Research note

International Journal of
Sports Science
& Coaching

International Journal of Sports Science
& Coaching
2016, Vol. 11(6) 872–879

DOI: 10.1177/1747954116676114
spo.sagepub.com
SAGE

Validity and reliability of a 3-axis accelerometer for measuring weightlifting movements

Francisco J Flores[1], **Silvia Sedano**[2],
Ana M de Benito[3] and **Juan C Redondo**[4]

Abstract

The purpose of the current study was to assess the validity and reliability of measures obtained by a 3-axis commercial accelerometer during weightlifting movements in comparison with kinematic data derived from the 3D videography. Kinematic data from 3D videography were obtained from 11 track & field throwers performing 3 trials each one at different loads in power snatch, power clean and jerk from the rack. The results showed that the accelerometer measures were highly correlated with derived acceleration data from 3D videography data in the vertical plane (Z axis) taking up to the pull phase (including first pull, transition and second pull) for power snatch and power clean and up to the highest point of the bar path before the catch position (including dip, drive and split phases) for jerk from the rack. On the basis of these results, this device was proven to be valid and reliable on Z axis on the weightlifting movements studied. Thus, this system may be a useful and easy to handle tool to measure acceleration during real-time training sessions.

Keywords

Barbell acceleration, explosive weightlifting, high speed video, motion analysis, track and field athletics

Introduction

Weightlifting is an official sport in which athletes attempt to lift as much weight as possible in the snatch and clean & jerk exercises.[1] The snatch and clean & jerk are the 2 lifts contested in the sport of weightlifting. The snatch is the first lift performed in competition and clean & jerk lift is the second which is divided in two parts; clean phase and jerk phase. These exercises, their variations and the methods used in the sport of weightlifting are also applied as a method of strength training for a wide range of other sports such as basketball, volleyball, football, track and field[2] and strength and conditioning programs.[3] Weightlifting movements are considered some of the best training exercises to maximize dynamic athletic performance and their kinetic and kinematic characteristics are specific to many athletic skills.[4]

Weightlifting exercises, including their variations (power clean, power snatch high pulls...), have been studied for a long period of time[5,6] and over the past few years biomechanical characteristics of weightlifting exercises have been widely investigated. [4–10] The main goals of these kind of investigations were to determine how the kinetic and kinematic variables influence success in weightlifting and to find out the best technique in these exercises.[3,4,8,10]

However, Stone et al.[6] reported great technical variability among weightlifters increasing the difficulty of prediction of weightlifting performance. To achieve a better understanding of weightlifting technique and the kinetic and kinematics of barbell acceleration may be helpful for coaches. Furthermore, very little information exists about the barbell acceleration during

---

Reviewers: Greg Haff (Edith Cowan University, Australia)
Harvey Newton (Newton Sports, USA)

[1]Service of Physical Education and Sports, University of Salamanca, Spain
[2]Laboratory of Physiology, European University Miguel de Cervantes, Valladolid, Spain
[3]Laboratory of Biomechanics, Catholic University of Valencia "San Vicente Mártir", Spain
[4]Faculty of Sports Sciences, University of Leon, Spain

Corresponding author:
Juan C Redondo, Faculty of Sports Sciences, Department of Movement and Sport Sciences, University of León, Campus de Vegazana s/n, 24007 - León, Spain,Telf. +34987293004 / Fax: +34987293008.
Email: jc.castan@unileon.es

weightlifting movements and their variations.[7,8,11,12] Although the barbell acceleration is not extensively analyzed, this factor is highly important in weightlifting movements insofar as it is directly proportional to force applied to the barbell while mass is a constant value.[8,9]

Barbell acceleration has been used to indicate fatigue[7–9] and to calculate force and power.[8,9] Therefore, in order to achieve a better understanding of the technique and to assess biomechanical characteristics responsible for performance in weightlifting, the development and use of any technology to carry out these goals may be desirable.[7–9]

