THE VALIDITY AND RELIABILITY OF AN iPHONE APP FOR MEASURING VERTICAL JUMP PERFORMANCE

Running title: *IPHONE APP FOR MEASURING VERTICAL JUMPS*

Key words: biomechanics, fitness, physical performance, strength

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Conflicts of interest: The first author of the paper is the co-designer of the app mentioned. The data from the app was obtained from two independent observers not related to the app development.

Abstract

The purpose of this investigation was to analyze the concurrent validity and reliability of an iPhone app (called: *My Jump*) for measuring vertical jump performance. Twenty recreationally-active healthy men (age: 22.1 ± 3.6 years) completed five maximal countermovement jumps (CMJ), which were evaluated using a force platform (*time in the air* –TIA– method) and a specially designed iPhone app. *My jump* was developed to calculate the jump height from flight time using the high-speed video recording facility on the iPhone 5s. Jump heights of the 100 jumps measured, for both devices, were compared using the intraclass correlation coefficient (ICC), Pearson product-moment correlation coefficient (*r*), Cronbach's alpha (α), coefficient of variation (CV) and Bland-Altman plots. There was an almost perfect agreement between the force platform and *My Jump* for the CMJ height (ICC = 0.997, $p < 0.001$; Bland-Altman bias= 1.1 ±0.5cm, $p < 0.001$). In comparison with the force platform, *My Jump* showed good validity for the CMJ height ($r = 0.995$, $p < 0.001$). The results of the present study show that CMJ height can be easily, accurately, and reliably evaluated using a specially developed iPhone 5s app.

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INTRODUCTION

Vertical jump tests are amongst the most common means of evaluating physical fitness in various populations (Buchheit, Spencer, & Ahmaidi, 2010; de Villarreal, Izquierdo, & Gonzalez-Badillo, 2011; Rodacki, Fowler, & Bennett, 2002; Taipale, Mikkola, Vesterinen, Nummela, & Häkkinen, 2013). Though principally used to evaluate leg power in sports such as basketball and football (Argus, Gill, Keogh, Hopkins, & Beaven, 2009; Duncan, Lyons, & Nevill, 2008; Hartman, Clark, Bemben, Kilgore, & Bemben, 2007), vertical jump tests have also been used to evaluate non-athletic populations (including children (Acero et al., 2011) and elderly people (Pereira et al., 2012)), particularly since vertical jump training has been reported to improve bone-mineral density (Allison, Folland, Rennie, Summers, & Brooke-Wavell, 2013). Vertical jump tests have been proposed as important for talent identification purposes, with young elite athletes displaying higher values than their non-elite counterparts (Fry et al., 2006; Gabbett, Georgieff, & Domrow, 2007). Moreover, the height jumped, in addition to providing an indication of lower limb muscular power (Markovic, Dizdar, Jukic, & Cardinale, 2004) and neuromuscular fatigue (Buchheit et al., 2010; Sanchez-Medina & González-Badillo, 2011), has shown strong negative correlations ($r > -0.90$) with indices of exercise exhaustion and stress, such as blood lactate (Sanchez-Medina & González-Badillo, 2011), ammonia (Sanchez-Medina & González-Badillo, 2011), and salivary-free cortisol concentrations (Balsalobre-Fernandez, Tejero-Gonzalez, & Del Campo-Vecino, 2014).

Several different approaches exist for measuring vertical jump height, with force platforms being considered the gold-standard (Glatthorn et al., 2011; Requena, Requena, García, de Villarreal, & Pääsuke, 2012; Sayers, Harackiewicz, Harman, Frykman, & Rosenstein, 1999). Force platforms can measure vertical jump height using both time in the air (TIA) and takeoff velocity (TOV) methods (Kibele, 1998;

Moir, 2008). While TOV is considered the most accurate method for measuring vertical jump height, TIA has also been shown to be highly valid and reliable, and most instruments nowadays calculate jump height by measuring the flight time of the jump (Glatthorn et al., 2011; Moir, 2008; Requena et al., 2012). Although force platforms, accelerometers, contact platforms, infrared platforms, and high-speed cameras (Casartelli, Muller, & Maffiuletti, 2010; Glatthorn et al., 2011; Requena et al., 2012) have been validated for measuring the flight time of vertical jumps, all of them have potential drawbacks. First, most of these devices are expensive for coaches and personal trainers and, as such, their use is largely confined to University laboratories and/or elite sports clubs. Secondly, these instruments can be bulky and often need specific computer software to analyze the data. Although the portability of this type of equipment has improved in recent years, it still provides a restriction which could affect its usability in field situations.

