KINEMATIC AND KINETIC PATTERNS IN OLYMPIC WEIGHTLIFTING

Kristof Kipp[1], Josh Redden[2], Michelle Sabick[3], and Chad Harris[4]
Department of Physical Medicine and Rehabilitation, University of Michigan, Ann Arbor, USA[1]
USA Weightlifting, Colorado Springs, USA[2]
Department of Mechanical and Biomedical Engineering, Boise State University, Boise, USA[3]
Department of Allied Health, Western New Mexico University, Silver City, USA[4]

The purpose of this study was to identify lower extremity kinematic and kinetic patterns during weightlifting movements and to compare them across different external loads. Subjects completed multiple sets of the clean exercise at various percentage loads. Principal component analysis (PCA) was used to extract kinematic and kinetics patterns of the hip, knee, and ankle joint across the loads. These patterns were then compared across joint and percentage load. Results indicate that lower extremity kinematics and kinetics can be characterized through combinations of PCA-derived patterns. Patterns differed predominantly between joints, but not across percentage loads. The results point to joint-specific lower extremity function during Olympic weightlifting and quantified important technical aspects.

KEYWORDS: principal component analysis, joint coordination, movement patterns

INTRODUCTION: Knowledge of task-inherent biomechanics, such as joint kinematics or kinetics, provides important information for technique training in sports. Success in Olympic weightlifting depends in large part on optimal control and coordination between the joints of the lower extremity (Baumann et al., 1988, Enoka 1988, Hakkinen et al., 1984). Relatively few studies, however, have examined lower extremity joint function during weightlifting movements (Baumann et al., 1988, Enoka 1988, Hakkinen et al., 1984). Moreover, these studies have largely relied on the analysis of discrete peak biomechanical variables. While these variables can provide information about general magnitudes of motions and moments etc. they do not account for the complex interaction between the multiple degrees of freedom that need to be controlled to successfully lift maximal weights during weightlifting movements. Principal component analysis (PCA) is a method that can quantify common synergistic joint coordination patterns across a variety of movements and thus addresses this problem.

In addition to the dearth of information about coordinative patterns during weightlifting movements, surprisingly little is known about load-dependent changes in lower extremity mechanics (Enoka, 1988). Yet knowledge of how these patterns change across loads at each of the lower extremity joints would facilitate a better mechanistic and technical understanding of weightlifting movements. The purpose of this study was thus two-fold; 1) to identify lower extremity kinematic and kinetic patterns during weightlifting exercise and 2) to compare these patterns across joint and load. To this end we used PCA to extract principal patterns of the lower extremity joints during the pull-phase of the clean and compared the extent to which these patterns differed between the hip, knee, and ankle joint across a variety of loads.

METHOD: Ten subjects participated in this study. All subjects participated in a training program that involved weightlifting exercises and were deemed technically competent and representative of collegiate-level lifters by a national USA Weightlifting coach. All subjects provided written informed consent approved by the University's IRB.

Subjects completed a brief warm-up that included lifting light loads up to 50% of their self-reported one repetition maximum (1-RM) for the clean exercise. After the warm-up, subjects performed 2-3 repetitions at 65%, 75%, and 85% of 1-RM with approximately 2-3 minutes rest between each set. Kinematic and kinetic data were collected during each set. Kinematic data were acquired from reflective markers attached to the subjects body with a 6-camera

Vicon motion capture system that sampled at 250 Hz. Kinetic data were collected at 1,250 Hz from two Kistler force plates that were built into an 8’x8’ weightlifting platform. Kinematic and kinetic data were filtered at 6 and 25 Hz, respectively. Euler angle rotation sequences were used to calculate ankle, knee, and hip joint angles. Kinematic and kinetic data were combined with anthropometric data and used to solve for net internal ankle, knee, and hip joint moments with an inverse dynamics approach. Moments were normalized to body height and weight. Data were calculated for right leg sagittal-plane variables and time-normalized to 100% of the lift phase (i.e. from the time the barbell left the platform to the time the vertical ground reaction force fell below 10 Newton’s at the end of the second clean pull-phase).

For each of the three joint rotations and three joint moments, the time-normalized waveforms for the three sets clean trials of each individual were subjected to a PCA. The input to the PCA for the kinematic and kinetic analysis thus comprised the time-normalized waveforms for all subjects, joints, and lift conditions (i.e. 10 subjects x 3 joints x 3 lift conditions = 90 waveforms), with the values at each 1% time-normalized increment considered the “variables” in the PCA. This yielded a 90 waveforms x 100 “variables” matrix for the joint rotations and moments. From these waveform matrices, principal patterns were extracted using a covariance matrix decomposition method. Only principal patterns that explained nontrivial proportions of the waveforms were retained for analysis. The retained patterns were each normalized to unit vectors and projected onto each original waveform. The sum of these projections over the entire lift phase gave a set of principal pattern scores that expressed the extent to which each pattern was present in the individual waveforms for each subject, joint, and condition. These scores were then used for statistical analysis.

