ASSOCIATIONS BETWEEN GROUND REACTION FORCES AND BARBELL ACCELERATIONS IN WEIGHTLIFTING

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The purpose of this study was to investigate associations between vertical ground reaction forces and vertical barbell accelerations during the snatch. Barbell kinematic and force plate kinetic data were collected during a weightlifting competition. Time-series data were normalized to 100% of lift phase and were entered into a pattern recognition algorithm that extracted principal patterns and calculated principal pattern scores. Significant associations indicate that a smaller, and temporally shorter, decrease in ground reaction forces during the transition phase is associated with a smaller decrease in barbell acceleration during the transition phase and a smaller peak barbell acceleration during the second pull phase. In order to optimize barbell acceleration, weighlifters may need to ensure a quick transition between the first and second pull.

KEY WORDS: functional data analysis, principal components, snatch, biomechanics

INTRODUCTION: Several research studies have investigated biomechanical variables associated with the snatch technique in the sport of weightlifting (Garhammer, 1985; Gourgoulis, et al., 2000, Stone et al., 1998). The primary outcome variables of these studies are related to the mechanics of the barbell (e.g., barbell velocity and acceleration). A particular effort has focused on investigating barbell accelerations during weightlifting exercises, partially because this variable is thought to capture key aspects related to lifting technique and performance (Isaka, et al., 1996; Sato, Sands, & Stone, 2012).
While several studies have contributed to the current understanding of barbell mechanics during the snatch, there is a relative dearth of information about the ground reaction forces during this lift (Baumann et al., 1988; Garhammer & Gregor, 1992). It is important, however, to characterize the externally applied ground reaction forces that act on the lifter-barbell system during the snatch because it is these propulsive forces developed during the lift that are then transferred to the barbell (Garhammer & Gregor, 1992). It follows that understanding how the external ground reaction forces contribute, or correlate, to the acceleration of the barbell would arguably be of applied interest.
Based on the posited importance of barbell acceleration and the lack of knowledge about the simultaneoulsy generated ground reaction forces, the purpose of this study was to determine the association between ground reaction forces and vertical barbell acceleration patterns during the snatch. It was hypothesized that aspects of the ground reaction forces would be associated with barbell accelerations during the snatch, and that these associations would help identify performance-based associations that could help guide the development of a more efficient technical model.

METHODS: 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 tlifters who had registered were briefed on the scope of the study. Six of the lifters (body-mass: 97.6kg; max snatch lift: 97.1kg) 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. All participants reported that they were free of musculoskeletal injury at the time of the study.
All data were collected during the snatch session of the competition. In all, data from 18 snatch attempts were collected. A six-camera motion analysis system (Vicon, Los Angeles, CA, USA) was used to collect 3-D position data from a strip of reflective tape that was secured around the long-axis at the center of the barbell. The barbell position data were

recorded at 250 Hz. In addition, two force plates (Kistler Instrument Corp., Amherst, NY, USA) were built into the lifting platform and positioned such that the lifters were able to place one foot on each force plate. Kinetic data from the force plates were recorded at 1250 Hz.
All data were smoothed with a recursive 4^{th} order low-pass Butterworth filter. The cut-off frequencies for the kinematic and kinetic data filters were 6 and 25 Hz, respectively. The filtered position data were double-differentiated with the central difference method to calculate barbell accelerations. Upon filtering the vertical ground reaction forces from both force plates were added together to caculate the total vertical force acting on the barbell-lifter system. The vertical barbell acceleration and vertical ground reaction force time-series data were then normalized 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 (Figure 1).

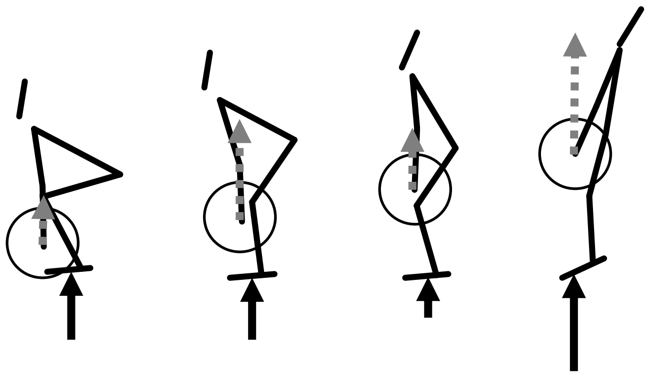

Figure 1: Vertical vectors of the ground reaction force (solid black line) and barbell acceleration (dotted grey line) during the pull phase of the snatch.