An inexpensive, portable approach for measuring vertical jump performance was validated recently (Balsalobre-Fernandez, Tejero-Gonzalez, Del Campo-Vecino, & Bavaresco, 2014) which combines the use of a low-cost high-speed camera and license-free computer software to evaluate vertical jump height. However, the approach still requires the transfer of video footage from the camera to the software to calculate the vertical jump height, thereby slowing the evaluation process. This process usually takes 5 min to transfer video footage, plus 30 s for each jump height calculation, according to the authors.

Recently, Apple Inc. (USA) released the iPhone 5s, an update of its smartphone, and one of its new features is a high-speed camera capable of recording at 120 Hz. As such, with the development of an appropriate application (app), the phone has the potential to record high-speed videos and subsequently to calculate jump height directly.

However, there are no previous studies validating an iPhone app for measuring vertical jump height. The aim of the present study, therefore, was to analyze the validity and reliability of a specifically designed iPhone app (named: *My Jump*) for measuring vertical jump height.

METHODS

Participants

Twenty recreationally-active, healthy, male, Sport Science students (N=20, age=22.1±3.6 yrs, height=1.81±0.08 m, body mass=74.0±10.4 kg, countermovement jump –CMJ– height=35.2±5.4 cm) were recruited for this study. The study protocol complied with the Declaration of Helsinki for Human Experimentation and was approved by St. Mary's University Ethics Committee. Written informed consent was obtained from each subject before participation.

Study design

The participants completed a standard 10-minute warm-up composed of jogging, lower-body dynamic stretches, and vertical jumps. Then, each participant performed five countermovement jumps (CMJ) on a force platform (Kistler 9287BA, Kistler Instruments Ltd., Hook, UK) while being recorded with an iPhone 5s (Apple Inc., USA) high-speed camera. All participants had experience of CMJ testing. Each jump was separated by a 2 minute passive rest period. The app (named: *My Jump*), which was developed *ad-hoc* for this study, calculated the flight time of the CMJ by identifying the takeoff and the landing frames of the video, and then transforming it into a jump height using the equation described in the literature (Bosco, Luhtanen, & Komi, 1983): $h = t^2 \times 1.22625$, with *h* being the jump height in meters and *t* being the flight time of the jump in seconds. The same equation was also used to calculate jump heights from the force platform data.

Countermovement jump performance

Participants performed each CMJ with hands on their hips, starting from a static standing position and with their legs straight during the flight phase of the jump (Haekkinen & Komi, 1985). The landing was performed with both feet simultaneously keeping ankle dorsiflexion. Participants were instructed to jump as high as possible.

Equipment

App for the iPhone 5s

The app to calculate CMJ height was developed using software (XCode 5.0.5 for Mac OSX 10.9.2; Apple Inc., USA) specifically designed to provide the necessary tools to write apps for the iPhone 5s using Objective-C language. When finished, the app (named: *My Jump*) was installed on an iPhone 5s, which includes a 120 Hz high-speed camera, at a quality of 720 p. *My Jump* was designed for analyzing vertical jumps to allow the calculation of the time (in ms) between two frames selected by the user and subsequently to calculate the height of the CMJ using the equation described above.

To record the CMJ with *My Jump*, a researcher lay prone on the ground with the iPhone 5s facing the participant (in the frontal plane), at approximately 1.5 m from the force platform, and zooming in on the feet of the participant. Two independent observers, with no previous experience on video-analysis were asked to select, with *My Jump*, the first frame in which both feet were off the ground (takeoff phase) and subsequently, the first frame in which at least one foot was touching the ground (landing phase). See Figure 1.

