IDENTIFYING JOINT-SPECIFIC LIMITATIONS AND TARGETS FOR IMPROVING WEIGHTLIFTING PERFORMANCE

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The purpose of this study was to determine the relative effort (RE) of the extensor and plantarflexor muscles during the pull phase of the clean. Five weightlifters performed the clean at 85% of their one-repetition maximum while motion capture and ground reaction forces were recorded and used to calculate lower body net joint moments via inverse dynamics (NJM_{ID}). Joint angle and angular velocity data were used as input to a musculoskeletal model that estimated maximum NJM (NJM_{max}) weightlifters could theoretically generate. The RE of the hip and knee extensor and ankle plantarflexor muscles were calculated as the ratios between NJM_{ID} and NJM_{max}. The results suggest that the knee extensor muscles operate close to max capacity during both pull phases, and that the plantarflexor muscles operate close to their max capacity during the second pull.

KEYWORDS: sports, biomechanics, modelling, relative effort, clean.

INTRODUCTION: Performance in the sport of weightlifting is determined by the load that a competitor can lift in the snatch and clean and jerk exercises (Vorobyev, 1987). Skilled weightlifters exhibited large average joint power magnitudes and produce high peak hip and peak knee extension moments, which in turn exhibit strong to moderate correlations with the mass of the lifter-barbell system and reflects the better performance level of these weightlifters (Baumann et al., 1988; Enoka, 1988, Kipp et al., 2012b). Weightlifting performance therefore appears to depend in part on a weightlifter's ability to generate large magnitudes net joint moments and powers.

While previous studies highlight the importance of joint-specific kinetics in relation to weightlifting performance, these studies calculated and reported only absolute net joint moments (NJM) (Baumann et al., 1988; Enoka, 1988, Kipp et al., 2011; Kipp et al., 2012a). Analysis of absolute NJM, however, has limitations that limit insight into the respective importance of specific muscle groups in relation to task performance (Bryanton et al., 2012). To gain a better understanding of the functional demands imposed on specific muscle groups during dynamic tasks, researchers sometimes calculate the relative effort (RE) of these muscle groups. For example, Bryanton et al. (2012) calculated the ratio between the inverse dynamics based NJM (NJM_{ID}) and the maximal possible NJM (NJM_{max}) based on single-joint isometric testing. The authors subsequently investigated the effect of load on RE of the hip and knee extensor and ankle plantarflexor muscle groups during the back squat exercise and found that only the hip extensor and ankle plantarflexor RE, but not knee extensor RE, increased with load. Calculating RE for different muscle groups across different conditions can therefore yield important practical information about the functional capacity or relative demands imposed on specific muscle groups during dynamic tasks that are not possible with absolute NJM. The purpose of this study was to determine the RE of the extensor and plantarflexor muscles during the pull phase of the clean. The hypothesis was that the RE results would quantify functional demands of muscle groups and identify which of them are operating close to their maximal capacity during the pull phase of the clean.

METHODS: Five male weightlifters participated in this study (mean±SD height: 1.85±0.09 m; mass: 106.0±13.2 kg; one-repetition clean: 126.4±22.9 kg). The study was approved by the local University's Institutional Review Board and all weightlifters provided written informed consent before the beginning of data collection.

Reflective markers were attached to bony landmarks of each subject (Kipp et al., 2011), who then performed a brief warm-up that included light calisthenics and several sets of sub-maximal

(≤ 75% of 1-RM) cleans. After the warm-up, they performed 2 repetitions of the clean at 85% of 1-RM.

Kinematic and kinetic data were acquired during the set at 85% of 1-RM. Kinematic data were recorded with a motion capture system at 250 Hz (Vicon, Los Angeles, CA, USA). Kinetic data were recorded from two in-ground force plates at 1250 Hz (Kistler Instrument Corp, Amherst, NY, USA). Kinematic and kinetic data were smoothed with 4th order recursive low-pass Butterworth filters with cut-off frequencies of 6 Hz and 25 Hz, respectively. Standard y-x-z rotation sequences were used to calculate hip, knee, and ankle joint angles. The sagittal plane angles were numerically differentiated to obtain the respective joint angular velocities. Kinematic and kinetic data were combined with anthropometric data and used to solve for the internal hip, knee, and ankle NJM via inverse dynamics methods (NJM_{ID}). Although the calculations followed the right-hand rule, directions of joint angular motion were expressed such that joint extension occurs in the positive direction. Similarly, NJM_{ID} were expressed such that extension and plantarflexion moments are positive. The kinematic and kinetic data were trimmed to include the entire pull phase of the clean (i.e., first pull, transition, and second pull phase), defined to begin when a marker attached to the barbell exceed 0.25 m and end when the ground reaction forces fell below 10N. The kinematic and kinetic data were then linearly interpolated to 101 data points (i.e., 0-100% of the pull) (Figure 1).

