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Patterns of Barbell Acceleration During the Snatch in Weightlifting Competition.

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Abstract

The purpose of this study was to determine the association between weightlifting performance and vertical barbell acceleration patterns. Barbell kinematic time-series data were tracked from 18 snatches from six weightlifters during a regional weightlifting competition. These data were used to calculate vertical barbell accelerations. Time-series data were normalised to 100% of lift phase, defined as the time interval between barbell lift-off and maximum height of the barbell during each snatch lift. The time-series data were then entered into a pattern recognition algorithm that extracted principal patterns and calculated principal pattern scores. Body mass-normalised lift weight, which was used to quantify weightlifting performance, was significantly correlated ($r = 0.673$; $P = 0.033$) with a pattern

that captured a difference in peak vertical barbell acceleration between the transition and the second pull phase. This correlation indicated that barbell acceleration profiles of higher weight snatch lifts were characterised by smaller decreases in acceleration during the second knee bend and smaller peak acceleration during the second pull phase. Weightlifting coaches and sports scientist should monitor and track vertical acceleration of the barbell, with focus on acceleration profiles that limit (1) deceleration during the transition phase between the first and second pull and (2) peak acceleration during the second pull phase of the snatch.

Keywords

functional data analysis, principal component analysis, biomechanics

Introduction

Numerous studies have investigated the biomechanical features associated with technique and performance in the sport of weightlifting (Enoka, [5]; Garhammer, [8], [9]; Gourgoulis, Aggelousis, Mavromatis, & Garas, [11]; Kipp, Redden, Sabick, & Harris, [13], [14]; Stone, O'Bryant, Williams, Johnson, & Pierce, [19]). The motivation for these studies comes from the fact that the lifts that are contested in weightlifting (i.e. the snatch and the clean and jerk) are technical movements that require high levels of skill and physical power (Garhammer, [8], [9]; Gourgoulis et al., [11]). The biomechanical variables most commonly investigated in these studies are those that are related to the mechanics of the barbell, such as barbell trajectory, velocity, acceleration and power. These studies show that biomechanical variables can be used to distinguish between lifters of different skill levels or between successful and unsuccessful lift attempts (Gourgoulis et al., [11]; Gourgoulis, Aggeloussis, Garas, & Mavromatis, [10]). In particular, barbell accelerations during lift attempts have received recent attention, partially because barbell acceleration are thought to relate to key aspects of lifting technique and performance (Bottcher & Deutscher, [3]; Isaka, Okada, & Funato, [12]; Sato, Sands, & Stone, [16]). Given the ease of collecting an object's acceleration from either accelerometers or inertial measurement units, barbell acceleration data present an efficient mean to guide and monitor lifting performance during and across training sessions (Sato et al., [16]; Sato, Smith, & Sands, [17]).

A key, purported aspect related to weightlifting performance is a smooth barbell velocity profile that does not exhibit a noticeable decrease in vertical barbell velocity during the second knee bend (i.e. the transition between the first and second pull) (Baumann, Gross, Quade, Galbierz, & Shwirtz, [2]; Gourgoulis et al., [11]). The presence of a decrease in vertical barbell velocity is the result of a negative acceleration or braking phase during the second knee bend and has been considered by some researchers to represent a technical flaw in weightlifting technique (Bartonietz, [1]; Baumann et al., [2]; Gourgoulis et al., [11]). While negative vertical barbell accelerations during the pull and second knee bend phases of the snatch are considered undesirable, it is not clear how deleterious this technical mistake is with respect to weightlifting performance. Another biomechanical issue to consider is the magnitude of barbell acceleration necessary to successfully complete the snatch and clean. While it is apparent that a minimum vertical velocity is needed to propel the barbell into the final catch position for a given lift, Bottcher and Deutscher ([3]) argue that large vertical acceleration values are not necessary to lift heavy loads. In fact, these authors suggest that several common postural flaws, such as an uncoupled hip and shoulder rise during the first pull, are associated with rather large and extraneous vertical barbell accelerations. Bottcher and Deutscher ([3]) do not, however, provide statistical evidence of whether such aberrant barbell accelerations actually affect the weight lifted during the snatch or clean.

Based on the posited importance of barbell acceleration and the lack of knowledge about the patterning of these accelerations, the purpose of this study was to determine the association between vertical barbell acceleration patterns and weightlifting performance in the snatch. We hypothesised that a certain subset of barbell acceleration patterns would correlate with body mass-normalised lift weight of the snatch.

Methods

Participants

Participants for this study were recruited from a pool of competitive weightlifters who participated in a regional weightlifting competition. Prior to the start of competition, all weightlifters who had registered were briefed on the scope of the study. Six of the weightlifters at the competition agreed to participate, and then read and signed an informed consent document, which was approved by the local institutions Institutional Review Board for Human Subjects Testing. Anthropometric and demographic data are presented in Table I. All participants reported that they were free of musculoskeletal injury at the time of the study. The data collection fell within the competitive season for all weightlifters. Five of the six participants competed at the US collegiate level at the time of the study.