Recently, accelerometers have been shown to be a potential tool for evaluating and monitoring weightlifting performance.[7–9] Price, size, portability and easy use are some of the advantages of accelerometers in comparison with other device.[13] Thus, accelerometers may be considered a reasonable alternative to solve some limitations mentioned above and assess weightlifting movements[7,8] and the athletic performance.[13–15] Triple-axis accelerometers are the most advanced devices of this type of technology. They can be coupled to the barbells and have the potential to offer accelerations in the 3 planes of motion[14] allowing a global evaluation of the movement although bearing in mind that during the weightlifting movements the barbell rotation can cause issues for accelerometers.[16] Moreover, to mate an accelerometer to the barbell without lift disturbance in the athlete may be able to offer an instantaneous visual feedback to coaches and athletes.[7,8] Although visual feedback is not a newfangled practice per se, its practical use has been limited by the cost or portable access to involve these tools in field tests.[16]

Sato et al.[7] previously tested the validity of the PS 2119 accelerometer (PASCO, Roseville, CA) in the pull phase (portion of the snatch and clean in which the barbell is displaced from the floor to achieve the greater vertical displacement) of weightlifting movements. This tool is the previous version of the accelerometer used in the current research (PS-2136A, PASCO, Roseville, CA). Although PS2119 accelerometer was previously validated in 2D, we do not know if the information provided by each one of the three axes of motion is valid and reliable in analyzing every axis separately. Therefore, the purpose of this study was to determine the validity and reliability of the accelerometer PS-2136A in each plane of motion during weightlifting exercises. 3D motion-analysis system was used as a gold standard reference to determine the validity and reliability of the accelerometer studied (PS2136A). Our hypothesis was that the accelerometer analyzed would exhibit good validity and reliability during the pull phases (including first pull, transition and second pull) of the power snatch and power clean and up to the highest point of the bar path before the catch position (including dip, drive and split phases) of the jerk in each one of the three planes of motion compared with the gold standard used.

Methods

Subjects

Eleven male subjects were recruited to participate in this study. All subjects had an extensive background in strength and power training using weightlifting movements (12.45 ± 3.85 years of experience). All of them competed at the national level on their respective track and field events during the 2014 and 2015 seasons. The sample included 5 javelin throwers, 3 shot putters and 3 discus throwers. Prior to participation in the study, all subjects read and signed an informed consent in accordance with guidelines set by the Human Subjects Review Committee at University of Salamanca. Table 1 shows the descriptive characteristics of the subjects.

Materials

A 3-axis accelerometer (PS-2136A, PASCO, Roseville, CA) was utilized in the current research. This device is an altimeter plus accelerometer, but the altimeter function was overlooked in the current investigation. This accelerometer is factory calibrated and the standard configuration of the device allows recording acceleration values in the X, Y, and Z planes of motion. The accelerometer is coupled to a wireless device (Airlink 2 PS-2010, PASCO, Roseville, CA), which transmits the data to a laptop computer. Table 2 shows the physical

Table 1 Descriptive data for participant characteristics (*M* ± *SD*).

	Male (*n* = 11)
Age (years)	27.47 ± 3.61
Height (cm)	188.05 ± 8.76
Body mass (kg)	97.36 ± 8.73
Strength and power training experience (years)	12.45 ± 3.85

Table 2 Physical characteristics of the accelerometer and Bluetooth wireless device.

	3-axis PS-2136A	Airlink 2 PS-2010	Both device mated
Weight (Kg)	0.080	0.050	0.13
Width (cm)	3.8	3.8	3.8
Length (cm)	2	2	2
Depth (cm)	8.8	9	17.6

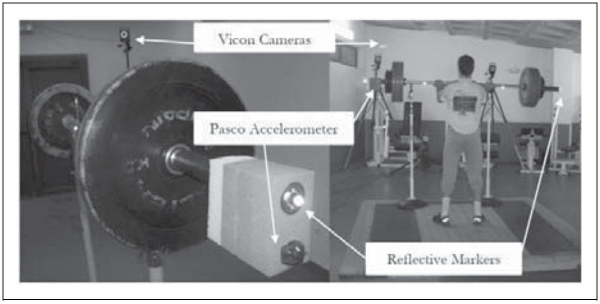

Figure 1 — System for acceleration assessment.

characteristics of the accelerometer and Bluetooth wireless device.