My Jump is available on the Appstore (Apple Inc., USA) as a free download.

*****FIGURE 1 NEAR HERE*****

Force platform

The force platform (600 × 900 mm), recorded data at a sampling frequency of 1000 Hz and was used to measure the flight times of the CMJ at the same time as they were being recorded on the iPhone 5s. The force platform was connected to a PC equipped with software to analyze the force data (BioWare V5.2.2.4, Kistler Holding AG, Switzerland). Flight times from analysis of the force platform data were used to calculate jump height using the same equation described earlier.

Statistical analyses

Several analyses were conducted to determine the reliability and validity of CMJ height using the app. First, to analyze the reliability of the app for measuring the CMJ height in comparison with the force platform data, the intraclass correlation coefficient (ICC) (2,1) was used. Secondly, to analyze the stability of the app when measuring the 5 CMJ of each subject, Cronbach's alpha and the coefficient of variation (CV) were used. Thirdly, to complement the ICC analyses, Bland-Altman plots were created, which are known to give a good representation of the agreement between two instruments (Bland & Altman, 1986). Fourth, to calculate the concurrent validity, the bivariate Pearson product-moment correlation coefficient (r) was used. Finally, to analyze the reliability of the app between observers, an ICC was used. The level of statistical significance was set at $p < 0.05$. All calculations were performed using IBM SPSS Statistics 22 for Mac (IBM Co., USA).

RESULTS

There was an almost perfect agreement between the *My Jump* and the force platform CMJ jump heights (ICC = 0.997, 95% CL: 0.996-0.998, $p < 0.001$) for both observers, with a mean difference between instruments of 1.1 ± 0.5 cm (observer 1) and 1.3 ± 0.5

cm (observer 2). *My Jump* values were significantly lower than those obtained with the force platform ($p < 0.05$). See Figure 2.

*****FIGURE 2 NEAR HERE*****

The app showed very good reliability for the five CMJ of each subject for jump height (observer 1: $\alpha = 0.997$, CV = 3.4%; observer 2: $\alpha = 0.988$, CV = 3.6%). Also, the Pearson product-moment correlation coefficient showed an almost perfect correlation between the app and the force platform measurements for jump height ($r = 0.995$, $p < 0.001$). See Figure 3.

*****FIGURE 3 NEAR HERE*****

Finally, when analyzing the reliability of the app, an almost perfect agreement between observer calculations was found for jump height (ICC=0.999, 95% CL=0.998-0.999, $p<0.001$). The mean difference between observers was 0.1 ± 0.4 cm. See Figure 4.

*****FIGURE 4 NEAR HERE*****

DISCUSSION

The purpose of this study was to analyze the concurrent validity and reliability of an iPhone app for measuring CMJ performance. *My Jump* was found to be highly valid and reliable in measuring the jump height of a CMJ in comparison with a force platform. Moreover, the data presented in Bland-Altman plots (Figures 2 and 4), show that most of the CMJ values are close to the mean of the differences between instruments (1.1 ± 0.5 cm) or observers (0.1 ± 0.4 cm), thereby representing a high level of agreement (Bland & Altman, 1986). Specifically, the differences between observers on the measurements of the jump height were very small (about 1 mm), despite the fact that the takeoff and landing frame selection had to be performed manually, which could increase the measurement error. Moreover, it is worth mentioning that the observers had no previous experience on video-analysis, which highlights the usability of *My Jump*. Also, when analyzing the reliability of *My Jump* for measuring the five CMJ for each participant, the results show values which were very close to the ones obtained with the force platform (considered the gold-standard for vertical jumps measurements (Duncan et al., 2008)), despite differences between devices in sampling frequency.