The normalized time-series data were pooled into two 18 x 101 (snatch lifts x time points) data matrices: one for the vertical barbell accelerations and one for the vertical ground reaction forces. Since all variables had the same units (i.e., m/s^2 or N) and were of similar magnitude, no other normalization procedure was used. The data matrices were entered into pattern recognition algorithm that used a functional data analysis framework to extract dominant modes of variance (i.e., principal patterns) based on principal components analysis (Ramsay & Silverman, 1997). Principal patterns were retained for analysis based on the analysis of a Scree plot. Principal pattern scores of the retained principal patterns were then calculated to determine how much of each pattern was present in each individual acceleration and GRF time-series (Ramsay & Silverman, 1997). These principal pattern scores were then used in subsequent statistical analyses to determine the associations between features of the ground reaction forces and barbell accelerations.
The statistical analysis consisted of non-parametric statistics (spearman rank correlation coefficients [ρ]) to analyse the associations between the principal pattern scores extracted from the ground reation force and barbell acceleration data. A priori alpha-levels for statistical significance and statistical trends were set at 0.05 and 0.10, respectively. All statistical analyses were performed in SPSS 20 (IBM, New York, NY, USA).

RESULTS: The principal components analysis extracted four principal patterns from the ground reaction force data and three from the barbell acceleration data. The statistical analyses indicated the presence of two statistically significant correlations. The first significant correlation occurred between the second principal pattern for barbell acceleration and the second principal pattern for the ground reaction force (ρ = 0.665, p = 0.005). The second significant correlation occurred between the second principal pattern for barbell acceleration and the fourth principal pattern for the ground reaction force (ρ = -0.674, p = 0.004).
The principal patterns that were significantly correlated in the statistical analyses explained unique portions of variance in the ground reaction force and barbell acceleration data. The

second principal pattern of barbell acceleration captured a difference in acceleration magnitudes during the second knee bend and the second pull phase (Figure 2).

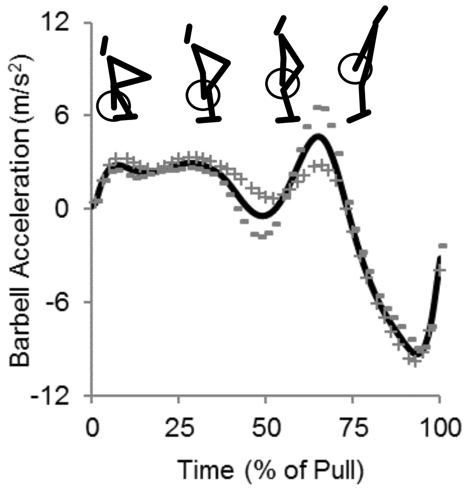

Figure 2: Effects of second principal pattern on the barbell acceleration data. Note that the black line represents the ensemble average data of all lifts and the +/- symbols represent the effects of a positive and negative principal pattern score, respectively, on the average data.

The second principal pattern of ground reaction force captured a difference in force magnitudes during the second knee bend and the second pull phase (Figure 3A), whereas the fourth principal pattern of ground reaction force captured the width of the force decrease during the transition phase (Figure 3B).