Separate 3 (joint) x 3 (condition) repeated measure ANOVAs were used to test for differences in principal pattern scores. Huynh-Feldt adjustments were made when assumptions of sphericity were not met. The α-level for statistical significance was set at 0.05. In the absence of significant interactions, data were pooled across joint and/or conditions for post hoc testing and compared with bonferroni-adjusted paired t-tests.

RESULTS: Main effects for principal kinematic pattern scores were observed for PP1 and PP2 (Figure 1a), which captured a general extension and an extension-flexion-extension motion, respectively (Figure 1b). More specifically, PP1 scores for the hip and knee were greater than for the ankle, whereas PP2 scores differed between all joints and were greatest for the knee, intermediate for the ankle, and smallest for the hip (Table 1).

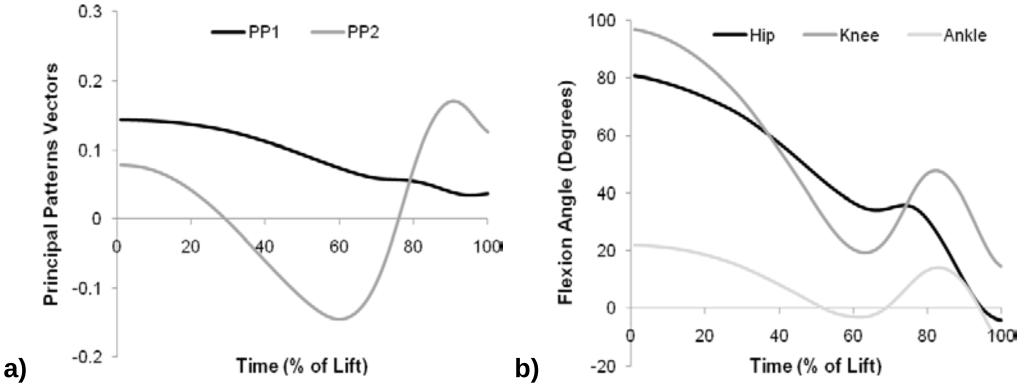

Figure 1. a) Kinematic principal patterns normalized to unit-vectors; b) joint angles during the pull-phase of the clean at 85% of 1-RM (Note: positive angles indicate joint flexion).

Table 1. Principal pattern scores across joint and load

		PC Scores				
		Kinematic		Kinetic		
Joint	Load	PP1	PP2	PP1	PP2	PP4
Hip	65	534.9±97.2*	-16.5±31.8*†	87.3±19.7*†	18.0±16.7	17.1±5.7
	75	530.0±115.0*	-38.7±29.0*†	94.5±22.5*†	20.7±16.2	17.5±3.9
	85	525.3±122.8*	-25.7±36.0*†	92.9±21.0*†	24.5±21.9	18.9±3.9
Knee	65	570.5±153.8*	111.4±25.6*‡	2.6±11.9*‡	20.7±13.2	22.6±11.3*
	75	570.0±142.4*	105.7±29.6*‡	6.6±16.1*‡	23.9±17.2	21.9±10.0*
	85	572.9±129.1*	114.6±32.1*‡	5.6±10.5*‡	19.2±14.9*	25.1±9.7*
Ankle	65	98.8±38.6†‡	41.8±17.5†‡	28.9±9.0†‡	34.9±6.9	10.9±10.8†
	75	112.0±47.5†‡	40.5±16.9†‡	30.8±10.0†‡	36.3±7.4	11.1±8.5†
	85	106.0±38.3†‡	43.6±17.3†‡	34.6±11.6†‡	46.1±8.4†	12.8±7.5†

* $p<.05$ vs. Ankle, † $p<.05$ vs. Knee, ‡ $p<.05$ vs. Hip

Main effects for principal kinetic pattern scores were observed for PP1 and PP4 (Figure 2a), which captured a general extension moment and an extension-flexion-extension moment transition, respectively (Figure 2b). More specifically, PP1 scores differed between all joints and were greatest for the hip, intermediate for the ankle, and smallest for the knee (Table 1). PP4 scores differed only between the knee and the ankle in that the PC scores was greater for the knee. Further, an interaction indicated that the PP2 score (Figure 2a), which captured an extension moment peak during the final part of the movement (Figure 2b), was greater for the ankle than the knee during the 85% condition (Table 1).