Previous studies have compared different technologies for measuring vertical jumps with force platform data. It has been demonstrated that an infrared platform has a difference about 1.0 cm in comparison with a force platform at 1000 Hz (Glatthorn et al., 2011). Also, it was shown that an accelerometric system (Myotest SA, Switerzland) has a mean difference of 3.6 cm in comparison with a force platform at 1000 Hz (Choukou, Laffaye, & Taiar, 2014); higher than the app analyzed in this study. Probably the most accurate systems for measuring vertical jump height (besides force platforms) are professional high-speed cameras (Balsalobre-Fernandez, Tejero-Gonzalez, Del Campo-Vecino, et al., 2014; Garcia-Lopez et al., 2005; Requena et al., 2012). For example, a professional high-speed camera recording at 1000 Hz has a difference of just 1.3 ms of flight time in comparison with a 1000 Hz force platform (Requena et al., 2012). Taking into account that information, the accuracy of *My Jump* (about 8.9 ms of flight time or 1.2 cm of jump height), compares well with much more expensive, and less portable devices. Moreover, the rapid advancement of new technologies suggests that, in the near future, smartphones will include cameras with higher recording frequencies that will reduce the measurement error of *My Jump*. In fact, after we submitted the first version of this manuscript, Apple announced the new iPhone 6, which features a 240 Hz high-speed camera. Indeed, it has been suggested that smartphones apps, because of their popularity, affordability, portability and advanced technology, will soon be commonplace for measuring variables (such as CMJ height) associated with physical performance and health with great accuracy (Bort-Roig, Gilson, Puig-Ribera, Contreras, & Trost, 2014).

The major drawback of *My Jump* is that, since it records videos at 120 Hz, there is a chance that the takeoff and/or landing frame will not be recorded. The equation for the calculation of the jump height uses the flight time squared, and that means that the measurement error increases with longer flight times (Balsalobre-Fernandez, Tejero-Gonzalez, Del Campo-Vecino, et al., 2014). However, the highest CMJ measured on this study, which was higher than an average professional basketball player (Alemdaroğlu, 2012) (51.5 cm) had a difference of only 1.6 cm with respect to the force platform. As such, *My Jump* is able to measure accurately jump heights for most populations, including trained athletes, and requires no previous video-analysis experience. This is the first study that validates a commercial iPhone app for measuring vertical jump height.

CONCLUSIONS

The ability to evaluate and monitor CMJ ability is important in areas of health, talent identification, and sporting performance. The results of the present study show that CMJ height can be easily, accurately, and reliably evaluated using a specially developed iPhone 5s app (named: *My Jump*) which is available on the Appstore (Apple Inc., USA) as a free download. These findings could help for coaches and trainers who wish to monitor the vertical jump ability of their athletes or clients in a valid and economic way.

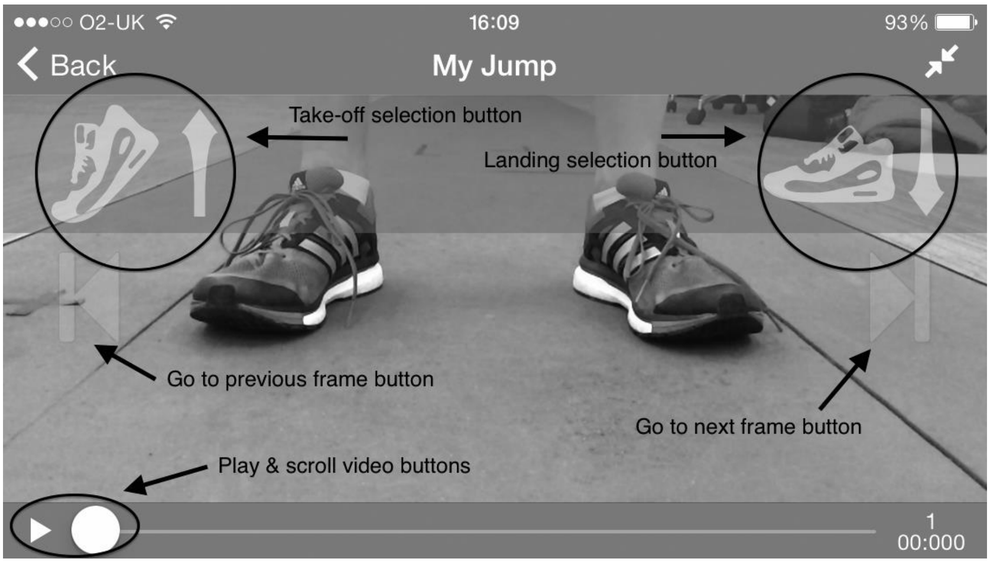

Figure 1. User interface of the app designed for this study.

