/FIT.0000000000000341
- Thompson, S. W., Rogerson, D., Dorrell, H. F., Ruddock, A., & Barnes, A. (2020). The Reliability and Validity of Current Technologies for Measuring Barbell Velocity in the Free-Weight Back Squat and Power Clean. *Sports, 8*(7), 94. doi: 10.3390/sports8070094