The sampling rate of the accelerometer was 100 Hz. Previous studies showed that 100 Hz is an appropriate sampling rate to record weightlifting exercises.[7,8] The measuring device was placed on the barbell by the foam unit shown in Figure 1 according to the specifications set by Sato et al.[7] This padded mount provided sufficient protection for the accelerometer absorbing the shock of dropping the bar on the lift platform.[7] The total mass of the measuring device plus the protection foam was 0.180 Kg, which is equivalent to a lightweight spring-type collar device.[7] This weight is not enough to induce asymmetric disturbances during the lift. The accelerometer unit was placed underneath and in line with the long axis of the barbell on the left edge of the bar in relation to the lifter's position (Figure 1). In that position, bar movements forward-backward, side to side and up-down are equivalents to X, Y and Z axis according to the factory configuration. The sensor unit position was checked according to the position described above before each attempt.

A three-dimensional motion analysis system (Vicon, Oxford, UK) consisted of seven VICON-460 infrared video cameras was utilized to track the trajectories of 4 markers (25 mm reflective markers) attached to the bar. Two markers at the edges of the bar and two more markers on the middle part of the bar near the snatch grip were placed (Figure 1 shows the position of the markers). The cameras sampled at a rate of 100 Hz.[7,17] This configuration allowed synchronization of video frames with acceleration values. Vicon system was calibrated according to the manufacturer's instructions prior to each data collection session.

A High-speed video camera (Casio Exilim, EX-F1, Tokyo, Japan) was positioned at a distance of 5 m in front of the barbell and lifter. The camera operated at 100 Hz to capture the barbell trajectory. This camera was used to allow a simple synchronization between accelerometer and 3D analysis system. The highest point of the bar's path was utilized taking as a reference the left end reflective marker, for event synchronization.

Data collection and processing were performed using Pasco Capstone software (Version 1.1.5, Pasco Scientific PASCO, Roseville, CA) and Vicon Nexus motion-capture software (Nexus 1.8.3, Vicon, Oxford, UK) for accelerometer and 3D device respectively.

Testing Procedures

After a warm-up similar to their weightlifting session, subjects randomly performed 3 sets of 1 repetition with different loads, ranging from 30 to 90% of 1RM, using loads between 50 kg to 140 kg. The recovery set was determined by the athlete, timed between 3 and 5 minutes. This protocol was followed in the three exercises assessed, the order of the exercises was: power snatch, power clean and jerk from the rack. Every subject was instructed to perform each lift as they routinely perform it, being very important do not rotate the bar just before the lift because the sensor's measures are directionally dependent. Any power snatch and power clean received in a squat position with the upper thigh below parallel to the floor was ruled unsuccessful.

Hook grip, weightlifting belt, weightlifting shoes and chalk were allowed to use by the subjects. Weightlifting straps were not allowed. In both testing sessions strong verbal encouragement was given to all subjects to motivate them to perform each lift as maximally and as powerfully as possible to maximize performance.

The three different instruments used in this work (accelerometer, 3D System and high speed video camera) recorded simultaneously each barbell movement. In any case, full movements were recorded. Nevertheless, bearing in mind that the turnover and recovery phase on power snatch and power clean usually cause accelerometer rotation[7] data obtained (full movement) should be divided into two phases: the first one until the highest point of the pull phase (second pull) starting from the ground (in power snatch and power clean) or from the rack up to the highest point of the bar path before the catch position (in jerk) and the second one the remainder.

Statistical Analyses

SPSS statistical software package (version 18.0; SPSS, Inc., Chicago, IL, USA) was used to analyze all data. Normality of the distribution was tested by means of the Kolmogorov-Smirnov test. Concurrent (criterion-related) validity of the accelerometer system was assessed using one-way ANOVA by comparing each selected measure (Pasco) with criterion (Vicon). According to Drouin et al.[18] the discrepancy between these measures was assessed for all trials performed by calculating the method error (ME) and the coefficient of variation of the method error (CV_{ME}). Calculated method error represents the variation (standard deviation) of the delta scores generated from two separate measures of the same variable. To represent this standard deviation appropriately it must be presented as a value normalized to the mean of the delta scores.[19] Therefore, to reflect the amount of variation in the difference scores between test measures, the coefficient of variation of method error (CV_{ME})[19] was calculated. Pearson product-moment correlation coefficient (r) was used to determine the specific relationship within each trial for the accelerometer and criterion accelerometer data. The reliability was investigated using intraclass correlation coefficients ($ICC_{2,1}$), ranging from ''questionable'' (0.7 to 0.8) to ''high'' (>0.9)[20] with 95% CI[21] and the associated standard error of measurement (SEM) for each ICC was also calculated.[21] Magnitude of effect within exercises was estimated with Cohen's effect size (ES). Cohen classified ES into ''small'' (0.2 – 0.3), ''medium'' (0.4 – 0.7), and ''large'' (> 0.8)[22]. The α level was set at 0.05.