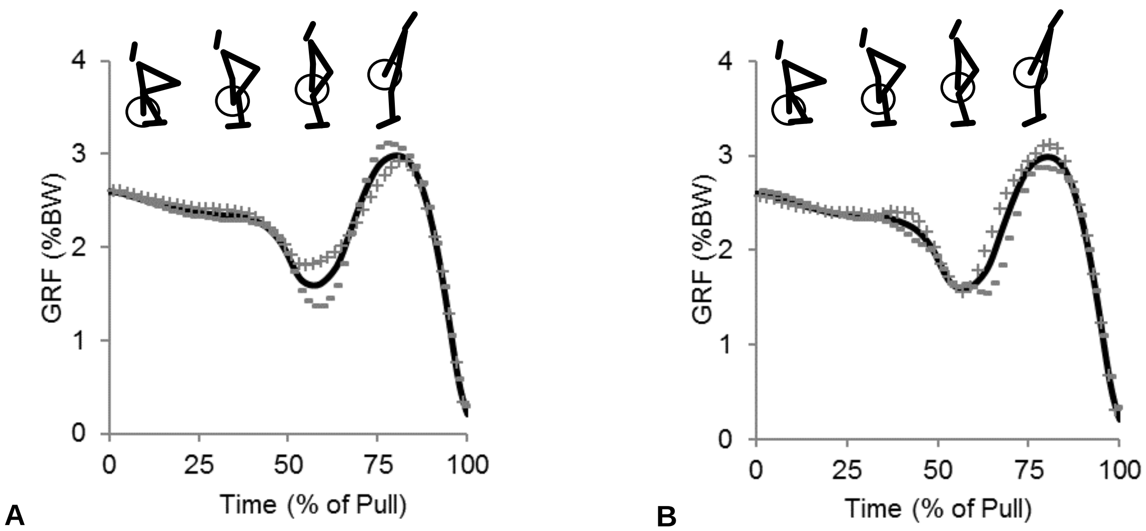

Figure 3: Effects of the second (A) and fourth (B) principal pattern on the ground reaction force data. Note that in each figure the black line represents the ensemble average data of all lifts and the +/- symbols represent the effects of a positive and negative principal pattern score, respectively, on the average data.

DISCUSSION: The results support our hypothesis in that several aspects of the ground reaction forces were associated with aspects of barbell accelerations during the snatch. Based on the interpretations of the principal patterns and the directionality of the associations the results indicate that a smaller, and temporally shorter, decrease in ground reaction forces during the transition phase is associated with a smaller decrease in barbell acceleration during the transition phase and a smaller peak barbell acceleration during the second pull phase.

A decrease in vertical barbell acceleration during the transition phase between the first and second pull of the snatch is typically considered a technical flaw, because a large enough

decrease in the acceleration profile may lead to negative accelerations, which would in turn lead to a concomitant decrease in vertical barbell velocity (Bartonietz, 1996; Baumann et al., 1988; Gourgoulis et al., 2000). Better lifters typically display a steady increase in velocity up to a single velocity peak with no notable dip in the velocity profile, while poor lifters typically display two distinct velocity peaks velocity (Baumann et al., 1988). Negative barbell accelerations and velocities also indicate a braking impetus during the transition phase, which has to be overcome with a greater level of effort during the second pull (Bartonietz, 1996). This becomes problematic because a lifter is generally presumed to be able to only generate a finite amount of force during the pull phases of the lift (Funato et al., 1996). Excessive vertical accelerations therefore indicate a waste of force that should be used to lift heavier loads rather than generate greater barbell accelerations.
Based on the results of the statistical analyses it therefore appears that the above-mentioned negative aspects of barbell acceleration profiles are associated with a large decrease in ground reaction force during the transition phase between the first and second pull. In addition, a relatively slower transition phase, as evidenced by a longer decrease in ground reaction force during the transition phase, also appears to be linked to negative aspects of barbell acceleration profiles. Garhammer and Gregor (1992) found that the temporal pattern of force application is an important element during maximal dynamic activities. In addition, faster eccentric phases, such as the transition phase during the first and second pull for the snatch, during weightlifting exercises generally correlate to better lift performance (Kauhanen et al., 1984).

CONCLUSION: Several aspects of the ground reaction forces were associated with aspects of barbell accelerations during the snatch. The results indicate that negative aspects of barbell acceleration profiles (i.e., those that limit lift performance) are correlated to specific characteristics in the ground reaction force profiles. In order to optimize lift performance it appears that weighlifters need to ensure a quick transition phase between the first and second pull. This information identifies performance-based relationships that may guide the development of a more efficient technical model of the snatch.

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