Table I. Anthropometric, demographic and barbell trajectory data for participants.

Body mass (kg)	97.6 ± 5.5
1-RM snatch (kg)	97.1 ± 5.5
Barbell trajectory "A" (%)	33.3
Barbell trajectory "B" (%)	33.3
Barbell trajectory "C" (%)	33.3

Note: 1-RM = 1-repetition maximum.

Data collection

Data were collected during the snatch session of the competition. In all, data from 18 snatch attempts were collected. A six-camera Vicon motion analysis system (Vicon, Los Angeles, CA, USA) was used to collect three-dimensional position data from a small strip of reflective tape that was secured around the long axis at the centre of the barbell. Data were recorded at 250 Hz for each lift and stored separately for further analysis.

Data processing

The stored position data were smoothed with a recursive fourth-order low-pass Butterworth filter at 6 Hz. The smoothed barbell position data were first analysed to classify the types of barbell trajectories that the lifters used for each lift (Vorobyev, [20]). This standard classification scheme uses three barbell trajectory paths (i.e. A, B and C) that relate to the directions of barbell path with respect to the vertical reference line of the barbell at lift-off. The filtered position data were double-differentiated with the central difference method to calculate barbell accelerations. The barbell acceleration time-series data in the vertical direction were then normalised to 100% of lift phase, which was defined as the time interval between barbell lift-off and the maximum height of the barbell during the snatch. The normalised time-series data were pooled into one 18 × 101 (snatch lifts × time points) data matrix. Since all variables had the same units (i.e. $m \cdot s^{-2}$) and were approximately of the same magnitude, no other normalisation procedure was used. The data matrix was entered into pattern recognition algorithm that extracts dominant modes of variance (i.e. principal patterns) based on principal component analysis (DeLuzio, Wyss, Zee, Costigan, & Serbie, [4]). Principal patterns were extracted with the SPSS software (IBM, New York, NY, USA). Principal patterns were retained for analysis based on the analysis of a Scree plot and if they explained at least 5% of the variance of the time-series data. Principal pattern scores of the retained principal patterns were then calculated with Microsoft Excel (DeLuzio et al., [4]) to determine how much of each pattern was present in each individual acceleration time series (Ramsay & Silverman, [15]). These principal pattern scores were then used for statistical analysis.

Statistical analysis

On account of the low sample size, non-parametric statistics were deemed appropriate for analysis. The independent variable in this study was the body mass-normalised barbell weight that was lifted during each lift attempt by each participant. The dependent variables were the extracted principal pattern scores from the vertical acceleration profiles. If a lifter performed multiple attempts at the same weight, the principal pattern scores were averaged before being entered into the analysis; otherwise, all lifts were considered independent trials (Stergiou, [18]). Given that this approach may have implications for the independence among trials, the use of non-parametric statistics, which are not based on assumptions of normality and independence, was further deemed appropriate. Spearman rank correlation coefficients were used to test for the associations between the dependent and independent variables. The statistical standard of proof was set an alpha level of 0.05. All statistical analyses were performed in SPSS 19.0 (IBM, New York, NY, USA).

Results

Three principal patterns of vertical barbell acceleration were extracted each from the snatch lifts. These patterns explained 39.6%, 31.7% and 9.9% of the variance in all acceleration profiles. Eight of the snatch lifts were successful and 10 of the snatch lifts were unsuccessful. However, successful and unsuccessful snatch lifts did not differ in any of the pattern scores and were thus pooled for analysis. Moreover, all the unsuccessful lifts were lost from the overhead squat position due to balance and stability issues. Barbell trajectory types were equally presented in all lifts (Table I).

The correlation analysis revealed a significant correlation between body mass-normalised lift weight and the second principal barbell vertical acceleration pattern ($r = 0.673$; $P = 0.033$), which captured the magnitudes of acceleration during the second knee bend and the second pull phase of the snatch (Figure 1b). Correlations between body mass-normalised lift weight and the first ($r = 0.067$; $P = 0.855$) and third ($r = 0.236$; $P = 0.511$) principal patterns of vertical barbell acceleration were non-significant.

Graph: Figure 1. Mean vertical barbell acceleration data (black line) for the snatch lifts and the effects of (a) principal pattern 1, (b) principal pattern 2 and (c) principal pattern 3 on the overall acceleration profiles. The effects of each principal pattern on barbell acceleration is illustrated with plus (+) and minus (−) signs. In this convention, a positive or greater principal pattern score shifts the acceleration profile in the direction of the plus signs, whereas a negative or smaller principal pattern score shifts the acceleration profile in the direction of the negative signs.