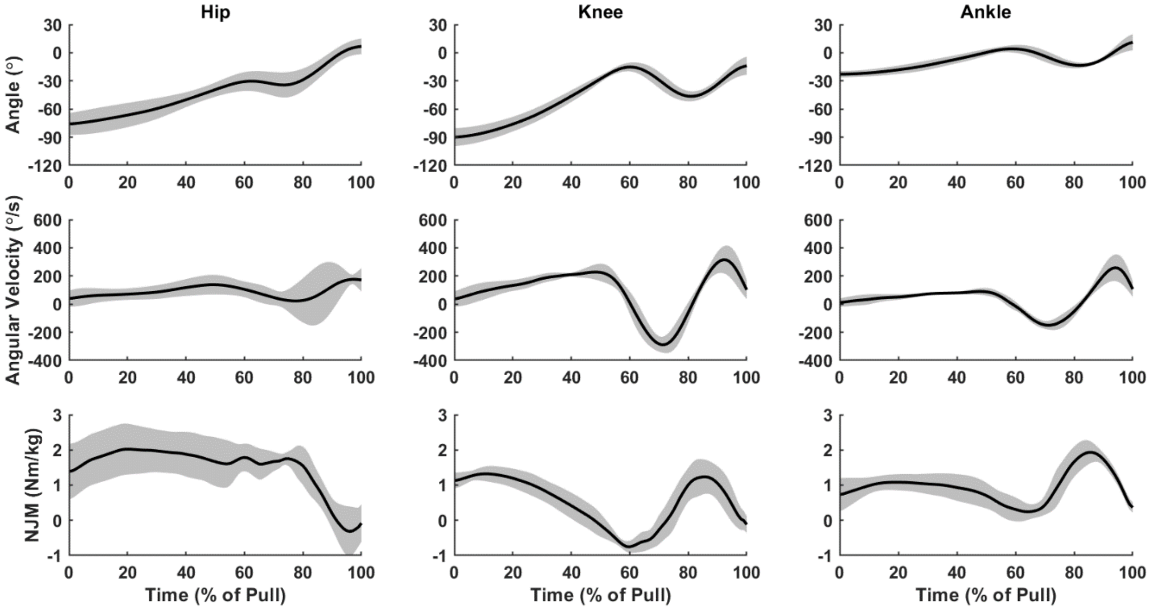

Figure 1. Biomechanical time series data (mean±SD) for the hip, knee, and ankle joints during the entire pull phase of the clean. NJM – net joint moment.

The time series joint angle, joint angular velocities, and NJM data were used as inputs to a musculoskeletal model that calculated the RE of the extensor and plantarflexor muscle groups. The model represents the constraints imposed by the moment-angle and moment-angular velocity associations and was used to predict the NJM_{max} for each joint based on the instantaneous interactions between joint angle (θ) and joint angular velocities ($\dot{\theta}$) (Figure 2). The shape of the model's surface was created from six literature-based regression parameters (C1 – C6) (Equation 1) (Anderson et al., 2007). Although the model can predict NJM_{max} from a muscle group's active and passive components, only the contributions from the active component were used in the current study.

$$NJM(\theta,\dot{\theta}) = \begin{cases} C1\cos\big(C2(\theta - C3)\big)\left(\frac{2C4C5+\dot{\theta}(C5-3C4)}{2C4C5+\dot{\theta}(2C5-4C4)}\right) & \dot{\theta} \geq 0 \\ C1\cos\big(C2(\theta - C3)\big)\left(\frac{2C4C5+\dot{\theta}(C5-3C4)}{2C4C5+\dot{\theta}(2C5-4C4)}\right)\big(1 - C6\dot{\theta}\big) & \dot{\theta} < 0 \end{cases} \quad \text{Equation 1}$$

To improve the subject-specific predictions of the NJM_{max} from the model, the NJM_{max} underwent two additional scaling procedures; 1) scaling to account for each subject's height and weight and 2) to account for greater than average muscle strength of weightlifters compared to the general population (Pearson et al., 2002). The RE for each muscle group were then calculated as the ratio between NJM_{ID} and NJM_{max}. As part of the RE calculations the knee extensor NJM_{ID} were doubled to account for the presence of co-contraction from the hamstring muscles during the first and second pull phases, so as not to underestimate RE (Kipp et al., 2020).

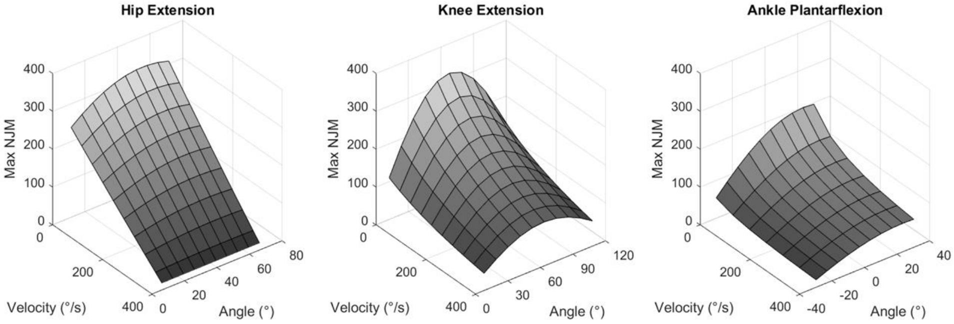

Figure 2. Regression-based surface that models associations between the moment-angle and moment-angular velocity properties of the hip and knee extensor and ankle plantarflexor muscle groups and the maximal possible net joint moments (NJM) they could produce.