Results

Validity

Table 3 reports one-way ANOVA analysis, method error (ME), coefficient of variation of the method error (CV_{ME}) and Pearson product-moment correlation coefficient (r) for each phase, axis and exercise. For all exercise, but exclusively for Z-axis, the results of acceleration demonstrate a good agreement between accelerometer and criterion measures because analysis of variance no revealed significant differences ($p > 0.05$) between Pasco and Vicon. Regarding the coefficient of variation, the scientific literature suggests it should be fewer than 10%, although these estimates have been a source of discrepancy.[23–25] The degree of discrepancy was negligible (CV_{ME} range: 1.13% – 1.88%) and would not threaten the credibility of Pasco measures in certain phases of the exercises.

In this sense, focusing on up to pull phase for power snatch ($p = 0.480$) and power clean ($p = 0.242$) and for jerk ($p = 0.302$) up to the highest point of the bar path before the catch position, the CV_{ME} observed (Table 3) between Pasco and Vicon was 1.38%, 1.44% and 1.13% (for power snatch, power clean and jerk respectively), the method error across all trials was $3.94\,m/s^2$, $4.02\,m/s^2$ and $3.35\,m/s^2$, respectively and Pearson correlation coefficients showed to be the highest in the 3 movements ($r = 0.841$; $r = 0.882$ and $r = 0.933$, respectively). Focusing on from pull phase to finish of the movement for power snatch and power clean and for jerk from the highest point of the bar path before the catch position to finish, the analysis of variance revealed significant differences ($p < 0.05$) between Pasco and Vicon in the 3 movements. Finally, with regard to the full movement, the CV_{ME} observed was 1.48%, 1.70% and 1.88% (respectively),the method error across all trials was $3.99\,m/s^2$, $4.36\,m/s^2$ and $3.37\,m/s^2$ (respectively) and Pearson correlation coefficients pointed out high correlations in the 3 movements ($p = 0.171$, $r = 0.841$; $p = 0.499$, $r = 0.882$ and $p = 0.086$, $r = 0.933$, respectively).

Reliability

Because of the results achieved in the validity, Table 4 only reports intraclass correlation coefficients for trial reliability (ICC), standard error of measurement (SEM) and magnitude of effect (ES) for the exercises analyzed focusing on up to pull phase for power snatch and power clean and for jerk up to the highest point of the bar path before the catch position and only for Z axis. Registered data demonstrated near perfect reliability ($ICC > 0.9$) for each technique. So the accelerometer is capable of providing accurate data.

Discussion

The results support the authors' hypotheses that the accelerometer studied provides valid and reliable measurements of acceleration data, however this validation should be only considered taking into account the vertical data (Z axis).

Past studies have tried to identify key components of weightlifting through kinetic and kinematic variables under competition[10,12,26,27] and training[8,9] conditions and during laboratory researches.[7] According to Sato et al. [7] the biomechanical characteristics collected in the laboratory are usually accessible after a data processing

Table 3 Concurrent validity of Pasco and Vicon for acceleration estimation.