Discussion

The primary finding of this study was that body mass-normalised lift weight of the snatch was correlated with a pattern of barbell acceleration that captured acceleration magnitudes during the second knee bend and the second pull phase of the lift. This correlation indicated that the barbell acceleration profiles of higher weight snatches were associated with smaller decreases in vertical accelerations during the second knee bend and smaller increases in accelerations during the second pull phase of the snatch.

A large decrease in vertical barbell acceleration during the second knee bend of the snatch is purported as an undesirable technical characteristic during weightlifting, especially if the decrease is large enough that the acceleration profile becomes negative, because this would lead to a concomitant decrease in vertical barbell velocity during the transition between the first and second pull phases (Bartonietz, [1]; Baumann et al., [2]; Gourgoulis et al., [11]). Baumann et al. ([2]) observed that the 10 best lifts at the 1985 World Weightlifting Championships displayed a steady increase in velocity up to a single velocity peak with no notable dip in the velocity profile, while the 10 poorest lifts had two distinct velocity peaks within each lift attempt. A decrease in barbell acceleration and velocity also indicates a negative or braking impetus, which has to be overcome through a greater level of effort during the second pull (Bartonietz, [1]). The findings of the current study therefore quantitatively corroborate previous assertions in that barbell acceleration patterns with smaller decreases in barbell acceleration during the second knee bend were correlated with higher body mass-normalised lift weights. It thus appears that minimising the decrease in vertical barbell acceleration during the transition between the first and second pull would enable weightlifters to lift greater loads during the snatch.

The association between excessive vertical barbell acceleration during the second pull and lower body mass-normalised lift weight appears logical in consideration of Newton's second law of motion. The basic technical model of the snatch requires that a lifter move the barbell into a position of overhead support in one smooth motion, which is done by applying forces onto the barbell during the different pull phases of the lift. It is generally presumed that a lifter can only generate a finite amount of force during the pull phases of the lift (Funato, Matsuo, & Fukunaga, [7]). Given that the goal in weightlifting is to lift maximum mass, and not to generate maximum acceleration, it becomes apparent that excessive vertical acceleration indicates a waste of force that should instead be transferred into lifting a heavier load rather than achieving greater barbell acceleration. Our findings are in agreement with this tenet since the correlation analysis showed that that barbell acceleration patterns with smaller acceleration peaks during the second pull were associated with higher body mass-normalised lift weights. It therefore appears that in addition to minimising the decrease in vertical barbell acceleration during the transition between the first and second pull, weightlifters should limit the peak magnitude of barbell acceleration during the second pull in order to lift greater loads during the snatch. Although it is questionable whether a lower peak acceleration during the second pull could be expected simply from greater barbell loads, it should be noted that the acceleration pattern of interest also captured aspects related to peak negative acceleration during the transition phase of the snatch pull. In combination, a greater peak negative acceleration during the transition phase and a greater peak positive acceleration during the second pull phase may characterise an acceleration pattern where the lifter has to apply higher forces during the second pull to overcome the braking forces due to inappropriate (i.e. negative) acceleration during the transition phase. It could therefore be argued that this pattern may indeed reflect an underlying technical element. Monitoring and tracking vertical barbell acceleration profiles, especially in longitudinal study designs, may help determine whether the force a lifter is applying to the barbell is producing excessive acceleration rather than allowing for an increase in load.

The findings of this study should be considered in light of a few limitations. First, the weightlifters who participated in this study were mostly US collegiate level lifters, as reflected in the load they lifted during the competition. The range of performance levels of the weightlifters in the current study was also fairly narrow. At the same time, the barbell trajectory profiles indicate that the lifters span a variety of common lift styles. The generalizability of the findings may therefore only extend to a population with comparable technical, competitive and performance levels. It should be noted though that the range of vertical barbell accelerations produced by the lifters in this study matches those of several other studies, regardless of the subject populations in those studies (Bottcher & Deutscher, [3]; Gourgoulis et al., [11]). Second, the time normalisation of the barbell acceleration data and interpolation to 100% of the lift phase may influence timing-related aspects of the extracted patterns. Although several other time-normalisation techniques exist, all would affect timing-related events to some extent (Ramsay & Silverman, [15]). It is therefore possible that other studies may identify associations not present in the current study. Last, the sample size was relatively small. Unfortunately, the number of competitive weightlifters is very small, and finding participants who agree to participate in research studies further limits the pool of participants. While the sample size was small, the analysis still identified significant correlations, which would indicate that sample size was not a major limitation. In addition, recent studies have supported the use of principal component analysis of time-series data or waveforms for analyses with small sample size due to greater sensitivity in detecting differences or correlations among biomechanical data (Federolf, Boyer, & Andriacchi, [6]). Nonetheless, the results should be interpreted in light of the small sample size and the statistical procedures used to produce these results.