Peak RE of the hip and knee extensor and ankle plantarflexor muscle groups were extracted from the first and second pull phase of the clean. Data are presented as means and standard deviations.

RESULTS: During the first pull, the peak RE values for the hip, knee, and ankle joint were 72±46%, 91±22%, and 70±21%, respectively. During the second pull, the peak RE values for the hip, knee, and ankle joint were 44±16%, 125±77%, and 129±22%, respectively (Figure 3).

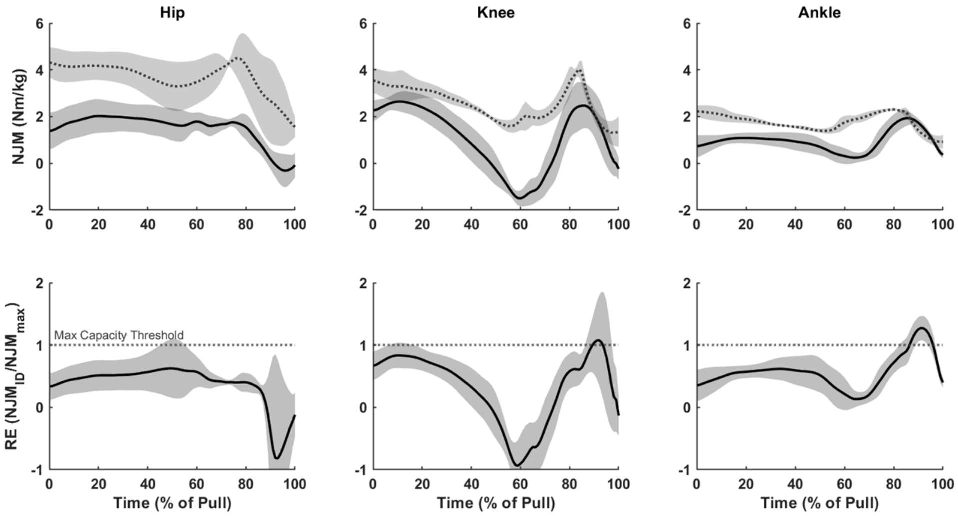

Figure 3. (Top Row) Model-based max net joint moments (NJM_{max} [Nm/kg] – dotted line) and inverse dynamics calculated net joint moments (NJM_{ID} [Nm/kg] – solid line). (Bottom Row) Relative effort (RE) – horizontal line at RE = 1 indicates the max capacity threshold.

DISCUSSION: The methods and results of the current study show how the concept of RE could be used to identify joint-specific bottlenecks during a sporting task. Specifically, calculating the RE ratios between inverse dynamics and musculoskeletal modeling derived maximal NJM can help determine which muscles operate at or below their predicted maximal capacity. Muscles that operate close to their maximal capacity would make logical targets for specific training interventions as they most likely limit the multi-joint performance in strength sports.

The RE data suggest that the knee extensor muscles operate close to maximal capacity during both pull phases, and that the plantarflexor muscles operate close to their maximal capacity during the second pull. The finding that during the first pull of the clean, the functional capacity of the knee extensor muscle group represents a limiting factor to weightlifting performance agrees well with reports from other studies where researchers suggested that a primary role of the knee joint is to accelerate the barbell during this phase (Bottcher and Deutscher, 1999; Kipp et al., 2020). The current findings also agree with previous research that ascribes better weightlifting performance to large knee extension and ankle plantarflexion NJM during the second pull (Baumann et al., 1988; Kipp et al., 2012b).

One limitation to the current study is that weightlifters only performed the clean with 85% of their 1-RM, which implies that the RE magnitudes should be interpreted with caution. Specifically, some RE values approached or exceeded the predicted NJM generating capacity of some muscle groups even though the intensity of the clean was sub-maximal. That said, the NJM_{max} values predicted by the model account for the association between NJM and joint angular velocities, which means that RE values could potentially reach near-maximal values if the joint angular velocities are fast enough. Another explanation may be that the NJM_{max} predictions are based on a model that used isolated concentric and eccentric contractions to model the moment-angle and moment-angular velocity constraints, which may limit its ability to effectively estimate NJM_{max} during activities that use the stretch-shortening cycle. Lastly, the current model did not account for the influence of biarticular muscles, which may also explain why some of the NJM_{ID} exceeded NJM_{max}.

CONCLUSION: The results show that during the first pull the RE is largest for the knee extensor muscles whereas during the second pull the RE are largest for the knee extensor and ankle plantarflexor muscles. Future research should investigate if targeted training of these muscle groups can decrease RE and improve weightlifting performance.

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