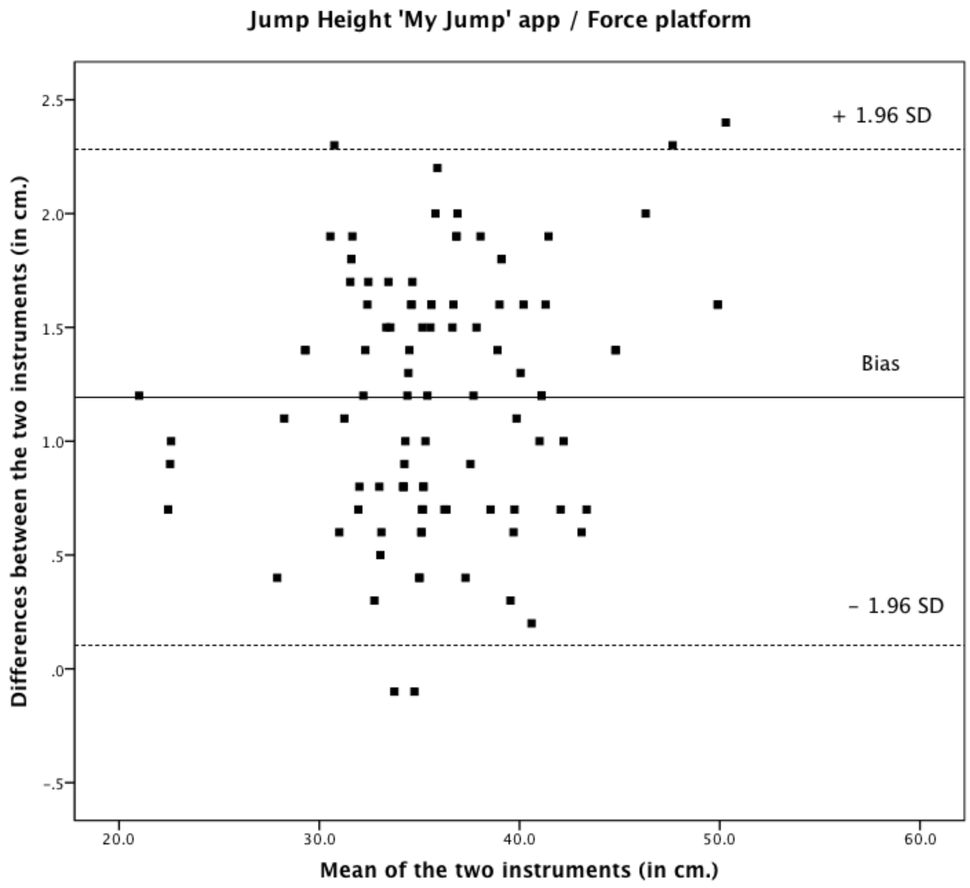

Figure 2. Bland-Altman plots for the force platform and *My Jump* app jump height data. The central line represents the absolute average difference between instruments, while the upper and lower lines represent ± 1.96 standard deviations (SD).