Conclusion

The purpose of this study was to determine the association between patterns of vertical barbell acceleration and weightlifting performance in the snatch. It was hypothesised that patterns of barbell acceleration of the snatch would correlate with body mass-normalised lift weight. The results supported the hypothesis in that one of the three extracted barbell acceleration patterns was correlated with body mass-normalised lift weight in the snatch. Based on the interpretation of this acceleration pattern, the moderate correlation indicated that greater body mass-normalised lift weights were characterised by smaller acceleration decreases during the second knee bend as well as by smaller acceleration peaks during the second pull phase of the snatch. Since barbell acceleration patterns are correlated to weightlifting performance, coaches and scientists should monitor vertical accelerations of the barbell with a specific focus on acceleration profiles that (1) limit negative accelerations during the transition phase between the first and second pull and (2) limit excessive peak acceleration during the second pull phase of the snatch.

References

1. Bartonietz, K. E. (1996). Biomechanics of the snatch: Toward a higher training efficiency. Strength and Conditioning Journal, 18, 24–31.
2. Baumann, W., Gross, V., Quade, K., Galbierz, P., & Shwirtz, A. (1988). The snatch technique of world class weightlifters at the 1985 world championships. International Journal of Sport Biomechanics, 4, 68–89.
3. Bottcher, J., & Deutscher, E. (1999). Biomechanische Ergebnisse zur Bewegungstechnik im Gewichtheben (Reißen). Leistungssport, 29, 55–62.
4. DeLuzio, K. J., Wyss, U. P., Zee, B., Costigan, P. A., & Serbie, C. (1997). Principal component models of knee kinematics and kinetics: Normal vs. pathological gait patterns. Human Movement Science, 16, 201–217.
5. Enoka, R. M. (1979). The pull in Olympic weightlifting. Medicine in Science and Sports, 11, 131–137.
6. Federolf, P. A., Boyer, K. A., & Andriacchi, T. P. (2013). Application of principal component analysis in clinical gait research: Identification of systematic differences between healthy and medial knee-osteoarthritic gait. Journal of Biomechanics, 46, 2173–2178.
7. Funato, K., Matsuo, A., & Fukunaga, T. (1996). Specific movement power related to athletic performance in weight lifting. Journal of Applied Biomechanics, 12, 44–57.
8. Garhammer, J. (1981). Biomechanical characteristics of the 1978 world weightlifting champions. International Series on Biomechanics, 3, 300–304.
9. Garhammer, J. (1985). Biomechanical profiles of Olympic weightlifters. International Journal of Sport Biomechanics, 1, 122–130.
10. Gourgoulis, V., Aggelousis, N., Garas, A., & Mavromatis, G. (2009). Unsuccessful vs. successful performance in snatch lifts: A kinematic approach. Journal of Strength and Conditioning Research, 23, 486–494.
11. Gourgoulis, V., Aggelousis, N., Mavromatis, G., & Garas, A. (2000). Three-dimensional kinematic analysis of the snatch of elite Greek weightlifters. **Journal of Sports Sciences**, 18, 643–652.
12. Isaka, T., Okada, J., & Funato, K. (1996). Kinematic analysis on the barbell during the snatch movement of elite Asian weight lifters. Journal of Applied Biomechanics, 12, 508–516.
13. Kipp, K., Redden, J., Sabick, M. B., & Harris, C. (2012a). Kinematic and kinetic synergies of the lower extremities during the pull in Olympic weightlifting. Journal of Applied Biomechanics, 28, 271–278.
14. Kipp, K., Redden, J., Sabick, M. B., & Harris, C. (2012b). Weightlifting performance is related to kinematic and kinetic patterns of the hip and knee joints. Journal of Strength and Conditioning Research, 26, 1838–1844.
15. Ramsay, J. O., & Silverman, B. W. (1997). Functional data analysis. New York, NY: Springer Verlag.
16. Sato, K., Sands, W. A., & Stone, M. H. (2012). The reliability of accelerometry to measure weightlifting performance. Sports Biomechanics, 11(4), 524–531.
17. Sato, K., Smith, S. L., & Sands, W. A. (2009). Validation of an accelerometer for measuring sport performance. Journal of Strength and Conditioning Research, 23, 341–347.
18. Stergiou, N. (2003). Innovative analyses of human movement. Champaign, IL: Human Kinetics.

19. Stone, M. H., O'Bryant, H. S., Williams, F. E., Johnson, R. L., & Pierce, K. C. (1998). Analysis of bar paths during the snatch in elite male weightlifters. Strength and Conditioning Journal, 20, 30–38.
20. Vorobyev, A. A. (1978). Textbook on weightlifting. Budapest: International.