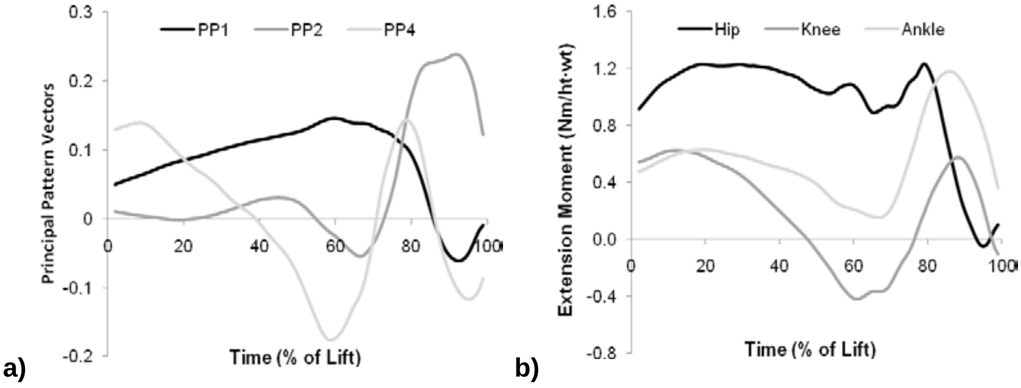

Figure 2. a) Kinetic principal patterns normalized to unit-vectors; b) net internal joint moments during the pull-phase of the clean at 85% of 1-RM (Note: positive moment indicates a net internal joint extension moment).

DISCUSSION: The purpose of this study was two-fold; 1) to identify lower extremity kinematic and kinetic patterns during weightlifting exercise and 2) to compare these patterns across joint and load.

The extracted kinematic patterns captured a general extension motion and an extension-flexion-extension transition. The general extension motion pattern was more prominent for the hip and knee than for the ankle. This pattern seems to reflect the fact that during the pull-phase of the clean the hip and knee joint move through a larger range of motion (Baumann et al., 1988). The second kinematic pattern exhibited a distinct hierarchy between joints and was largest for the knee, intermediate for the ankle, and smallest for the hip. The extension-flexion-extension characteristic of this pattern seems to reflect the double-knee bend transition between the first and second pull of the clean (Baumann et al., 1988, Enoka 1988, Hakkinen et al., 1984), which would explain why this pattern is most prominent at the knee.

The extracted kinetic patterns captured a general extension moment, an extension-flexion-extension moment transition, and an extension moment peak during the final part of the movement. The general extension moment displayed a distinct hierarchy in magnitude between joints and was largest for the hip, intermediate for the ankle, and smallest for the knee. The magnitude of the hip moment correlates well with the magnitude of the weight lifted during weightlifting competition (Baumann et al., 1988) and would indicate that this is a very important characteristic. Similar to the kinematic analysis, the kinetic PCA also extracted an extension-flexion-extension pattern that appeared to reflect the double-knee bend transition. Since this kinetic pattern was greater for the knee than the ankle, the results would indicate that neuromuscular control of the knee joint is more important during this phase than that of the ankle. The analysis also captured an extension moment peak during the final part of the movement that was greater for the ankle than the knee during the 85% of 1-RM load condition. This interaction indicates that the contribution of the ankle extensor musculature during the final pull phase in weightlifting is more prominent at higher load percentages.

Collectively, the PCA-derived patterns are able to describe lower extremity function during weightlifting exercise. Hip function during weightlifting is characterized by a general extension motion and large extension moment, which in combination indicates a large requirement of mechanical work from the hip extensor muscles. Knee function was most notably characterized by an extension-flexion-extension pattern in both joint motion and joint moment, which underscores the technical importance of the double knee bend during weightlifting. Lastly, ankle function consisted of small amount of angular excursion, intermediate extension-flexion-extension motion and moment magnitudes. Interestingly, when compared to the knee joint, the magnitude of ankle joint moment was greatest at higher loads, which underscores the importance of ankle function as lift weight increases.

CONCLUSION: The results indicate that lower extremity kinematics and kinetics can be described by PCA-derived patterns. Kinematic patterns differed between joints, but appeared robust and invariant in response to changes in external load. Although two kinetic patterns differed between joints only, one kinetic pattern exhibited more complex behaviour in that it differed across joint and load. Collectively, these patterns were able to provide technical perspectives on lower extremity function during weightlifting exercise.

REFERENCES:

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.

Enoka, R.M. (1988). Load- and skill-related changes in segmental contributions to a weightlifting movement. *Medicine and Science in Sports & Exercise,* 20, 178-87.

Hakkinen, K., Kauhanen H., & Komi P.V. (1984). Biomechanical changes in the olympic weightlifting technique of the snatch and clean & jerk from submaximal to maximal loads. *Scandinavian Journal of Sports Sciences,* 6, 57-66.

Acknowledgement

We would like to thank Seth Kuhlman for help with data processing.