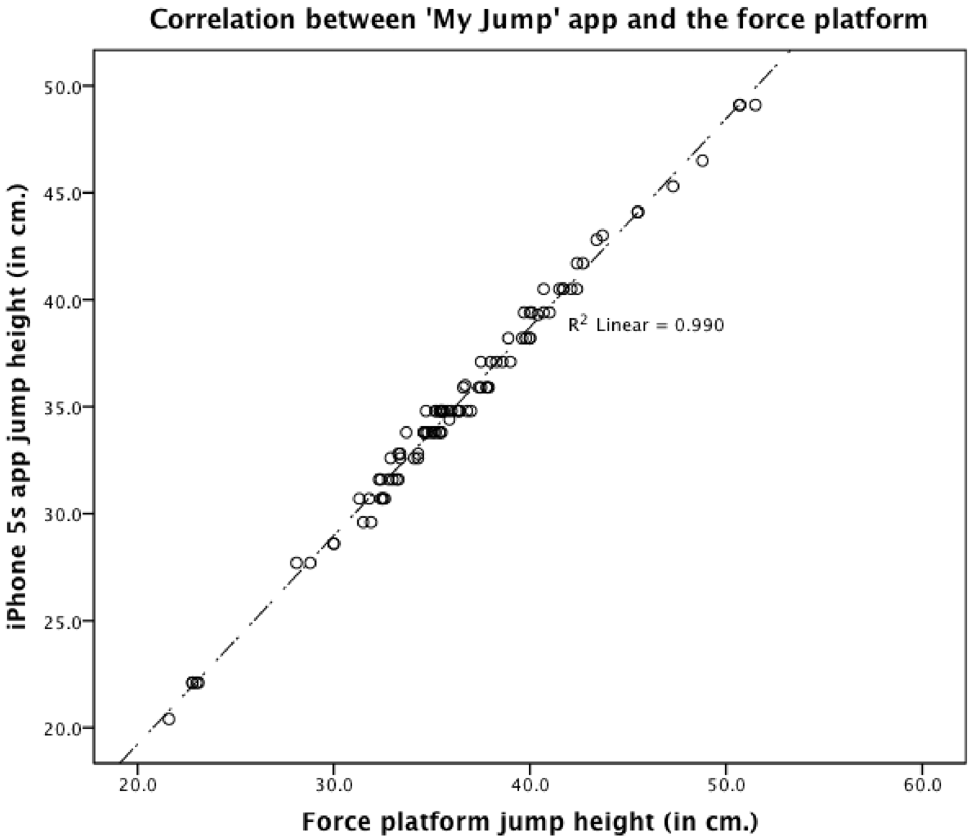

Figure 3. Concurrent validity between the force platform and *My Jump* app.