			One-way ANOVA				
Exercise.	Phase	Axe	*F*-value	*p*	r	ME	CV_{ME} (%)
POWER SNATCH	up to pull phase	X	46.651	0.000	0.502*	3.18	2.77
		Y	19.818	0.000	0.076*	5.13	2.36
		Z	0.498	0.480	0.841*	3.94	1.38
		Resultant	6172.189	0.000	0.627*	1.98	2.38
	from pull phase to finish	X	60.608	0.075	0.033*	2.73	1.13
		Y	2.278	0.131	0.185*	0.97	1.30
		Z	54.881	0.000	0.723*	1.15	1.20
		Resultant	11144.617	0.000	0.048*	2.06	1.37
	full movement	X	24.28	0.000	0.324*	3.26	1.82
		Y	17.981	0.000	0.128*	5.08	1.54
		Z	6.472	0.171	0.814*	3.99	1.48
		Resultant	12194.593	0.000	0.551*	2.07	1.35
POWER CLEAN	up to pull phase	X	18.035	0.000	0.452*	3.60	1.55
		Y	59.211	0.000	0.047*	5.59	1.33
		Z	1.372	0.242	0.882*	4.02	1.44
		Resultant	5376.657	0.000	0.573*	1.98	1.32
	from pull phase to finish	X	9.684	0.000	0.068*	2.52	1.20
		Y	68.550	0.000	0.131*	0.90	1.33
		Z	7.535	0.000	0.727*	1.37	1.24
		Resultant	5579.983	0.000	0.381*	1.91	1.33
	full movement	X	26.848	0.000	0.347*	4.19	1.68
		Y	125.048	0.000	0.083*	6.20	1.66
		Z	0.457	0.499	0.773*	4.36	1.70
		Resultant	9901.115	0.000	0.530*	1.98	1.49
JERK	up to catch position**	X	220.747	0.000	−0.001	1.90	1.46
		Y	0.371	0.543	0.056*	4.25	1.23
		Z	1.068	0.302	0.933*	3.35	1.13
		Resultant	7359.248	0.000	0.598*	1.40	1.16
	from catch position **to finish	X	188.121	0.000	0.017	2.05	1.07
		Y	2.227	0.136	0.106*	1.34	1.85
		Z	25.398	0.000	0.736*	1.10	1.20
		Resultant	7713.893	0.000	0.229*	1.70	1.37
	full movement	X	406.321	0.000	0.006	2.72	1.55
		Y	0.633	0.426	0.090*	4.64	1.72
		Z	9.033	0.086	0.888*	3.67	1.88
		Resultant	12156.683	0.000	0.531*	1.56	1.34

*$p < 0.05$, r = Pearson correlation coefficient, ME = method error, CV_{ME} = coefficient of variation of method error
**The highest point of the bar path before the catch position

and not immediately after the execution attempt. Two previous research papers used the accelerometer employed in the current study taking advantage of data obtained in real time.[8,9] In both investigations, the authors pointed out the importance of being able to show an instant feedback after each movement.

However, the results of the current research suggest that one should be careful interpreting the feedback offered by this device in the three axes of movement because outcomes reported only significate correlations in the Z axis (vertical plane) showing poor Pearson coefficient for the X and Y axes. Although positive agreements between the measures of accelerometer studied and the gold standard used were found taking into account the acceleration data of full movement in the exercises investigated, according to our results and

Table 4 Reliability assessed using intraclass correlation coefficients and standard errors of measurement on Z axis.

	ICC	95% CI	SEM	ES
POWER SNATCH (up to pull phase)	0.952	0.932–0.966	1.77	0.000
POWER CLEAN (up to pull phase)	0.963	0.945–0.975	1	0.001
JERK (up to catch position**)	0.990	0.985–0.993	0.55	0.023

CI = confidence interval; ICC = intraclass correlation coefficient; SEM = standard error of measurement; ES = Cohen's effect size
**the highest point of the bar path before the catch position

Sato et al.[7] these agreements are due to the inclusion of data up to pull phase (power snatch and power clean) and up to the highest point of the bar path before the catch position (jerk).

As previously noted by Sato et al.[7] the PS 2119 accelerometer is directionally dependent of its position, just as the case with the current model analyzed in this work (PS-2136A). Due to this fact it is required to eliminate the data obtained in those phases in which the accelerometer varies its initial position during the exercise (turnover and recovery phase for power snatch and power clean and catch and recovery phase for jerk from rack).

According to this, our study suggests that only the data obtained in the vertical plane (Z axis) and up to the pull phase for the power snatch and power clean and up to highest point of the bar path before the catch position during jerk from the rack could be considered valid with the device studied. This supports previous research by Crewther et al.[14] who pointed that bar movements on the horizontal plane could be a source of errors, especially during free weights exercise. Therefore, we disagree with the authors[8,9] who reported the convenience of training resultant acceleration values to assess weightlifting movements using the previous version of the accelerometer studied.

Garhammer[17] pointed out that weightlifting movements have a very small horizontal component that can be neglected. In the same line, Kraemer and Fleck[28] reported that if the horizontal movement from the center is less than 7%, this effect can be ignored. Therefore, according with these authors the information of vertical plane provided by the accelerometer studied could be useful for coaches and lifters to control the weightlifting performance.

This research, similar to Sato et al.[7] suggests that one of the major limitations of the accelerometer is the device's orientation which must be constant throughout the movement to avoid misrepresentation of the data. For this reason, as we already previously commented, data obtained of some phases (the turnover and recovery phase on power snatch and power clean and catch and recovery phase on jerk) should be removed taking only data up to the pull phase for power snatch and power clean and up to the highest point of the bar path before the catch position for jerk. Consequently, the chances to assess the entire movement are restricted. On the other hand, data obtained in the pull phase offers an important tool to develop weightlifting training and test process.[2,29,30]

Finally, it should be mentioned the necessity to protect the device against the external shocks of this type of exercises.[7] The users must be aware of the importance to keep safe the system with some kind of foam that prevents tool damage and misrepresentation of the data. The protection system used in this research (Figure 1) was homemade attaching shower's sponges. This system has demonstrated enough protection for the device, but because the sensor is directionally dependent, a spotter (partner or coach) should replace the system before each repetition. This must be considered as a limitation of the device.

In summary, there are numerous ways of quantifying sport performance, from sophisticated and expensive laboratory tests to low-cost and less-precise field tests. Although laboratory test conditions are frequently well controlled and gold standard methods are used to test the sport performance, the field tests are often more practical, relevant, sport specific and preferred by coaches and athletes. The 3 axis commercial accelerometer validated in the present study may be a useful piece of equipment to measure barbell acceleration in weightlifting movements in comfortable field areas.

Monitoring biomechanical variables like acceleration could provide a deeper understanding of weightlifting performance, but coaches and biomechanists must be cautious with the suitability of the devices used and the interpretation of the data obtained. The accelerometer tested appears to provide validated acceleration data on the Z axis (vertical plane) being necessary to reject acceleration data reported in X and Y axes. This information would allow coaches to make proper decisions and become more sophisticated in the training processes. However coaches and athletes must be aware of limitations of the device for measuring other than the vertical plane.

An additional application of this validation could be the assessment of other variables from acceleration value. This one provides an interesting visual feedback and a proper tool to control weightlifting performance, but other biomechanical data like force or power output could also be calculated using this value. In that sense Thompson and Bemben[31] showed that velocity and power calculated from accelerometers can provide useful and reliable results.

Conclusion

The 3-axis accelerometer (PS-2136A, PASCO, Roseville, Calif.) has been validated with satisfactory results in the vertical plane (Z axis) up to pull phases (including first pull, transition and second pull) in power snatch and power clean and up to the highest point of the bar path before the catch position (including dip, drive, and split phase) in jerk from the rack. This system could be used multiple times per season even in every weightlifting training, being easy to handle and cost effective tool by coaches and athletes. However the acceleration data obtained of X and Y axes must be interpreted with cautions since they presented lower correlations.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