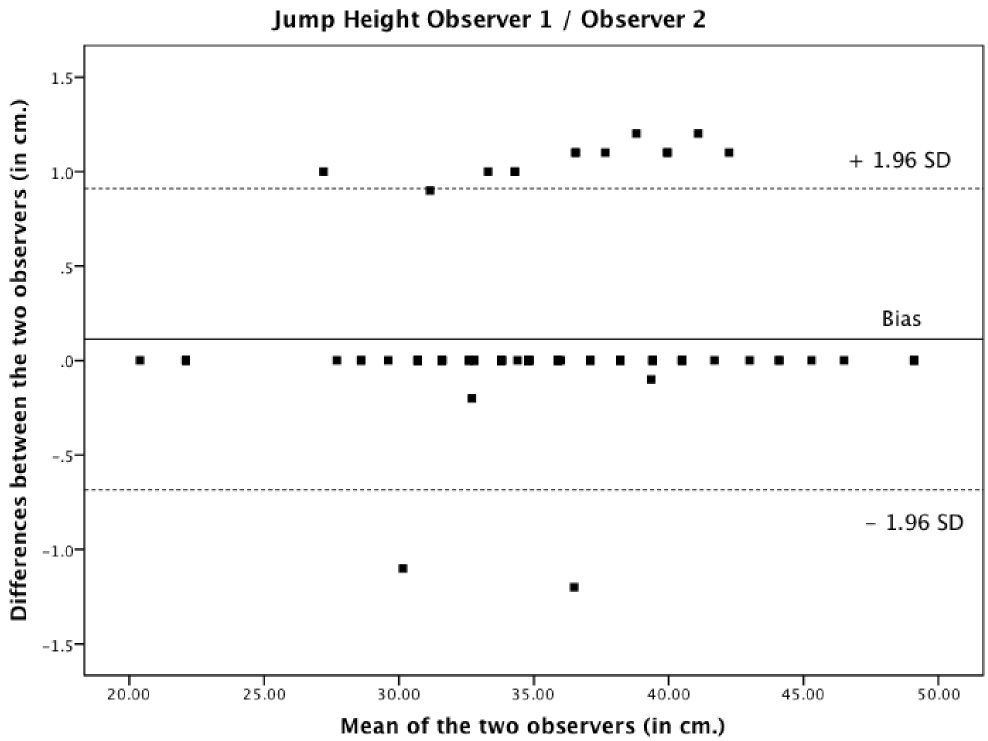

Figure 4. Bland-Altman plots between observers for jump height. The central line represents the absolute average difference between observers, while the upper and lower lines represent ± 1.96 standard deviations (SD).

REFERENCES

Acero, R. M., Fernández-del Olmo, M., Sánchez, J. A., Otero, X. L., Aguado, X., & Rodríguez, F. A. (2011). Reliability of Squat and Countermovement Jump Tests in Children 6 to 8 Years of Age. *Pediatric exercise science, 23*(1), 151-160.

Alemdaroğlu, U. (2012). The Relationship Between Muscle Strength, Anaerobic Performance, Agility, Sprint Ability and Vertical Jump Performance in Professional Basketball Players. *Journal of Human Kinetics, 31*, 149-158.

Allison, S. J., Folland, J. P., Rennie, W. J., Summers, G. D., & Brooke-Wavell, K. (2013). High impact exercise increased femoral neck bone mineral density in older men: a randomised unilateral intervention. *Bone, 53*(2), 321-328. doi: 10.1016/j.bone.2012.12.045

Argus, C. K., Gill, N. D., Keogh, J. W. L., Hopkins, W. G., & Beaven, C. M. (2009). Changes in Strength, Power, and Steroid Hormones During a Professional Rugby Union Competition. *Journal of Strength & Conditioning Research, 23*(5), 1583-1592.

Balsalobre-Fernandez, C., Tejero-Gonzalez, C. M., & Del Campo-Vecino, J. (2014). Hormonal and Neuromuscular Responses to High Level Middle and Long-Distance Competition. *International journal of sports physiology and performance, 9*, 839-844.

Balsalobre-Fernandez, C., Tejero-Gonzalez, C. M., Del Campo-Vecino, J., & Bavaresco, N. (2014). The concurrent validity and reliability of a low-cost, high-speed camera-based method for measuring the flight time of vertical jumps. *Journal of Strength & Conditioning Research, 28*(2), 528-533. doi: 10.1519/JSC.0b013e318299a52e

Bland, J. M., & Altman, D. G. (1986). Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet, 1*(8476), 307-310.

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 (Auckland, N.Z.), 44*, 671-686. doi: 10.1007/s40279-014-0142-5

Bosco, C., Luhtanen, P., & Komi, P. V. (1983). Simple method for measurement of mechanical power in jumping. *European Journal Of Applied Physiology, 50*(2), 273-282.

Buchheit, M., Spencer, M., & Ahmaidi, S. (2010). Reliability, Usefulness, and Validity of a Repeated Sprint and Jump Ability Test. *International Journal of Sports Physiology & Performance, 5*(1), 3-17.

Casartelli, N., Muller, R., & Maffiuletti, N. A. (2010). Validity and reliability of the myotest accelerometric system for the assessment of vertical jump height. *Journal of Strength & Conditioning Research, 24*(11), 3186-3193.

Choukou, M. A., Laffaye, G., & Taiar, R. (2014). Reliability and validity of an accelerometric system for assessing vertical jumping performance. *Biology of Sport, 31*(1), 55-62.

de Villarreal, E. S. S., Izquierdo, M., & Gonzalez-Badillo, J. (2011). Enhancing jump performance after combined vs. maximal power, heavy-resistance, and plyometric training alone. *Journal of Strength & Conditioning Research, 25*(12), 3274-3281.

Duncan, M. J., Lyons, M., & Nevill, A. M. (2008). Evaluation of peak power prediction equations in male basketball players. *Journal of Strength & Conditioning Research, 22*(4), 1379-1381.

Fry, A. C., Ciroslan, D., Fry, M. D., LeRoux, C. D., Schilling, B. K., & Chiu, L. Z. F. (2006). Anthropometric and performance variables discriminating elite american junior men weightlifters. *Journal of Strength & Conditioning Research*, *20*(4), 861-866.

Gabbett, T., Georgieff, B., & Domrow, N. (2007). The use of physiological, anthropometric, and skill data to predict selection in a talent-identified junior volleyball squad. *Journal of Sports Sciences, 25*(12), 1337-1344.

Garcia-Lopez, J., Peleteiro, J., Rodgriguez-Marroyo, J. A., Morante, J. C., Herrero, J. A., & Villa, J. G. (2005). The Validation of a New Method that Measures Contact and Flight Times During Vertical Jump. *International Journal of Sports Medicine, 26*(4), 294-302.

Glatthorn, J. F., Gouge, S., Nussbaumer, S., Stauffacher, S., Impellizzeri, F. M., & Maffiuletti, N. A. (2011). Validity and reliability of Optojump photoelectric cells for estimating vertical jump height. *Journal of Strength & Conditioning Research*, *25*(2), 556-560.

Haekkinen, K., & Komi, P. V. (1985). Effect of explosive type strength training on electromyographic and force production characteristics of leg extensor muscles during concentric and various stretch-shortening cycle exercises. *Scandinavian Journal of Sports Sciences, 7*(2), 65-76.

Hartman, M. J., Clark, B., Bemben, D. A., Kilgore, J. L., & Bemben, M. G. (2007). Comparisons Between Twice-Daily and Once-Daily Training Sessions in Male Weight Lifters. *International Journal of Sports Physiology & Performance, 2*(2), 159-169.

Kibele, A. (1998). Possibilities and Limitations in the Biomechanical Analysis of Countermovement Jumps. *Journal of applied biomechanics, 14*(1), 105.

Markovic, G., Dizdar, D., Jukic, I., & Cardinale, M. (2004). Reliability and factorial validity of squat and countermovement jump tests. *Journal of Strength & Conditioning Research, 18*(3), 551-555. doi: 10.1519/1533-4287(2004)18<551:rafvos>2.0.co;2

Moir, G. L. (2008). Three Different Methods of Calculating Vertical Jump Height from Force Platform Data in Men and Women. *Measurement in Physical Education & Exercise Science, 12*(4), 207-218.

Pereira, A., Izquierdo, M., Silva, A. J., Costa, A. M., Bastos, E., Gonzalez-Badillo, J. J., & Marques, M. C. (2012). Effects of high-speed power training on functional capacity and muscle performance in older women. *Experimental gerontology, 47*(3), 250-255. doi: 10.1016/j.exger.2011.12.010

Requena, B., Requena, F., García, I., de Villarreal, E. S.-S., & Pääsuke, M. (2012). Reliability and validity of a wireless microelectromechanicals based system (Keimove™) for measuring vertical jumping performance. *Journal of Sports Science & Medicine, 11*(1), 115-122.

Rodacki, A. L. F., Fowler, N. E., & Bennett, S. J. (2002). Vertical jump coordination. *Medicine & Science in Sports & Exercise, 34*(1), 105-116.

Sanchez-Medina, L., & González-Badillo, J. J. (2011). Velocity Loss as an Indicator of Neuromuscular Fatigue during Resistance Training. *Medicine & Science in Sports & Exercise, 43*(9), 1725-1734.

Sayers, S. P., Harackiewicz, D. V., Harman, E. A., Frykman, P. N., & Rosenstein, M. T. (1999). Cross-validation of three jump power equations. *Medicine & Science in Sports & Exercise, 31*(4), 572-577.

Taipale, R., Mikkola, J., Vesterinen, V., Nummela, A., & Häkkinen, K. (2013). Neuromuscular adaptations during combined strength and endurance training in endurance runners: maximal versus explosive strength training or a mix of both. *European Journal Of Applied Physiology*, *113*(2), 325-335.