References

1. Lloyd RS, Oliver JL, Meyers RW, et al. Long-term athletic development and its application to youth weightlifting. *Strength Cond J* 2012; 34(4): 55–66.
2. Haff G, Whitley A, McCoy L, et al. Effects of different set configurations on barbell velocity and displacement during a clean pull. *J Strength Cond Res* 2003; 17(3): 95–103.
3. Comfort P, McMahon JJ and Fletcher C. No kinetic differences during variations of the power clean in inexperienced female collegiate athletes. *J Strength Cond Res* 2013 Feb; 27(2): 363–368.
4. Comfort P, Allen M and Graham-Smith P. Kinetic comparisons during variations of the power clean. *J Strength Cond Res* 2011; 25(12): 3269–3273.
5. Otto WH, Coburn JW, Brown LE, et al. Effects of weightlifting vs. kettlebell training on vertical jump, strength, and body composition. *J Strength Cond Res* 2012; 26(5): 1199–1202.
6. Stone MH, Pierce KC, Sands WA, et al. Weightlifting: a brief overview. *Strength Cond J* 2006; 28(1): 50–66.
7. Sato K, Smith SL and Sands WA. Validation of an accelerometer for measuring sport performance. *J Strength Cond Res* 2009; 23(1): 341–347.
8. Sato K, Fleschler P and Sands WA. Barbell acceleration analysis on various intensities of weightlifting. In: *Annual Conference of the International Society for Biomechanics in Sports*, Limerik, Irland 2009.
9. Sato K, Sands WA and Stone MH. The reliability of accelerometry to measure weightlifting performance. *Sports Biomech* 2012; 11(4): 524–531.
10. Kipp K, Harris C and Sabick M. Correlations between internal and external power outputs during weightlifting exercise. *J Strength Cond Res* 2003; 27(4): 1025–1030.
11. Enoka RM. The pull in Olympic weightlifting. *Med Sci Sports* 1979; 11(2): 131–137.
12. Kipp K and Harris C. Patterns of barbell acceleration during the snatch in weightlifting competition. *J Sports Sci* 2015; 33(14): 1467–1471.
13. Sell TC, Akins JS, Opp AR, et al. Relationship between tibial acceleration and proximal anterior tibia shear force across increasing jump distance. *J Appl Biomech* 2014; 30(1): 75–81.
14. Crewther B, Kilduff L, Cunningham D, et al. Validating two systems for estimating force and power. *Int J Sports Med* 2011; 32(4): 254.
15. Comstock BA, Solomon-Hill G, Flanagan SD, et al. Validity of the Myotest(R) in measuring force and power production in the squat and bench press. *J Strength Cond Res* 2011 Aug; 25(8): 2293–2297.
16. Sakadjian A, Panchuk D and Pearce AJ. Kinematic and kinetic improvements associated with action observation facilitated learning of the power clean in Australian footballers. *J Strength Cond Res* 2014; 28(6): 1613–1625.
17. Garhammer J. A review of power output studies of Olympic and powerlifting: Methodology, performance prediction, and evaluation tests. *J Strength Cond Res* 1993; 7(2): 76–89.
18. Drouin JM, Valovich-mcLeod TC, Shultz SJ, et al. Reliability and validity of the Biodex system 3 pro isokinetic dynamometer velocity, torque and position measurements. *Eur J Appl Physiol* 2004; 91(1): 22–29.
19. Portney LG and Watkins MP. *Foundations of clinical research: applications to practice*. New Jersey: NJ, Prentice Hall Upper Saddle River, 2000.
20. Vincent W and Weir J. *Statistics in kinesiology*. Leeds, United Kingdom: Human Kinetics, 1999.
21. Weir JP. Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. *J Strength Cond Res* 2005; 19(1): 231–240.
22. Cohen J. *Statistical power analysis for the behavioral sciences*. Hillsdale, NJ: Lawrence Earlbaum Associates, 1988.
23. Atkinson G and Nevill AM. Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Med* 1998; 26(4): 217–238.
24. Cronin JB, Hing RD and McNair PJ. Reliability and validity of a linear position transducer for measuring jump performance. *J Strength Cond Res* 2004; 18(3): 590–593.
25. Garnacho-Castaño MV, López-Lastra S and Maté-Muñoz JL. Reliability and validity assessment of a linear position transducer. *J Sports Sci Med* 2015; 14(1): 128.

26. Szyszka P and Mastalerz A. The relationship between biomechanical indicators of the snatch technique and female weightlifters' levels. *Pol J Sport Tourism* 2014; 21: 218–222.
27. Lin Y, Hsu C and Ho W. Performance Evaluation for Weightlifting Lifter by Barbell Trajectory. Performance Evaluation. *Int J Med H Biomedical Pharm Engi* 2015; 9: 193–196.
28. Kraemer WJ and Fleck SJ. *Optimizing strength training: designing nonlinear periodization workouts*. Leeds, United Kingdom: Human Kinetics, 2007.
29. Hadi G, Akkus H and Harbili E. Three-dimensional kinematic analysis of the snatch technique for lifting different barbell weights. *J Strength Cond Res* 2012; 26(6): 1568–1576.
30. Kipp K, Redden J, Sabick M, et al. Kinematic and kinetic synergies of the lower extremities during the pull in Olympic weightlifting. *Journal Appl Biomech* 2012; 28: 271–278.
31. Thompson CJ and Bemben MG. Reliability and comparability of the accelerometer as a measure of muscular power. *Med Sci Sports Exerc* 1999; 31(6): 897–902.